



## COVID-19 pandemic

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The current pandemic is arguable the hardest health threat since the appearing of SARS and Ebola. It is still developing in many countries around the world. Governments worldwide have implemented restriction and isolation measures in order to avoid the spreading of COVID-19. The economic impact of this pandemic is already having far-reaching adverse consequences for enterprises and citizens. It is likely that a big recession will occur in the next months. There have been also social repercussions: we have been somehow disconnected from our social relationships, which could also have some consequences in our health and productivity. Hundreds of research papers on this virus have been already published. In this text, we will visualize some curves based on the official numbers of infected globally and we will look at some models proposed for studying and forecasting the spread of COVID-19.

*Disclaimer. The epidemic is currently taking place. Data about this disease can change quickly and the sources cited might contain incomplete or inaccurate information. This text should not be taken as a guide for present or future developments.*

### 1 Antecedents on COVID-19

In December 2019, several cases of atypical pneumonia in the Chinese city of Wuhan attracted global attention due to its special characteristics. An epidemiological link was established to the Huanan Seafood Wholesale Market [6]. At the beginning of January 2020, SARS-CoV, MERS-CoV, avian flu and common respiratory viruses were ruled out. The genetic sequence of a new virus was public on January 12th 2020, carried out by Chinese scientists [6]. This sequence was of great help for developing diagnostic PCR tests. On January 30th the World Health Organization declared the COVID-19 outbreak a public health emergency of international concern (PHEIC) [10]. The new virus was named SARS-CoV-2 on February 11 by the International Committee on Taxonomy of Viruses (ICTV).

It is still too early to know it for sure, but SARS-CoV virus it is likely to be an animal virus that crossed to humans, like MERS-CoV and SARS-CoV. The most common symptoms are fever, dry cough, and tiredness. Temporary loss of smell and/or taste has also been reported [5]. Other less common symptoms include aches and pains, nasal congestion, headache, conjunctivitis, sore throat, diarrhea, rash on skin or discoloration of fingers or toes [11]. One of five individuals infected with COVID-19 becomes seriously ill and develops difficult breathing. Older and people with preexisting health conditions (high blood pressure, heart and lung problems, diabetes, cancer, etc.) are more susceptible to develop a severe form of this disease. As of June 16th 2020 there are 8,150,931 official confirmed cases and 439,892 confirmed deaths, with numbers increasing daily. According to the current reports, the case fatality rate of COVID-19 lies between 0.5 and 1 % [9]. This case fatality rate changes from country to country [1].

### 2 Visualization of current current cumulative data on COVID-19

The data was retrieved from the COVID-19 Data Repository by the Center for Systems Science and Engineering (CSSE) at Johns Hopkins University provided as time series at its github website [2]. The data was cleaned, processed and plotted using the pandas and pyplot libraries of python (data retrieved on June 16th).

In the first figure, we can see the cumulative number of confirmed cases since January 22nd until June 16th.

