Effect of voluntary event cancellation and school closure as countermeasures against COVID-19 outbreak in Japan

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Abstract

Background: To control the COVID-19 outbreak in Japan, sports and entertainment events were canceled throughout Japan for two weeks from February 26 through March 19. That policy has been designated as voluntary event cancellation (VECSC).

Object: This study assesses the VECSC effectiveness using predicted outcomes.

Method: A simple susceptible–infected–recovery model was applied to data of patients with symptoms in Japan during January 14 through March 25. The respective reproduction numbers before VECSC (R), during VECSC (R_e), and after VECSC (R_a) were estimated.

Results: Results suggest R before VECSC as 1.992 and its range was [1.892, 2.088]. Moreover, R_e was estimated as 1.125 [0.933, 1.345] and R_a was estimated as 3.083 [2.375, 4.067].

Discussion and Conclusion: Results demonstrated that VECSC can reduce COVID-19 infectiousness considerably, but the value of R rose to exceed 2.5 after VECSC.

Introduction

The initial case of COVID-19 in Japan was a patient returning from Wuhan, China who showed symptoms on January 3, 2020. Subsequently, as of April 6, 2020, the Ministry of Labour, Health and Welfare (MLHW) in Japan reported 3,906 cases in Japan, including asymptomatic cases but excluding those from a large cruise ship, the Diamond Princess [1].

Sports and entertainment events were canceled in Japan for two weeks from February 26 through March 11 according to a government advisory. At the same time, it was advised that small business and private meetings be cancelled voluntarily, meaning that the measure was not enforced by law. Therefore, people were not arrested even if they did not comply with this government requirement [2]. Nevertheless, the effort depends on voluntary compliance of the people. Moreover, this was the first time to require voluntary event cancellation. Those reasons complicate the *ex ante* prediction of the proportion of events which were cancelled and the extent to which contacts were reduced. Moreover, since March 3, almost all schools were closed from the middle of March to spring vacation as a measure to control the spread of COVID-19. Even though they can be infected and can transmit the virus to adults, school closure effects were questionable *ex ante* because schoolchildren are not the most susceptible age class for

COVID-19 [3–5]. Therefore, these policies must be evaluated *ex post*. The policy is known widely as voluntary event cancellation (VECSC).

If the effective reproduction number under these measures (R_e), is less than one: the outbreak can be expected to be contained. Alternatively, even if R_e were markedly less than R_0 but greater than one, it could be expected instead to prolong the outbreak.

The present study was conducted to evaluate VECSC from the epidemic curve because no evidence exists for the number of cancelled events. The obtained result might be expected to contribute to a government’s decision to implement VECSC as a countermeasure in Japan.

Method

We applied a simple susceptible–infected–recovery (SIR) model [6] to the epidemic curve in Japan for its population of 120 million. We assume an incubation period following the empirical distribution from the early stage of the outbreak. The person on the i th day of incubation will move to a symptomatic or asymptomatic state with the probability of the i th day on the empirical distribution of the incubation period or move to the i+1th day in the incubation state with one minus the probability. The maximum length of the incubation period was defined as 19 days.

Symptomatic and asymptomatic states continued for one week and then moved to a recovery state with probability of one. We are unconcerned about outcomes or necessary medical resources in this model. Therefore, the states of death or hospitalization were not incorporated into the model.

Asymptomatic cases are not observable unless complete laboratory-based surveillance is performed. One exceptional study indicated them as 3/23 from a sample of elderly people [7]. We checked its robustness for the proportion of asymptomatic cases assuming a ratio of 4/19 [8].

The infectivity by severe patients and by mild patients were assumed to be equal. Moreover, we assumed that asymptomatic cases have the same power of infectivity as symptomatic cases [7]. That is merely an assumption. Therefore, we verified its robustness through sensitivity analysis of the infectiousness of asymptomatic cases, such as 50% assumed for simulation studies for influenza [9–13]. The distribution of infectiousness in symptomatic and asymptomatic cases was assumed to be 30% on the onset day, 20% on the following day, and 10% for the subsequent five days [7]. Regarding its robustness, we also applied a uniform distribution for a week.

Because VECSC was conducted during February 27 through March 19, we divided the data period into three periods of before VECSC, during VECSC, and after VECSC, with corresponding reproduction numbers represented as R_0, R_e, and R_a. We modeled the change of the reproduction number for each day for February 27 through March 20 given the prior day's reported number of persons susceptible, incubation, symptomatic, asymptomatic, and in a recovered state.

