To procrastinate or not to procrastinate: the optimal timing of containing the global COVID-19 pandemic spread

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Research Article

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Abstract

As global public health is under threat by the 2019-nCoV, an urgent question to ask is what the optimal strategy of epidemic prevention and control (P&C) measures would be, especially in terms of the timing of enforcing aggressive policy response so as to maximise health efficacy and to contain pandemic spread. Here, we developed a logistic probability function configured SEIR model to analyse the COVID-19 outbreak and estimate its transmission pattern under different "anticipate- or delay-to-activate" policy response scenarios in containing the pandemic. We wound that the potential positive effects of stringent P&C measures would be cancelled out in case of significantly delayed action, whereas a partially procastinatory wait-and-see control policy may still be able to contribute to containing the degree of epidemic spread although its effectiveness may be significantly compromised compared to a scenario of early intervention coupled with stringent P&C measures. A *laissez faire* policy adopted by the government and health authority to tackling the uncertainly of COVID19-type pandemic development during the early stage of the outbreak turns out to be a very bad strategy from optimal control perspective, as significant damages would be produced in that case.

Authors Jun Li and Yimin Zhou contributed equally to this work.

1. Introduction

Recently, the global outbreak of the COVID−19 epidemic has led to serious socioeconomic consequences*. Mitigating and containing the spreads of COVID−19 has become a top priority of international community. According to WHO (2020−3−25), 136 countries have implemented measures that significantly intervened international traffic as defined under Article 43 of the International Health Regulations (2005) as of 25th March. This pandemic has posed a daunting challenge to the global health governance[1,2], especially for the lower income countries. [3]

Past weeks have made it clear that the novel coronavirus CoVID−19 emergence in Wuhan, China, and its global spread is a rapidly evolving situation.[4,5,6,7] Over 2.1 million cases have been confirmed in the world as of 16th April 2020, affecting 212 countries and regions as well as 2 international conveyances, causing more than 140,000 deaths.[8] The pandemic has been sweeping all continents. For the time being, Europe and the US have been particularly struck by the pandemic and have the largest number of infected.[9] Across Atlantic, US has now the largest number of confirmed cases in the world and the situation sharply deteriorated over the last two weeks. On the other hand, many developing countries and lower income nations are particularly vulnerable and may face serious humanitarian crisis in case of unconstrained cross-globe spread, especially in Africa, due to underdeveloped local public health infrastructure.[10]

A central question that remains to be addressed by national and transnational government is how to take the *time* effect into pandemic control when introducing and enforcing national responses.[11,12,13] Fig. 1 delineates the dynamics of total confirmed cases in six main countries (US, China, Italy, Spain, Germany and France) that have been seriously rampaged by COVID−19 since its outbreak up to date. It shows that

the situation started to deteriorate rapidly with the number of confirmed cases taking off exponentially around in European countries and in the USA since the middle of March, as a direct result of lack of preparedness (NYT, 2020**). Since then most new cases have been confirmed in Europe and the US. By contrast, the situation has been under control with only a small number of new confirmed cases in China since early March due to the Chinese government's draconian quarantine policy and transmission control measures implemented throughout the entire country***. The curve of the Chinese confirmed case has remained flat after reaching the plateau around early March.

The question is as to when to activate aggressive policy responses such as closing of public transport, mandatory self-quarantine, social distancing and diversion of production to maximise the national health system's efficacy to help contain pandemic spread. Fig. 1 implies that the timing of adopting the strict prevention and control measures (P&M) is crucial in shaping the national curves of spread and affection of the COVID−19. Delaying the stringent P&C measures would risk exacerbating the peak of mass infections which would exhaust the national health system's maximum capacity, putting the medical system on the verge of collapse. However, a review of previous literature suggests that the effectiveness and optimality of timing of COVID−19 pandemic P&C measures remain unknown.[8,14,15]