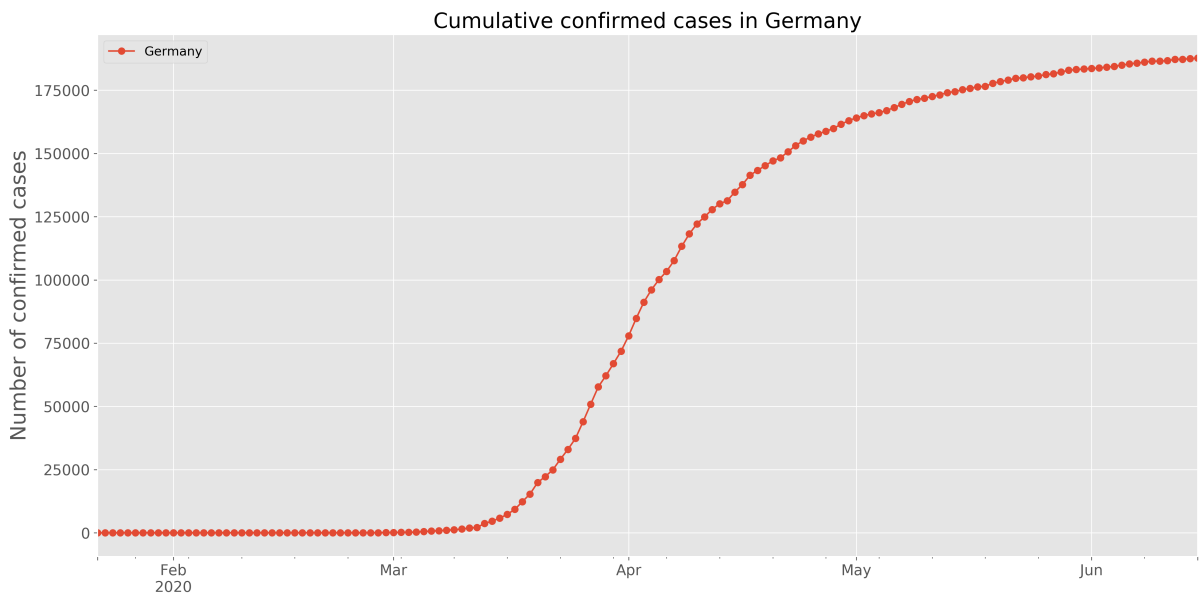


Figure 1: Confirmed cases in Germany

In the next figure, we compare the curves of cumulative number of cases between different countries.

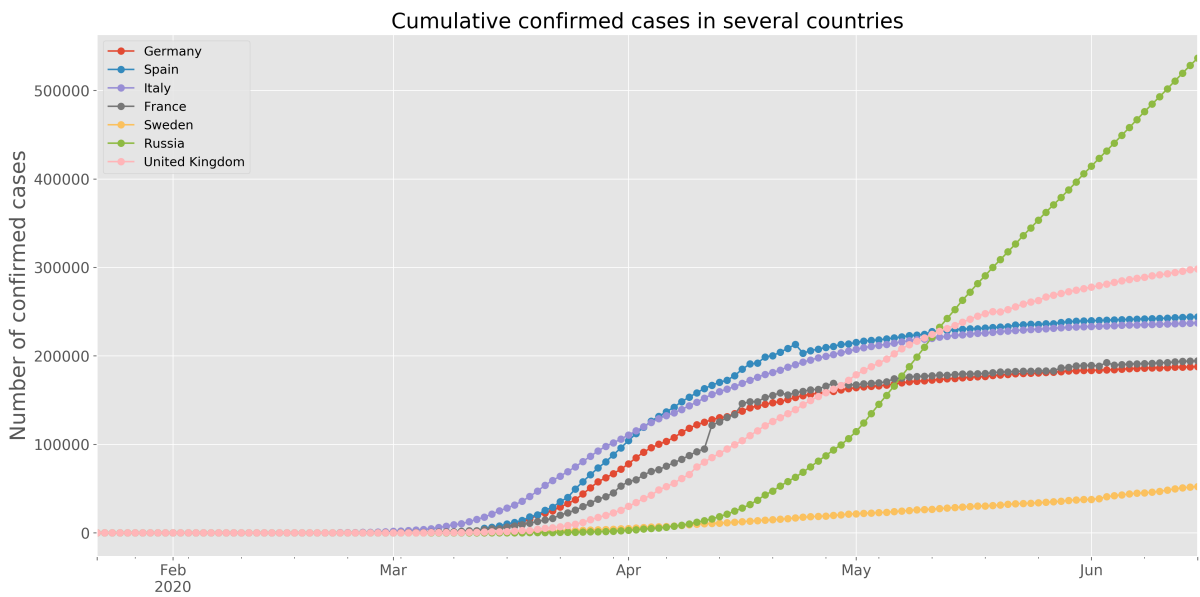


Figure 2: Confirmed cases in several countries

It is interesting to note in Figure 2 how the curves change sometimes drastically from country to country. With the information that so far we know, it is very difficult to explain and assess the differences. The curves reflect the result of the implemented local measures and the behavior of the population.

In the next figure, we visualize the number of confirmed infections per day in Germany since January 22nd until June 16th. It is seen how the curve "flattens" and the number of confirmed infections per day has now decreased.

