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Understanding the First and the Second Waves of the COVID-19 in Germany: Is our Social Behavior Enough to Protect us from the Pandemic?

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Abstract

Like other European countries, Germany has experienced the 2nd wave of the COVID-19 amid obligations of social distancing and wearing of face masks in public spaces. Although Germany successfully contained the virus during the 1st wave, it has faced difficulties in controlling the COVID-19 during the 2nd wave. This study develops a computer model representing the COVID-19 flow in Germany by comparing the effects of the measures taken during the 1st and the 2nd waves. The computer model is based on the SEIR concept and the system dynamics (SD) approach in which some unknown parameters are estimated through the calibration process. Moreover, the SEIR computer model is developed by considering different cases in older and young people and the SEIR model successfully reproduces similar patterns of infected, recovered, and death cases in the 1st and the 2nd waves in Germany. The SEIR model also shows that the measures taken in the 1st wave have different efficacies than those in the 2nd wave, leading to higher infected cases during the 2nd wave. Since the SEIR model can successfully reproduce similar patterns, the SEIR model can be a basis for further studies in estimating other resource needs such as health workers, and bed capacities.

Keywords: System dynamics, COVID-19, Coronavirus, Germany COVID-19 cases, SEIR model

Introduction

Originally, earlier cases of coronavirus disease 2019 (COVID-19) were reported in Wuhan, China in December 2019. Less than 6 months after the 1st case was confirmed, the COVID-19 has spread across the world, making it a global pandemic. The WHO has reported the latest figures on *infected cases* and death cases from all affected areas across the world since January 2020. The report from WHO aims to increase our awareness of the widespread impact of the COVID-19.

Germany, the largest economic producer in Europe, inevitably has also experienced this pandemic. The 1st confirmed case in Germany was reported in late January 2020 when the 1st confirmed patient was contacted by his infected colleague(s) from China [1]. Within 2 months, more than new 100 confirmed cases were formally recorded in Germany [2]. The confirmed cases increased exponentially by about 6,000 in mid-April 2020.

To anticipate the massive flow of the COVID-19, the German government introduced public closures of schools, universities, and restaurants starting from March 16 [2]. A further measure was also applied such as the national curfew and restricting people from gathering. In principle, people were advised to stay at home and they should only leave home for basic needs.

Following lockdowns, Germany decreased infected cases significantly by the end of the 1st wave (January - July) as seen in **Figure 1**. Thus, the country had relaxed some measures such as opening restaurants and gymnasiums - starting from August 2020. Although some measures such as physical distancing and wearing masks in public spaces were still implemented, Germany has experienced the 2nd wave of the COVID-19 - starting from September 2020. In general, infected cases were relatively higher in the 2nd wave than those in the 1st wave.