A common feature of the severely rampaged countries in dealing with the COVID−19 pandemic across Europe and US is that a rather 'wait and see' style containment strategy was adopted by their national or federal governments at the initial stage of epidemic outbreak, and the public was then not sufficiently advised of taking immediately necessary prevention measures such as self-protection (e.g. wearing face mask when going out), home-isolation and social distancing by national health authorities, whereas more stringent and radical policies such as city and nationwide lockdown, internal traffic restriction and outbound/inbound travel ban, were only launched to contain the spread when the pandemic situation has already passed a critical point beyond which accelerated interpersonal transmission and spread of the epidemic is already out of control, with national health system's capacity facing serious saturation challenges and domestic medical resources being rapidly exhausted. Unconventional control and prevention policies such as lockdown and strengthened confinement policy continue to be generalized through all European countries since the serious outbreak in Italy around mid-February.

The effectiveness of stringent P&C measures is highly influenced by the public authority's degree of epidemic monitoring and enhanced management of health system. Another critical factor is related to the degree of public compliance,[16] which is largely relied on how the quarantine measures are enforced by the government. This was particularly relevant during the early stage of the epidemic outbreak in many European countries. Even after the strict national lockdown and confinement policies have been announced by national government, it is lacked in general strict implementation of social distancing in countries such as Italy and France, as people subject to confinement zones were still allowed to outdoors trip by possession of a travel permit or justification such as going to work or shopping daily needs. In our previous paper, it is shown clearly that the likelihood of success of containing the COVID−19 is highly dependent upon the whether the isolation measure is fully implemented.[17]

In this paper, we provide an estimate of the scale of the pandemic spread under different scenarios of variation in key influencing parameters with a hybrid model. We developed a new hybrid model of infectious disease transmission based on configured epidemiology SIR (Susceptible-Infected-Removed) model coupled with a logistic probability function to analyse the COVID–19 outbreak and estimate its transmission pattern. A probabilistic contamination network is embedded in the pandemic transmission model to capture the randomness feature of person-to-person spread of the novel virus. We used the improved BP-SIR (Back Propagation-SIR) model to quantify the population contact state with isolation measures under different continuous time series contact probability. We adjusted the modelling parameters to verify the model performance in accordance to the data from the reports published by the various national governments and international organizations, including Center for Disease Control (CDC) and public health authority.

To account for the uncertainty in relation to the timing of health policy intervention in terms of consequences of infectious contamination and mortality, we simulated two contrasting scenario groups in this paper. The first business-as-usual (BAU) scenario represents a trajectory where the government decides to maintain their modestly aggressive containment policy which reflects the *status quo* of the epidemic development in these countries during the early stage of outbreak, whereas a stringent policy scenario describes a non-delay or immediate policy response by assuming proactive P&C measures adopted and implemented effectively from the very beginning of epidemic outbreak. Furthermore, we simulated the consequences of postponing the stringent P&C policies by varying the delay in activation from 0 to 4 weeks to assess the varied consequences in terms of damage. This allowed us to illustrate the importance of intervening in a timely manner in accordance with optimal timing strategy. A delay in deciding to take strong action at early stage would result in postponed arrival of the inflection point which in turn would delay the eventual control of virus transmission and exacerbate global pandemic spread.

Our modelling results indicate that early-stage preventive measures are the most effective way to contain the pandemic spread. In addition, appropriate state interventions in macro-management of human and socio-economic resources, i.e., enforcing social distancing and quarantines, setting up special hospital facilities, are all essential to constrain the global transmission of the virulent infection. With the rapid spread of novel coronavirus worldwide, this pandemic has no longer single country's affair, but is on the way to develop into a global security concern requiring cooperation and control of all countries.18 To do so, internationally coordinated actions are required through sharing good practices.