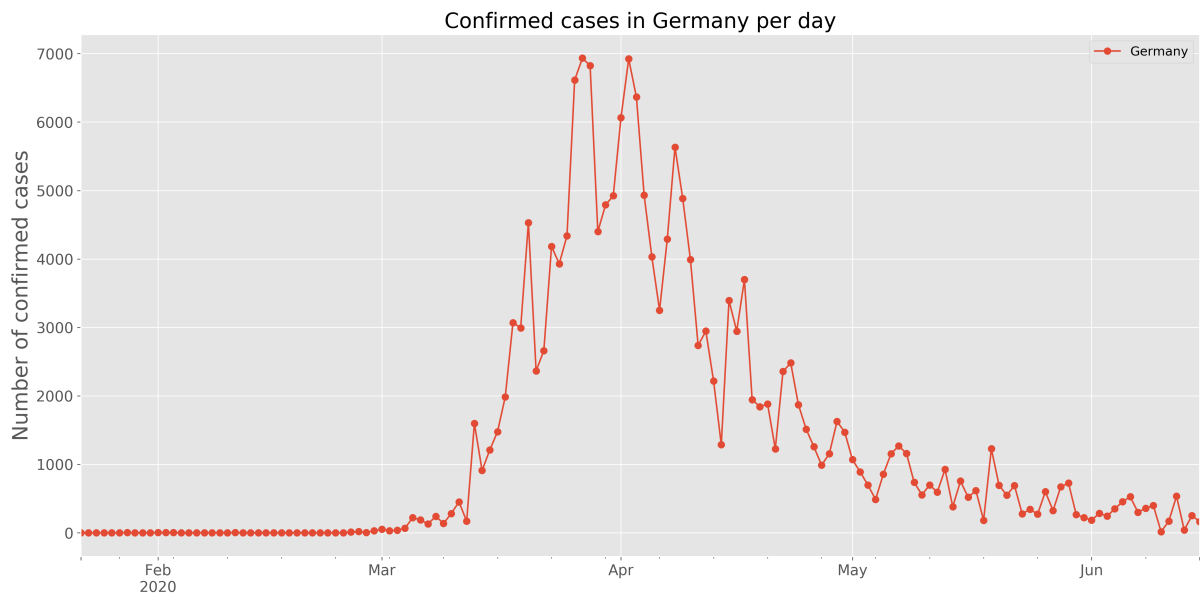


Figure 3: Confirmed infections per day in Germany

We can see in Figure 2 that the curve does not go uniformly up and then down. We observe oscillations which are consistent with real data. They can be explained in terms of small outbreaks, errors and adjustments in the numbers, among other reasons.

In the next figure, we look at the curves corresponding to the cumulative number of confirmed deaths in several countries.