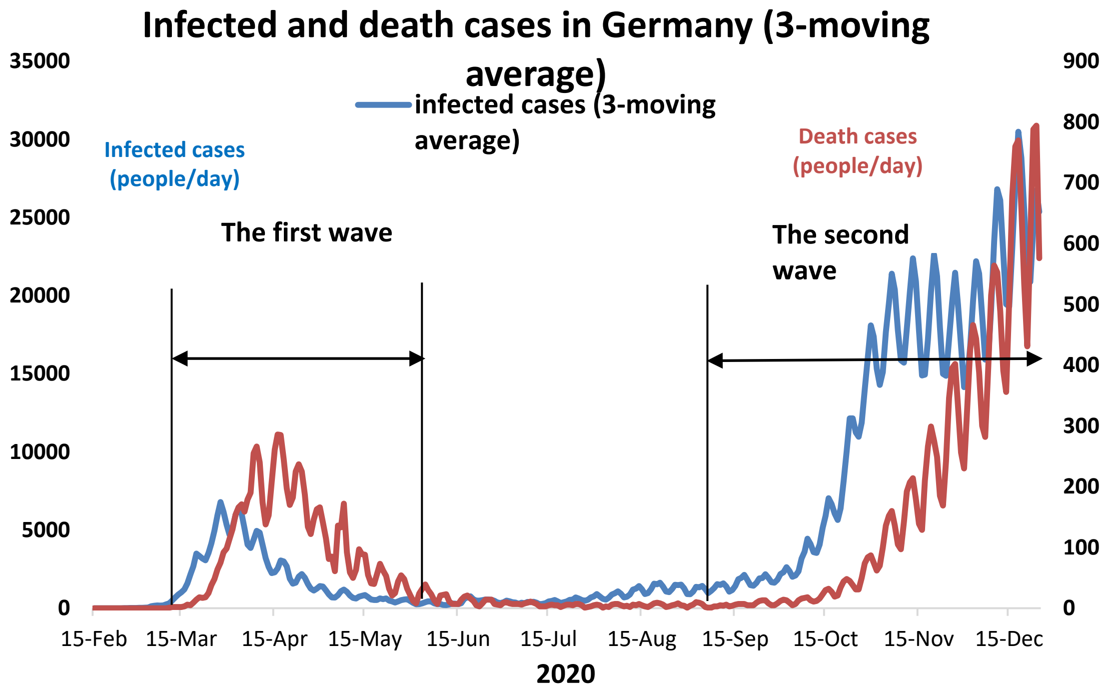

Figure 1 Confirmed infected and death cases in Germany (Feb 15th - Dec 15th).

Several studies analyzed the COVID-19 flow in Germany. For instance, existing studies [3,4] introduced a mathematical model in understanding the dynamic flow of the COVID-19 while other existing studies [5-7] explained demographic patterns of the patients. The flow of the COVID-19 has also been the main focus of existing studies [1,8]. Other recent studies compared issues such as modeling the 2nd wave in Germany [9] and differences between the 1st and the 2nd wave in Europe [10,11].

Despite important contributions, no available study investigated and compared the flow of the COVID-19 in the 1st and the 2nd wave in Germany. Existing studies [3,4] only explained the flow of the COVID-19 in Germany but they did not separate 2 different measures in tackling the flow of the COVID-19. This is important as existing studies [12,13] indicated 2 types of measures or policies: behavior reduction policy (behavior attitude such as wearing a face mask and physical distancing) and lockdowns (public closures). Examining the roles of these different policies enables us to understand their significance in slashing the COVID-19 flow.

Thus, this study aims to compare the 1st and the 2nd waves in Germany. Especially, this study aims to compare the efficacy of the 1st policy and the 2nd policy during the 1st and the 2nd waves. In doing so, the Susceptible-Exposed-Infective-Recovered (SEIR) model of the COVID-19 will be developed to embed the 1st and the 2nd policies and analyze the efficacy of the 1st and the 2nd policies during the 1st and the 2nd waves.

Materials and method

Data were collected from http://www.worldometer.com and Robert Koch Institute (RKI - http://www.rki.de). This study also collected data related to important measures from ECDC (2021) as this portal provides information step by step on the government's taken measures in tackling the flow of the COVID-19. Data collection includes several data types such as infected, death and recovered cases. The other important data such as ages, incubation time, and recovery time were also collected.

The computer model follows the SEIR concept. The SEIR model is built based on the SD approach as a lot of studies have successfully simulated infectious, non-infectious diseases, and other healthcare issues using the SD approach [14-17].

To estimate unknown parameters, this study calibrates unknown parameters using the Markov Chain Monte Carlo (MCMC) calibration, available in Vensim©. To obtain the best parameter values, the SD model compares 2 outputs including infected cases and deaths. These 2 simulated variables (infected and death cases) are compared to respective historical (historical infected and death cases) in obtaining the best parameter values in which the best-estimated parameter values lead to the smallest errors. The calibration process was conducted for the 1st and the 2nd waves.