2. Results

The modelling results of infection cases and death caused by COVID–19 in the four countries under four "delay" scenarios are presented in Fig. 2. We assumed in the model that for each country, a 2-week observation time, starting from the initial outbreak in the country, is allowed for the government to make decision about when to take strong P&C actions, any further postponed actions in making such decisions will be considered a delayed intervention in controlling the spread of the pandemic, spanning from 1 to 4 weeks.

It can be clearly seen that timing *per se* is a critical factor in shaping the infection and death curves in the coronavirus outbreak countries, regardless of whether the government has decided to take strong (e.g. city lockdown and public space shutdown in Northern Italy) or moderate actions (e.g. herd immunity strategy initially adopted by the UK government) at the initial stage of the outbreak.

In other words, if a government envisages taking strong policies to tackle the COVID–19 epidemic, the decision of whether it chooses to implement the policy immediately or to delay in activating the stringent P&C measures such as city lockdown and mandatory self-quarantine, might produce stark difference in epidemic spread in terms of number of infections and death. Delaying the epidemic control policy may bring out irreversible large impacts on the infected countries as a result of overwhelming peak of number of infections and saturated medical resources. For instance, in the case of strong policy scenario in France, doubling the delay period (from 2 to 4 weeks) of implementing the stringent quarantine measures would increase the peak number of active infection cases by a factor of more than 4.

Under the current circumstances of rapid transmission of the coronavirus disease, all the countries in the world are obliged to take strong actions to minimize the irreversible damage and to avoid a global heath calamity. As such, taking strong policy as early as possible is an optimal strategy as any delays may result in irreversible damages. The epidemic distribution curves may be effectively flattened by timely intervention of public authority coupled with stringent P&C measures. The peak infections would increase exponentially if the immediately subsequent weeks following the outbreak were forgone without appropriate pandemic control policy. Stringent P&C measures may allow all countries to significantly reduce both infected cases and number of death caused by the COVID–19 across all four countries. However, in the case of significant delay, the stringent policy measures are less likely to flatten the infection cases' distribution curves.

Our hybrid modelling results clearly indicate the paramount importance of taking timely preventive measures in public health system when dealing such contagious pandemic as COVID–19 given its high person-to-person transmission risk, as disastrous consequences would be generated if the optimal window of intervention were forfeited at the early stage of outbreak, in particular in the densely populated areas (i.e., the intra-network transmission probability may be increased exponentially) with scarce medical resources. It is of paramount importance to cut off virus contamination channels through social networks and interpersonal spread at the beginning of epidemic outbreak.

In particular, timing is more important than the degree of policy stringency per se in accelerating the arrival of peak of infection (or the so-called inflection point). In other words, the positive effects of stringent P&C measures would be cancelled out in case of significantly delayed action, whereas a moderately delayed control policy may still be able to contribute to containing the degree of epidemic spread although its effectiveness may be significantly compromised compared to a scenario of early intervention coupled with stringent P&C measures. A procastinatory activation strategy adopted by the government and health authority to deal with the uncertainly of COVID19-type pandemic development at

the early stage of outbreak turned out to be a very bad strategy from optimal control perspective, as significant irreversible damage would be produced in which case.

More importantly, early action help flatten significantly the shape of distribution of contamination. This will allow the society to reduce the transmissibility and severity which are the 2 most critical factors that determine the effect of an epidemic.[23] The more a country delays implementing proactive P&C measures, the larger irreversible damage in terms of infection and mortality the epidemic would produce.[24]

3. Discussion

The results of this research have important implications for global pandemic containment cooperation, in particular for the most vulnerable countries with weak medical response to COVID–19 spread. The would-be outbreak in African and middle-east countries may draw some useful lessons from the Chinese and European experiences[25] in terms of optimal timing, i.e., activating emergency response mechanisms and adopting mandatory quarantine measures with close monitoring of the epidemic developments within and out of boundary at the early stage of outbreak. Any delay in implementing stringent P&C measures would produce irreversible disastrous consequences, posing sever threats to national and global health security and public welfare.