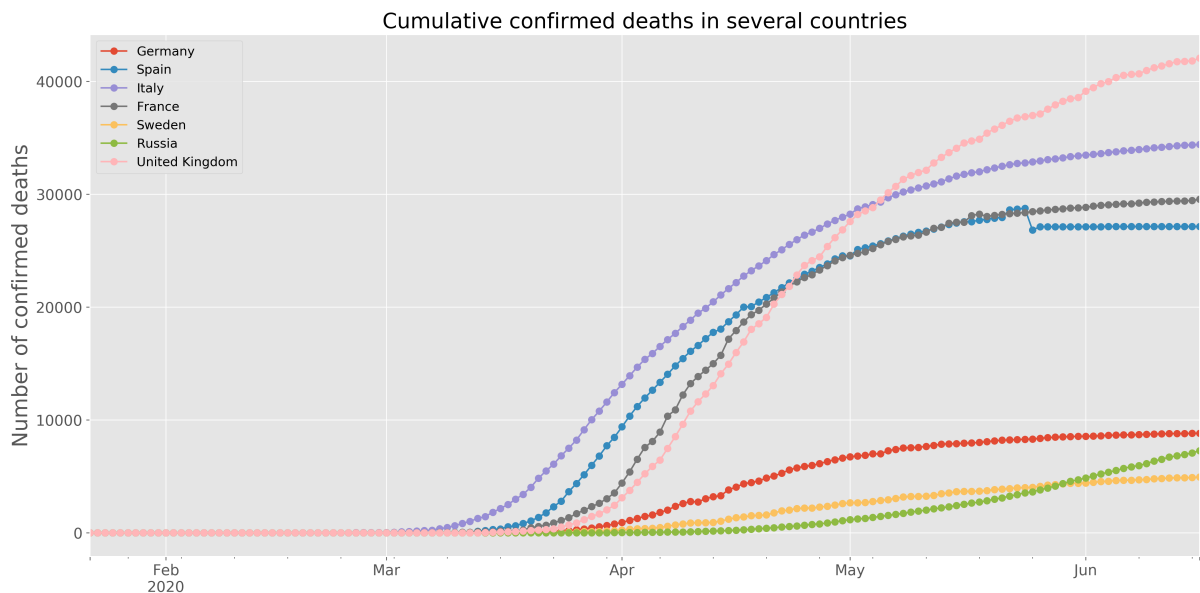


Figure 4: Confirmed deaths in several countries

The relation between the number of infected individuals and the number of deaths is not same in all countries. Of course, there are many factors causing those differences. One factor might be the fact that a larger number individuals belonging to a higher risk group became infected causing more deaths. However, there is still too little information and we do not wish to speculate about the reasons behind these differences.

Next, we will look at two different models on COVID-19. Since the pandemic is still taking place, the models were developed in order to fit the current data.

### 3 A SIR model of COVID-19

A group of scientist of the MPI for Dynamics and Self-Organization in Göttingen developed a SIR model of COVID-19 in March 2020 [4]. At that moment the number of cases was quickly increasing in Germany. Their objective was to forecast three possible scenarios:

- We do nothing (no restrictions in the contacts between people).
- If we partially restrict our contacts and only meet about half as many people.
- If we introduce much stricter measures for all people.

The authors employed the well-established and simple compartmental SIR (susceptible-infected-recovered) model. They inferred the parameters describing at best the available data and then those parameters were used to forecast future developments. The population of size  $N$  is split into  $N = S + I + R$ , following this system of differential equations:

$$\begin{aligned}\frac{d}{dt}S(t) &= -\lambda \frac{I(t)S(t)}{N} \\ \frac{d}{dt}I(t) &= \lambda \frac{I(t)S(t)}{N} - \mu I(t) \\ \frac{d}{dt}R(t) &= \mu I(t)\end{aligned}\tag{1}$$

This model assumes that the disease is spread at rate  $\lambda$  from a infected to a susceptible person, and an infected individual becomes recovered at rate  $\mu$ . The data set, as any other data set is discrete in time (with  $\Delta t = 1$  day). Therefore, the authors solved a discrete system

$$\begin{aligned}S_t - S_{t-1} &= -\lambda \Delta t \frac{I_{t-1}S_{t-1}}{N} =: -I_t^{\text{new}} \\ R_t - R_{t-1} &= \mu \Delta t I_{t-1} =: R_t^{\text{new}} \\ I_t - I_{t-1} &= \left(\lambda \frac{S_{t-1}}{N} - \mu\right) \Delta t I_{t-1} = I_t^{\text{new}} - R_t^{\text{new}}.\end{aligned}\tag{2}$$

The quantity  $I_t$  represents the number of active infected cases and  $I_t^{\text{new}}$  is the number of new infections. It is assumed that at the beginning only a very small fraction of the population is infected and therefore  $S/N \approx 1$ , and the differential equation for the infected individuals is transformed into a linear one  $dI/dt = (\lambda - \mu)I$ , which exhibit a exponential growth since the solution is  $I(t) = I(0)e^{(\lambda - \mu)t}$ .

Next, they estimate the parameters of the model using Bayesian inference with Markov-chain Monte-Carlo (MCMC). They use the implementation of the python package pymc3 with NUTS (No-U-Turn Sampling). The authors started by choosing random initial parameters which evolve according to the model's equations. Then, the parameters are updated recursively using MCMC. Finally, for the forecast they take samples from the MCMC and then they perform the integration in different scenarios.

The authors carried out simulations considering the official numbers for Germany between March 1st-15th. They affirm that by reducing the social contacts the parameter  $\lambda$  decreases. It is however expected that the rate of recovery  $\mu$  might increase with social distance. They did not model an explicit change of  $\mu$ , however it is assumed to be incorporated into a change of  $\lambda$ .

In the next figure, taken from the authors' paper, we can see part of their simulations, where they consider different kind of social distancing, starting at different dates.