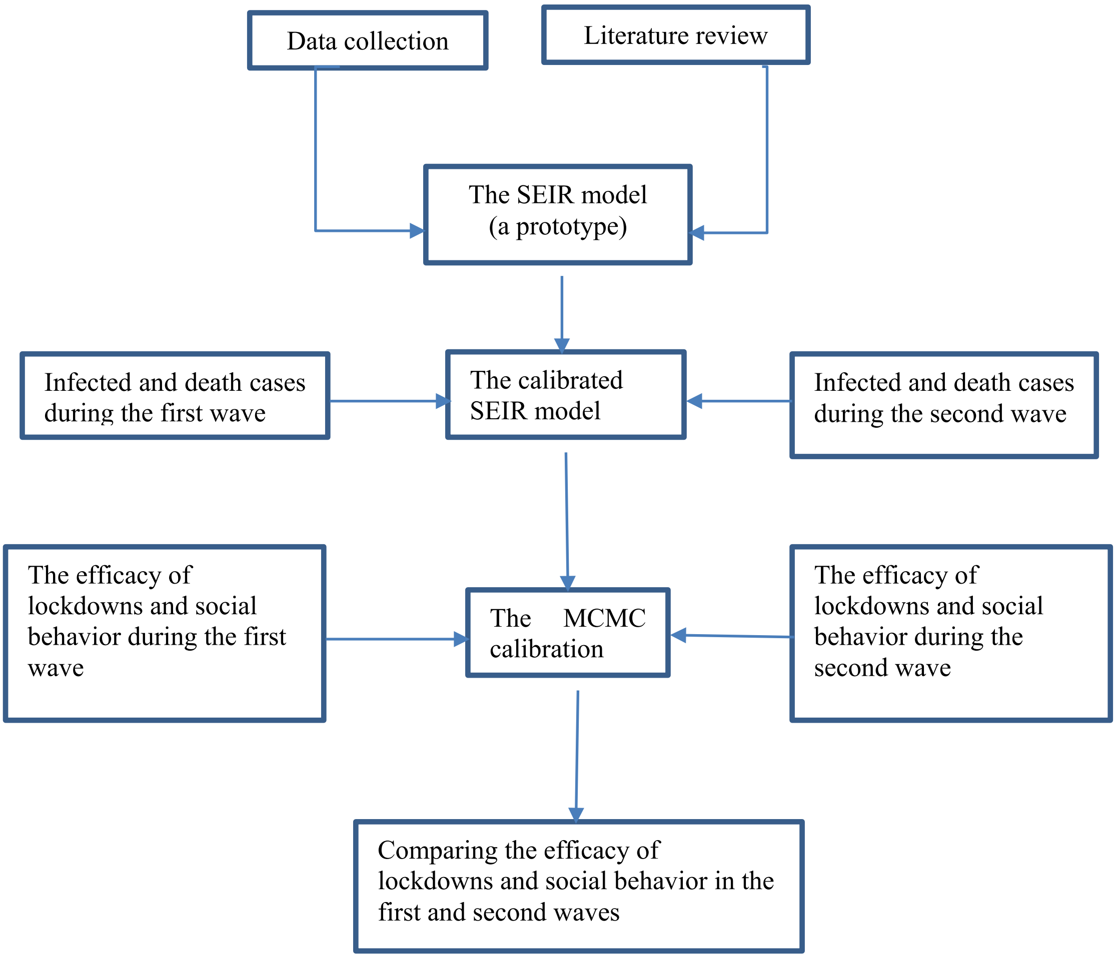

Figure 2 The step-by-step research method.

This study also introduces 2 measures or policies in tackling the flow of the COVID-19. The 1st policy is called behavioral risk reduction and the 2nd one is lockdowns (public closures). The main reason to separate policies is that the 1st policy is useful once infected people and uninfected people are easy to identify or the number of cases is relatively low. The 1st policies are, for instance, handwashing, and physical distancing. However, once separating infected and uninfected people is relatively difficult owing to rising coronavirus cases, the 2nd policy, i.e., lockdown, is the best solution to stop the transmission of diseases [18]. Separating these 2 policies is also essential owing to 2 reasons. The 1st reason existing studies explained the importance of the 1st policy [12,13], and the 2nd reason is that while the 1st policy is usually not supported by legal enforcement, the 2nd policy is usually supported by law enforcement [13].

In the end, the best-estimated parameter values during the 1st and the 2nd waves are calculated to compare the efficacy of the 1st and the 2nd policies. The step-by-step research method is summarized in **Figure 2**.

Results and discussion

The SEIR model consists of 2 groups: old (≥ 60 years) and young patients (< 60 years). This aims to capture the imbalance proportion of infected and death cases in both groups. Several studies [6,7] pointed out that the imbalance effects of the COVID-19 were experienced by older people as they tend to have the highest death cases. Specifically, RKI (2020) has explained that the 1st group consists of about 95 % of total deaths and about 21 % of total infected cases, while the 2nd group covers about 5 % of total deaths and 79 % of total infected cases. Again, separating the cases between young and older groups also accommodates possible different factors such as recovery time and infection duration between the 2 groups.

As previously mentioned, the MCMC calibration process is conducted to obtain the best values of unknown parameters. **Table 1** displays the main variables used in this study and their estimated ranges based on existing studies. During the MCMC calibration, values of unknown parameters are set based on **Table 1**.