The main purpose of preventive intervention is to eliminate or minimise the source of infections, to cut off the route of transmission and to protect the susceptible population, i.e., reducing public gatherings and close interpersonal contact, good hygiene practice such as wearing masks outdoors and washing hands frequently, cancelling entertainment, social and religious gathering activities, limiting traffic and mobility, strengthening quarantine at transportation hubs such airports, railway and bus stations, closing temporarily schools and public places, and carrying out thorough disinfection when necessary.[26] In addition, to increase the efficiency of isolation of infected population, early detection, diagnosis and treatment are highly recommended, including routine temperature detection of vulnerable population, screening and monitoring of fever patients, centralised isolation of the suspected cases and confirmed patients. In the event of high risk of contamination, more draconian quarantine measures such as home confinement of the entire infected areas with tight mobility restriction should be implemented (such as the case of lockdown in Wuhan and North Italy). [27]

Italy, as the second most seriously affected country (death toll in Italy is ranked the first in the world) by the pandemic outside of China, has taken strict prevention measure similar to the Chinese pattern, i.e., close down the seriously infected towns and regions in order to make the interpersonal spread under control since the early stage. However, the current situation is far from being controlled effectively due to non-strict implementation of confinement and lack of stringent measures, such as home isolation and total suspension of urban mobility, since the confinement started a week ago, it is reported that people are keeping moving around within the isolation zones, and cost-efficient self-protection measures such as face mask wearing practice have not been generalised to minimise the risk of person-to-person transmissions through respiratory airway. In addition, the situation was further complicated by the

overload on local health system as a sharp increase in infected persons in a short period of time and local medical capacity had soon been saturated. The national intervention efficacy may not sustain without timely external support from third party such as the European Union. The comprehensive mobilisation and support pattern during the Wuhan Crisis at the beginning of February in China may provide a useful blueprint of efficient intervention for both the European Union and Italian decision-makers.

In this regard, the effective isolation and quarantine measures can help minimise the uncontrolled spread of virus in the early stage of outbreak. For instance, in Singapore, anyone who is subject mandatory stay-home-notice (usually a 14-day period home isolation) may face severe judicial punishment if she/he violates the notice's requirement. Likewise, similar experience in Wuhan, the epicentre of COVID−19, shows that the city lockdown policy brought significant benefits in terms of reducing new confirmed cases and mortality only after strict traffic control and compulsory isolation P&C measures came into effect two weeks following the lockdown notice on 23rd January.

In order to optimize the efficacy of pandemic prevention and control measures, implementation guidelines need to be formulated for effective infectious disease control, while coordinating personnel from health care, public security, transportation and social service departments of local community. An integrated resources management and allocation system needs to be established to allow local medical and social workers to jointly complete the work of screening and controlling the sources of infection. The success of joint implementation of the pandemic control guideline depends upon the response of emergency plan such as cutting off the route of transmission and protecting the susceptible population with isolation and treatment of infectious diseases.[28,29]

4. Methods

A number of prior studies have addressed this issue around prevention effectiveness by using different modelling paradigms,19,20 many of them employed conventional bio-mathematical modelling strategies that describe the dynamics of the spread of infectious diseases such as Susceptible-Exposed-Infected-Removed (SEIR) model,21 or stochastic transmission model.22 However, few of them have integrated the probabilistic approach into the SEIR modelling consideration. Our modelling strategy is briefly described as follows.