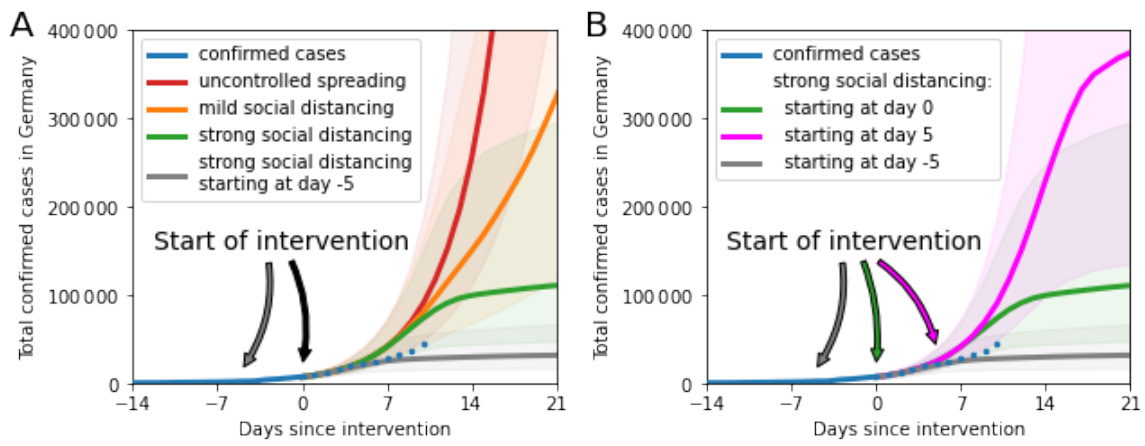


Figure 5: Different scenarios simulated

## 4 A time delay model for the outbreak of COVID-19

We will look at a model proposed in [4]. This paper considered cumulative data from China between January 23th to February 9th, before the big outbreak in Europe. COVID-19 could be spread in the incubation period and the authors argue that for this reason many classical models such as SIR, SEIR and SEIJR are not appropriate for describing the outbreak of COVID-19. The authors apply a delay time process to include this incubation period. The authors also consider isolation in their model, since the Chinese government already had started to implement isolation policies.

In this model, the population is split into 4 groups:  $I(t)$  accumulated number of infected individuals at the time  $t$ ,  $J(t)$  diagnosed individuals,  $G(t)$  currently isolated infected cases, but still in the incubation period, and  $R(t)$  accumulated number of recovered individuals.

The authors assume that the infected individuals transmit COVID-19 at rate  $\beta$ . The infected persons have an incubation period, where they are asymptomatic; this incubation period lasts in average  $\tau_1$  days. It is also assumed that once the infected persons develop symptoms, they will seek medical treatment and therefore become diagnosed. Some of the infected persons will be exposed in the incubation period; the average period of exposure is  $\tau_1 - \tau_1'$  days, or in other words, they will be diagnosed in the next  $\tau_1'$  days. Some other part of the infected persons will remain isolated. The accumulated diagnosed individuals consist of the infected persons at time  $t - \tau_1$ . They assume that a person in isolation or treatment will no longer transmit the virus. The exposed persons at the time  $t$  are  $I(t) - G(t) - J(t)$ . The diagnosed individuals take in average  $\tau_2$  to recover at rate  $\kappa$  or die at rate  $1 - \kappa$ .

The interactions in this model are described by a system of differential equations. The cumulative diagnosed cases  $J(t)$  and the number recovered individuals are always available from the National Health Commission of China. These numbers are used by the authors for the identification of parameters. The problem is then transformed into a two optimization problems. In the next figure taken from [3], we can see a simulation where the authors consider the model without isolation (a) and with isolation (b).

According to the authors, if the isolation rate is set to 0.5 it is possible to finish the outbreak in 50 days. They affirm that the need of medical assistance would reach its peak at the day 35th. They also insist in the implementation of strict isolation policies.