Table 1 The setting of parameter values for the calibration process.

Variables	Values	References
The 1st confirmed case(s).	January 27th	[1,19]
Ro (basic reproduction number)	(2.4 - 3.8)	[4,20]
Incubation time	(2 - 7) days	[1,4,20]
Infection duration	(45 - 75) days This variable is only for older patients (≥ 60 years)	[6-8]
Recovery time * recovery time1 ** recovery time2 These variables represent a recovery time for older patients (≥ 60 years) and younger patients (< 60 years) respectively.	 (3 - 35) days* (3 - 7) days**	[6,7]
Fraction based on age structure (fraction of group 1 compared with the total infected patients)	(19 - 22 %)	[20]
Two existing studies (Lüdecke and Knesebeck [12]; Hoenig and Wenz [13]) found the importance of protective behavior and public health campaigns to minimize the COVID-19 flow. They started in mid-February 2020. Two variables, "behavioral reaction time" and "behavioral risk reduction", represent the efficacy of these measures and the starting time	A value of "behavioral reaction time" is (19 - 25 days) and a value of "behavioral risk reduction" is assumed between 10 and 50 %. The behavioral reduction time is measured between the 1st infection case and the beginning of the behavioral risk reduction act.	[2,21]

Variables	Values	References
respectively.		
The effects of the national lockdown are assumed very high. The national lockdown is represented by “lockdown risk reduction” and its starting time is represented by “lockdown reaction time”.	Public closures started on March 16th and a ban on gatherings of more than 2 people started on March 22nd. So, in the SEIR model, a value of “lockdown reaction time” is (56 - 62) days. This means that the national lockdown started (56 - 62) days after the 1st infection. A value of another variable, “lockdown risk reduction”, is assumed between 60 and 85 %. Because German states may not apply the lockdown in the same day, another variable i.e., “delay time” (1 - 5 days) is inserted into the SEIR model.	[19,20]

Figure 3 shows that (SD) or the SEIR model separates infected patients into 2 groups. This also means that for each group, the SD model calculates the number of infected cases, recoveries, and deaths. In the SEIR model, recovery time1 is defined as an average time between symptom onsets and recoveries, while infected duration1 is defined as the average time between symptom onsets and deaths, which is only applied for the 1st group (≥ 60 years). For the 2nd group (< 60 years), the SEIR model uses recovery time 2 to measure an average time between symptom onsets and recoveries.