First, The BP network is used to train the model which is a regression problem. As Italy was so far the foremost affected country with the largest number of dead caused by the pandemic, we use Italy's case as the baseline model. The model input are the active infected cases and death rate in Italy from 15th Feb, 2020 to 15th Mar, 2020, here, we define: total affected cases = active affected cases + removed cases, removed cases = death + recovered. We select the fitted objective as the infection rate from the susceptible state (*S)* to the infected state (*I)*.. The transition state from the infected to the removed is defined as a constant variable since the isolation is the mainly concerned which has little influence on the death and recovery of patients. The estimate of the infected cases is obtained with the combination of

SIR model and the calculation of the infection rate from each iteration, then the loss function is calculated as the mean square error (MSE) between the estimate and real infected cases. The mathematical expression of the infection rate is expressed by a logistic function:

$$RateSI = \frac{ce^{-\alpha(t+bias)}}{(1+e^{-\alpha(t+bias)})^2} \quad (1)$$

where α is the rate of change of *RateSI; bias* is used to select the starting point of the function variation. According to the real data, set bias = - 10, and c is the initial value of *RateSI.*

To make the model realistic and interpretable, we first calibrated the data of Italy to fit the model such that key parameters in Eq. (1) may be derived. We used the real data from 15th Feb, 2020 to 15th Mar, 2020 in Italy published by WHO to train the SIR-BP model and the fitted model estimate is compared with the actual data, shown in Fig. 3. It can be seen that the developed model can well predict the virus transmission situation.

Two prevention control strategies are used as follows:

(1) Business as usual or delayed prevention & control policy, adopted by government currently (issued at 10th Mar, 2020), which is embodied in the *a, bias, c* parameter settings for modelling prediction.

(2) Stringent policy case, where countries began to take strict quarantine measures similar to Hubei Province, China from 16th Mar, 2020. In the model, the values of α and *bias* were modified based on the situation of Wuhan from 23rd Jan 23 to 28th Feb (i.e., Italy was similar to Hubei Province in terms of population and initial epidemic development), and the other parameters unchanged. (strict quarantine)

It can be seen from Fig. 4(a) that the total affected cases would be stable after 57 days (day 0 in the Figure refers to the 15th Mar, 2020), while the epidemic situation can be stabilized after 36 days with strict quarantine measure being taken similarly to Hubei province in China. So the number of the total infected cases with BAU isolation measures is about three times of that with strict measures while achieving stable status.

From Fig. 4(b), it can be seen that the active infected cases will reach peak at the 34th day (roughly 65,000) and the 19th day (roughly 155,000), the so called ‘inflection point’, with current isolation measures adoption and strict quarantine measures adoption similarly in Wuhan district, respectively. The peak value of the active affected cases in BAU epidemic control strategy is about 2.5 times higher than that in strict prevention control strategy. We used the real data from 15th Mar, 2020 to 18th Mar, 2020 to test the developed model and the estimate results with active infected cases and total infected cases. Based on this baseline model, we present in the next section the projected infection cases in four major countries which experienced sharp increase since the widespread outbreak outside China early March, namely US, Italy, Germany and France.

Declarations

Contributors

JL and YMZ conceived of and designed the study. LJY set up the experiments and collected the data. LJY and JL analysed the data. JL, YMZ, LJY and ZC interpreted the results. JL and YMZ wrote the manuscript. All authors read and approved the final manuscript.

Declaration of interests

We declare no competing interests.

Funding disclosure statements

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Footnotes

*Taking global financial market responses as an illustrative example, the NSE's DW index lost more than 2, 000 points twice in a week as coronavirus fears accelerated (CNBC, 12-03-2020). The oil prices collapsed by more than half and fallen to their lowest level in 17 years (Financial Times, 18-03-2012)