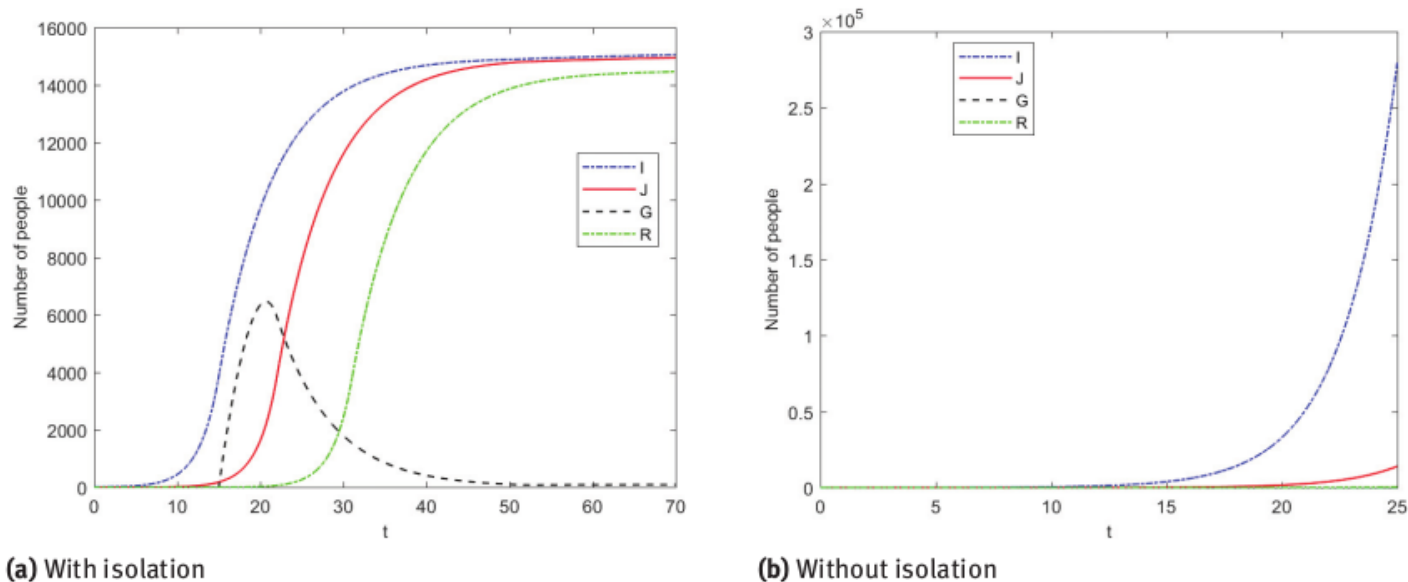


Figure 6: Time delay model without and with isolation

## 5 When is this pandemic ending?

Well, it is still too early to answer something reasonable to this question. There have group of scientist around the world designing different strategies and contemplating several scenarios. What does happen if there is no effective vaccine against SARS-CoV-2 in the next few years? What if the immunity acquired by people who was been infected, disappears after some months? A paper that appeared in Science in May 2020 [8] and the 9th Report of the Imperial College COVID-19 Response Team [7] propose both intermittent lockdowns. The main idea behind these intermittent lockdowns is to keep the number of current cases below the Intensive Care Unite (ICU) capacity, hopping that in the time being a vaccine will be developed, otherwise we will repeat this process until heard immunity is achieved.

One big issue is the consequences for our mental health and the financial stability during these new lockdowns. The strategy carried out by South Korea and Taiwan which consisted in contact tracing, testing and isolating have proven to be quite effective. Several apps have been developed in order to trace the contacts in real time. Of course, it is absolutely necessary to protect the anonymity and privacy of people. Therefore, privacy-first apps with publicly-available code are needed to protect users' private information.

The authors of the article [8] argue that intermittent social distancing may be necessary until 2022. They state that longitudinal serological studies are needed to determine the extent and duration of immunity to SARS-CoV-2. The also mention that a resurgence in contagion could be possible as late as 2024.

If an effective vaccine is developed, even in the absence of long-term immunity, the possibility of regular vaccinations could assure us protection against COVID-19. If a vaccine is never developed (like in the case of HIV), we will have to modify our rules of behavior, do contact tracing and isolating until our scientists find a treatment for this disease.

## 6 Recapitulation

- The pandemic of COVID-19 started in China in December 2019 and since then there have been more than 440 000 confirmed deaths worldwide and more than 8,150,000 confirmed infections. The agent causing this disease is a virus closely related to the one provoking SARS. So far there is neither a vaccine nor an effective treatment for COVID-19.
- A SIR model was developed by scientist of MPI for Dynamics and Self-Organization. They study three scenarios in Germany considering no restrictions, partial or stricter restrictions. The data in their study correspond

to the month of March 2020. Early and stricter restrictions have a huge impact in reducing the number of new infections.

- In the next model, a time delay was introduced in order to consider the incubation period, where individuals are already infectious but they are asymptomatic. This model considers only the data from China between January 23th to February 9th. Based on their simulations, the authors suggest that the local government should implement high isolation programs.

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