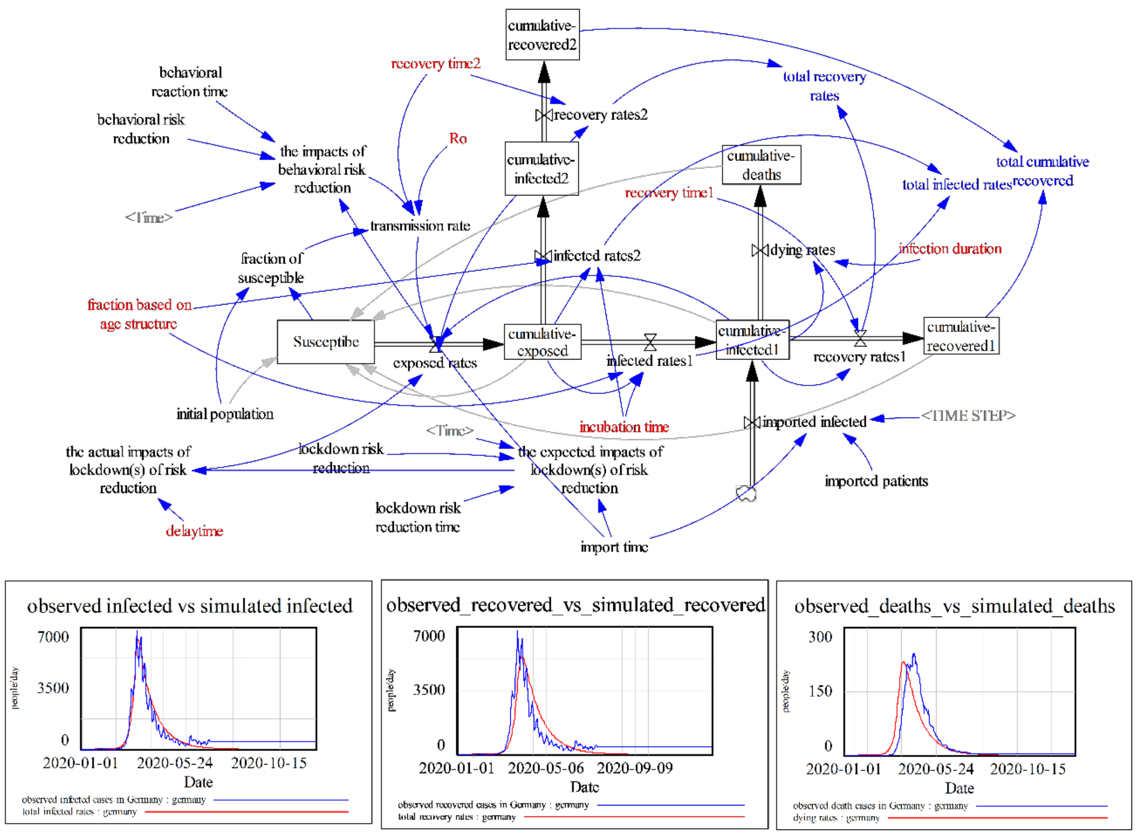

Figure 3 The SD model of Germany COVID-19 (the SEIR model is freely available at: https://osf.io/3k6db).

The number of infected cases, deaths, and recoveries are based on Eqs. (1) - (3) (similar equations apply for *infected rates2* and *recovery rates2*) as follows:

infected rates1 = "cumulative-exposed"/incubation time*fraction based on age structure (1)

dying rates = "cumulative-infected1"/infection duration (2)

recovery rates1 = "cumulative-infected1"/recovery time (3)

The transmission rate measures the number of exposed people and as Fiddaman [22], the transmission rate is calculated based on Eq. (3). For the 1st policy, its impact is calculated based on Eq. (4). Eq. (4) means that the 1st policy of behavioral risk reduction decreases transmission rate based on 2 factors: “behavioral reduction risk” and “behavioral reduction time”.

Transmission rate = (Ro/recovery time2)*fraction of susceptible*(1-the impacts of behavioral risk reduction) (4)

A similar equation is applied for the 2nd policy as seen in Eq. (5). Eq. (5a) guarantees that the number of infected rates is decreased through decreased exposed rates. Again, Eqs. (5b) and (5c) explain that the effects of the 2nd policy and its starting time.
exposed rates = (("cumulative-infected1"+"cumulative-infected2")*transmission rate*(1-"the actual impacts of lockdown(s) of risk reduction")) (5a)

the expected impacts of lockdown risk reduction = IF THEN ELSE(Time>=import time+"lockdown risk reduction time”, “lockdown risk reduction”, 0) (5b)

the actual impacts of lockdown risk reduction = DELAY3I("the expected impacts of lockdown risk reduction", delaytime , "the expected impacts of lockdown risk reduction"). (5c)

Table 2 The best parameter values of the SEIR model.

Variables	Estimated values
Ro (basic reproduction number)	3.45 (2.4 - 3.8)
Incubation time (days)	3 (2 - 7) days
Infection duration (days)	64.5 (45 - 91) days
Recovery time (days) * recovery time1 (≥ 60 years) ** recovery time2 (< 60 years)	 5 (3 - 35) days* 3.5 (3 - 7) days**
Fraction based on age structure	22 %
The behavioral reaction time (days)	15
The behavioral risk reduction	10 %
The lockdown risk reduction time	61
The lockdown risk reduction	84.5 %
Delay time (days)	4.5

After running the MCMC calibration, the author collects the best parameter values as seen in **Table 2**. As expected, the infection duration of older groups is about 65 days, longer than the recovery time of older groups around 5 days. However, the recovery time of older groups (5 days) is relatively longer than that of younger groups (3.5 days). Two variables, the behavioral reaction time and the lockdown risk reduction time, are about 15 days and 61 days. This means that the effects of the 1st and the 2nd policies effectively start 15 days and 61 days after the 1st infection case.

It is also found that the 2nd policy efficacy (85 %) is higher than the 1st policy efficacy (10 %). This means that the 1st and 2nd policies can decrease the transmission rate by about 10 and 85 % respectively. This finding may explain the importance of lockdowns in minimizing the COVID-19 flow in Germany.