**https://www.nytimes.com/2020/03/13/opinion/china-response-china.html?0p19G=3248

***Majority of the new infections in China are imported cases now.

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Figures

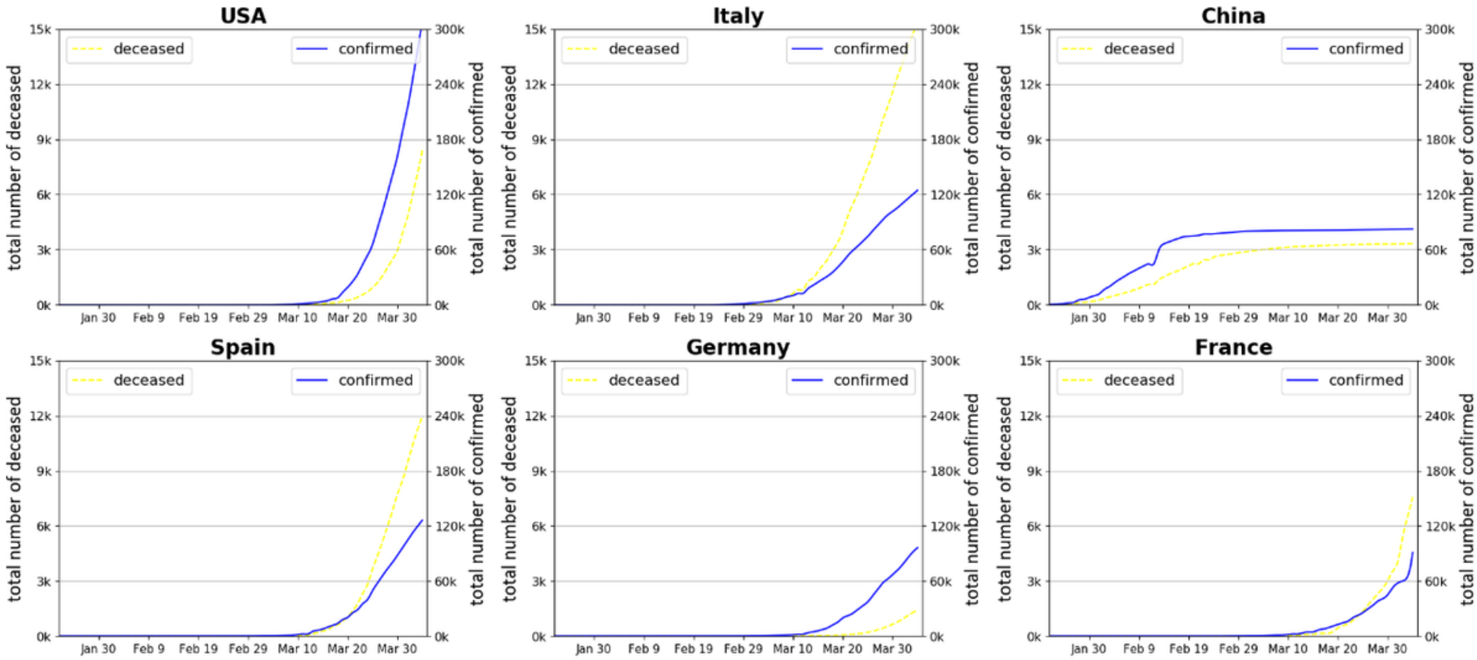


Figure 1

Number of confirmed cases and deceased patients in six countries Source: WHO (2020) database; Sciences Po Coronavirus country comparator https://boogheta.github.io/coronavirus-countries/

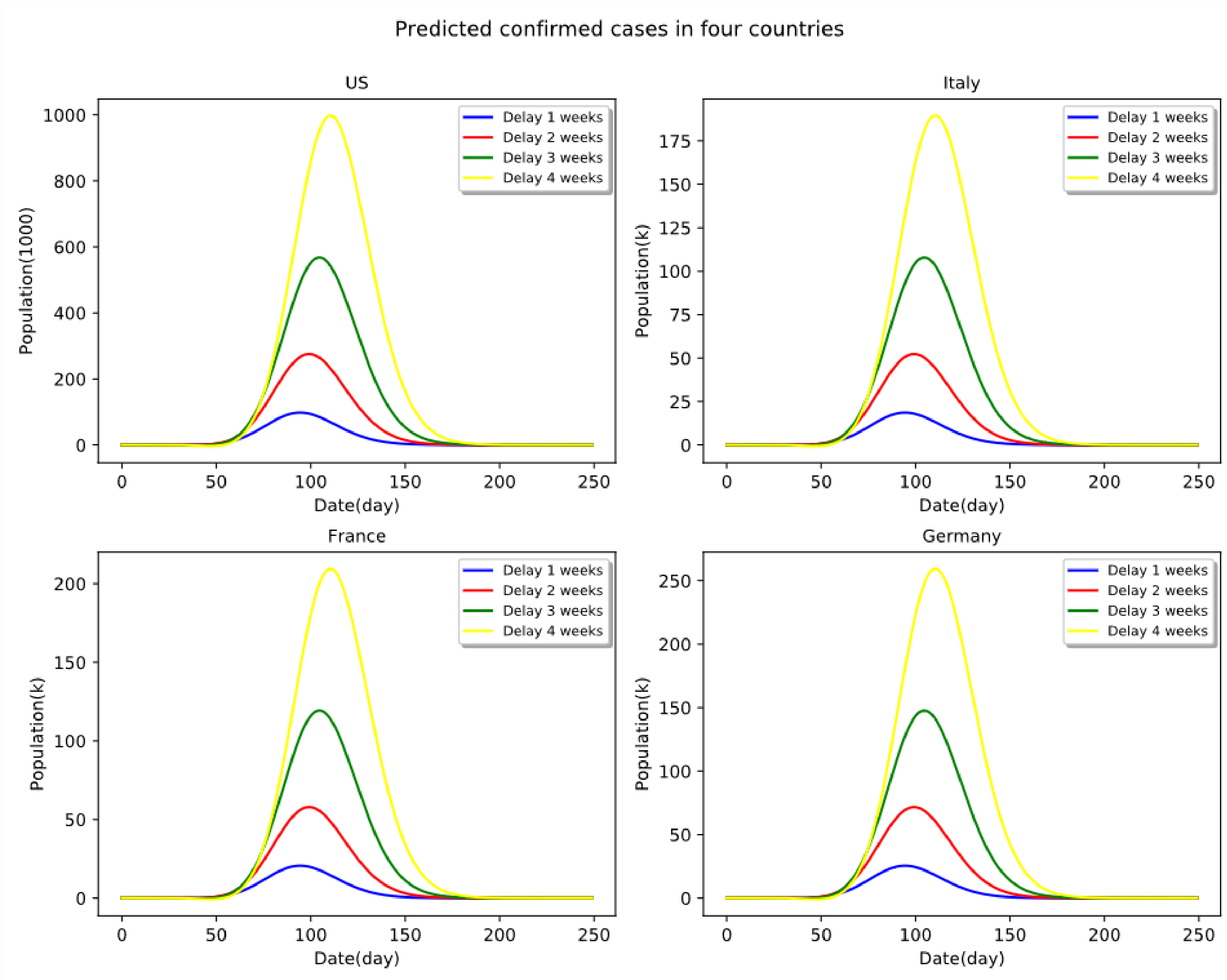


Figure 2

Proactive versus Delayed implementation of P&C measures under stringent policy Note: Numbers shown in the panel graphs are relative to the no-delay cases.