It appears that the SD model can successfully reproduce similar outputs compared to respective observed outputs as seen in **Figure 2**. The SD model performance shows that the SD model has symmetric Mean Percentage Errors (sMAPE) less than 10 % (**Table 3**).

Table 3 sMAPE for the SEIR model.

Variables	sMAPE
Infected cases	< 5 %
Death cases	< 5 %
Recovered cases	7 %

Sensitivity analysis

Following another study [23], this study conducts sensitivity analysis and separates tested parameters into 3 categories: highly sensitive, very sensitive, and insensitive parameters. Tested parameters were categorized as highly sensitive and sensitive parameters if a 10 % change of parameter leads to changes of output higher than 35 % and less than 15 % respectively. The other parameters are called very sensitive parameters. **Table 4** highlights that 4 parameters such as Ro, incubation time, and infection duration are categorised as highly sensitive parameters. The other parameters are sensitive parameters as a 10 % change leads to less than 15 % change of given outputs (infected, recovered, and death cases).

Table 4 Sensitivity analysis for each given parameter.

No	Variables	Sensitivity results
1	Ro (basic reproduction number)	> 35 %
2	Infection duration (days)	> 35 %
3	Incubation time (days)	> 35 %
4	Recovery time1	> 35 %
5	Recovery time2	< 15 %
6	Delay time (days)	< 15 %
7	The behavioral risk reduction	< 15 %
8	The behavioral reaction time (days)	< 15 %
9	The lockdown risk reduction	< 15 %
10	The lockdown risk reduction time	< 15 %
11	Fraction based on age structure	< 15 %

This study also conducts the multivariate sensitivity analysis based on Latin Hypercube Sampling (LHS) in which highly sensitive parameters are varied simultaneously. As seen in **Figure 4**, it is found that the peaks of simulated infected, recovered and death cases lie within 100 % of the total sample. For instance, the peak of observed infected and recovered cases was 7,000 people/day which is in the range of 100 % sampling of sensitivity analysis for infected and recovered cases (5,000 - 15,000 people/day).

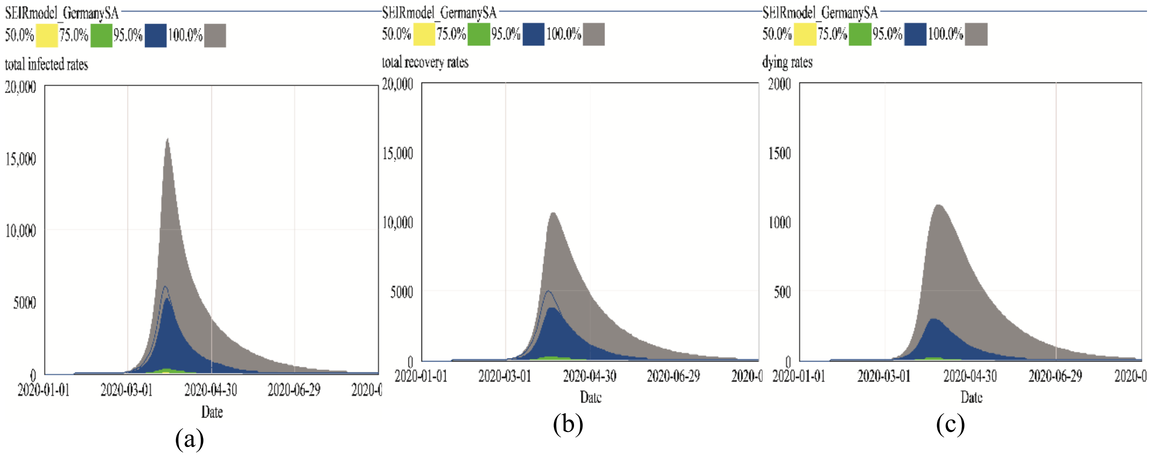

Figure 4 Sensitivity analysis, infected rates (a), recovered rates (b), death rates (c).

The results of sensitivity analysis inform us that the healthcare management should focus on these uncertain parameters as highly sensitive parameters can lead to rising infected cases. Shortly, the preparedness for the pandemic should be considered in highly sensitive parameters. Once these highly sensitive parameters can be controlled properly, then it is hoped that the flow of infectious diseases can be minimized properly.

Reproducibility of the SEIR model in the second wave

To increase the SEIR model confidence, the previous SEIR model is calibrated based on observed data during the 2nd wave. After running the MCMC calibration, optimized values for new variables are given in **Table 5**. Based on optimized values seen in **Table 5** (for unlisted parameters, their optimized values are the same as those in **Table 1**), the SEIR model can reproduce similar patterns of the 2nd wave cases in Germany as seen in **Figure 5**.

Table 5 Optimized values of new parameters during the 2nd wave.

Variables	Estimated values
Behavioral risk reduction during the 2nd wave	30 %
Lockdown risk reduction during the 2nd wave	45 %

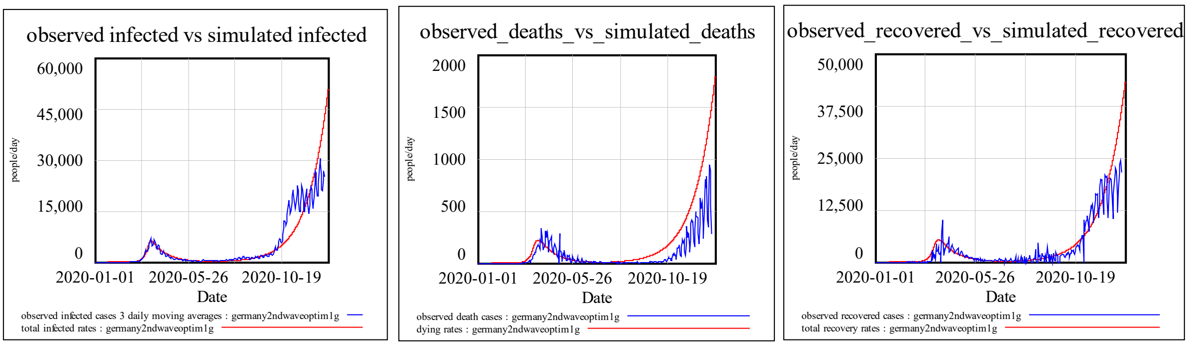

Figure 5 Simulated cases and observed cases during the 1^{st} and the 2^{nd} waves.

As expected, during the 2^{nd} wave, behavioral risk reduction has a higher impact (30 %) than that during the 1^{st} wave (10 %). As wearing a face mask is an obligation during the 2^{nd} wave [2], it is not surprising that the efficacy of the 1^{st} policy is relatively higher during the 2^{nd} wave than that in the 1^{st} wave. On the opposite, lockdown risk reduction has relatively lower impacts in the 2^{nd} wave (45 %) than that in the 1^{st} wave (85 %). It is plausible as the government has relaxed lockdowns since July 2020 [2], leading to the peak of infected cases in December 2020.

Conclusions

This study fills the gap in which existing studies have not separated the impacts of the 1^{st} policy (the society behavior) and the 2^{nd} policy (the government actions) in tackling the COVID-19 flow in Germany. To measure the impacts of the 1^{st} and the 2^{nd} policy, this study develops the SEIR model based on the SD approach and obtains the best parameter values through the MCMC calibration. Moreover, the sensitivity analysis highlights the importance of highly sensitive parameters in the flow of COVID-19. Stakeholders should be concerned about controlling these highly sensitive parameters during the pandemic.

It is shown that the 1^{st} policy i.e., preventive behavior such as handwashing and physical distancing is important in minimizing the flow of the COVID-19. However, the 2^{nd} policy i.e., lockdowns has the most important role in flattening the COVID-19 curve. However, it should be noted that opening public spaces must be initiated carefully as, despite the importance of preventive behavior, the 1^{st} policy is not sufficient to significantly decrease the flow of the COVID-19. Moreover, as seen in the observed system, relaxed lockdowns have led to the 2^{nd} wave of the COVID-19.

As the government has enforced people to wear a face mask and observe physical distancing prior to the 2^{nd} wave, the efficacy of the 1^{st} policy is relatively higher during the 2^{nd} wave than that during the 1^{st} wave. However, as this study finds that the 2^{nd} policy is less efficient during the 2^{nd} wave, the 2^{nd} wave has higher infected and death cases than the 1^{st} wave.

This study also shows that the cohort SEIR model can successfully reproduce similar patterns of the COVID-19 flow during the 1^{st} and the 2^{nd} waves. As it is the cohort SEIR model, it can be used to estimate the imbalance effects of the COVID-19 on different age groups. Moreover, the cohort SEIR model can be a basis to simulate impacts of the COVID-19 on other issues such as the availability of health workers and hospital beds.

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