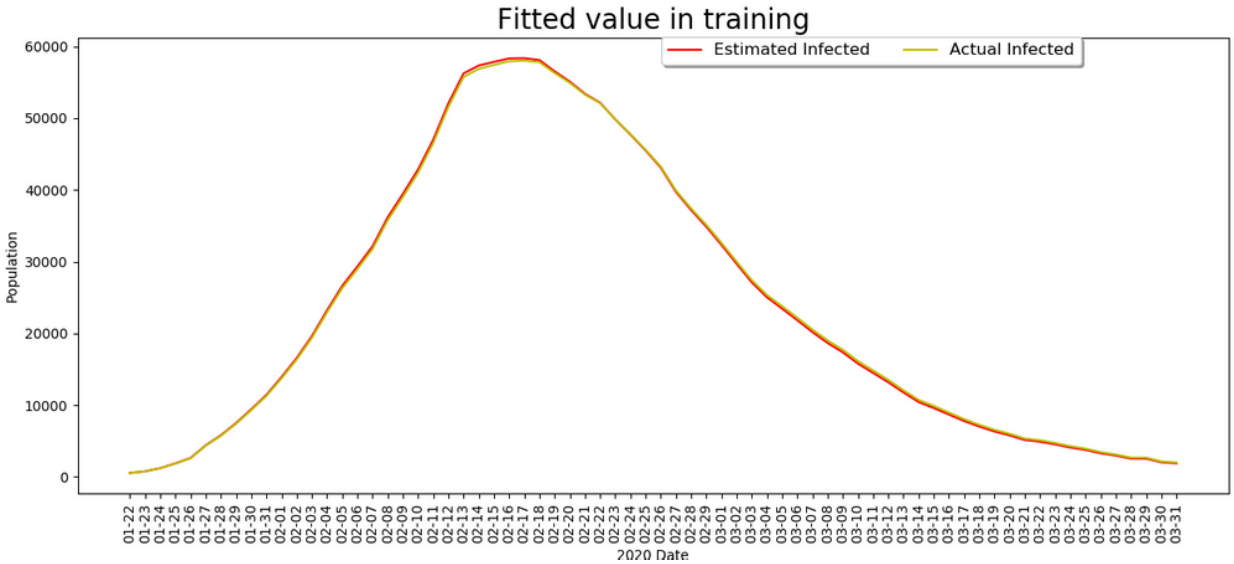
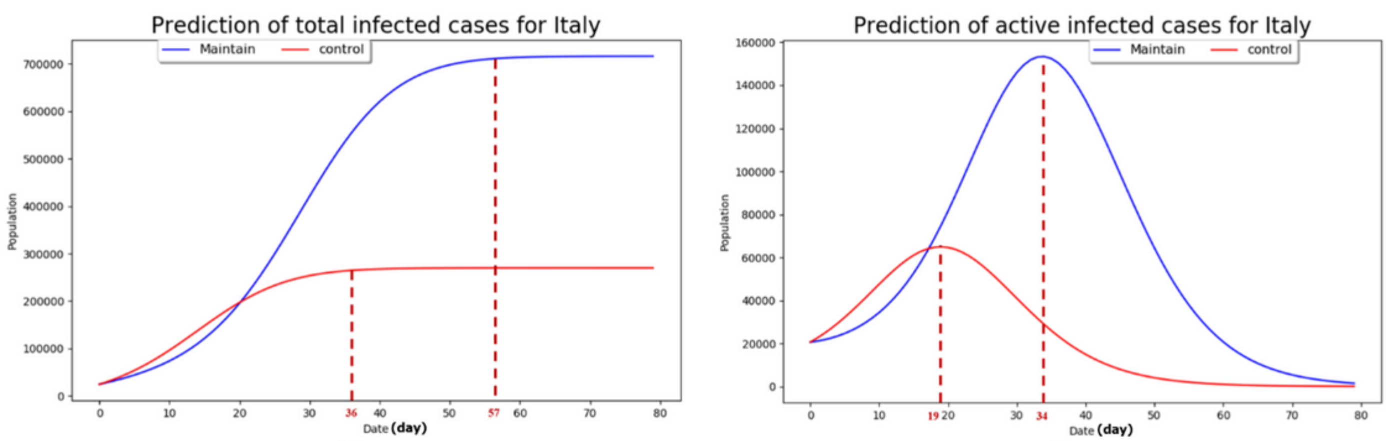


Figure 3

The comparison of the infected cases between the model estimate and real data



(a) (b)

Figure 4

The predictions based on the developed model. (a) The estimate of the total infected cases with two prevention control strategies; (b) The estimate of the current infected cases with two prevention control strategies.