The values of R_0, R_e, and R_a were sought to fit the data to minimize the sum of absolute values of discrepancies among the bootstrapped epidemic curve and the fitted values. The estimated distribution of three reproduction numbers was calculated using 10,000 iterations of bootstrapping for empirical distribution of the data for symptomatic patients.

The bootstrapping procedure which was used fully replicated bootstrapping with a fixed number of initial cases. There were N patients in the data, with numbering of the patients from the initial case to the last case. Initially, there was no patient on the bootstrapped epidemic curve. If the random generator of the uniform distribution on (0,1) showed that the number was included in $[i/(N-1), (i+1)/(N-1)]$, then we added one to the onset date of i+1th patient to the bootstrapped epidemic curve. We replicated this procedure N-1 times. Finally, we added the initial patient, whose onset date was January 14, to the bootstrapped epidemic curve. Then we found a bootstrapped epidemic curve with N patients starting from January 14.

We estimated the curve sequentially as follows. First, we estimated R_0 as the best fit to bootstrapped data for the pre-VECSC period. Then, based on the obtained R_0 and the course of the outbreak before the VECSC period, we estimated R_e as the best fit to bootstrapped data in the VECSC period. Finally, based on the obtained R_0 and R_e, we estimated R_a as the best fit to bootstrapped data for the post-VECSC period. In each step, reproduction numbers were grid searched in the interval of (0,10) by 0.001.

We conducted three sensitivity analyses for one way: the infectiousness power of asymptomatic cases was 50% of symptomatic cases; the proportion of asymptomatic cases was 4/19 as symptomatic cases; infectiousness and infectious patterns showed a uniform distribution for one week.

We adopted 5% as significant level. We used Matlab 2014a to code difference equations for estimation, as explained above.

Data source

The numbers of symptomatic patients during January 14 – March 25 were published by the MLHW [1] as of April 6. During this period, 1516 cases were recorded with onset dates. We excluded imported cases and those presumed to have been infected persons from the Diamond Princess because they were presumed not to be community-acquired in Japan.

Ethical consideration

All information used for this study has been published [1]. There is therefore no ethical issue related to this study.

Results

Figure 1 depicts the empirical distribution of the incubation period among 59 cases for which the exposed date and onset date were published by MHLW. Its mode was six days. The average was 6.6 days.

The value of R_0 before VECSC was introduced was estimated as 1.992; its range was [1.892, 2.088]. However, R_e during the VECSC period was estimated as 1.125 [0.933, 1.345]. After VECSC, R_a was estimated as 3.083 [2.375, 4.067].

Figure 2 depicts the observed epidemic curve and predicted epidemic curve based on the estimated R_0, R_e, and R_a. It showed goodness of fit was pretty good. The null hypothesis that $R_{0,}$ R_e and R_a were the same was rejected significantly

One-way sensitivity analysis showed that if the infectiousness of asymptomatic cases were 50% of symptomatic cases instead of 100%, then R_0 would be estimated as 2.187 [2.033, 2.287], R_e would be 1.182 [1.001, 1.485] and R_a would be 3.271 [2.571, 4.360].

If the asymptomatic cases were 4/19 as symptomatic cases instead of 3/32, R_0 would be estimated as 2.019 [1.892, 2.104], R_e would be 1.114 [0.933, 1.345], and R_a

would be 3.061 [2.189, 4.000]. If the infectious pattern formed a uniform distribution for a week instead of the base case, then R_0 would be estimated as 2.210 [2.060, 2.314], R_e would be 1.138 [0.962, 1.361], and R_a would be 3.206 [2.354, 4.367].

Because ranges were overlapped, these factors might not affect the results so much, at least in the considered and reasonable region of the parameters and distribution. Especially, the estimated R_e and R_a were almost similar among four scenarios. The estimated R_0 was the most sensitive such as the scenarios of that the infectiousness of asymptomatic cases were 50% of symptomatic cases and uniform distribution as infectious pattern were higher than others.

Discussion

We applied a simple SIR model including asymptomatic cases that had not been incorporated into the model to date. An earlier study [14–16] estimated R_0 for COVID-19 as 2.24–3.58 in Wuhan. Our R_0 obtained for the period before VECSC was similar. However, an earlier study [17] estimated R_0 in Japan as 0.6. That figure might mislead policies for countermeasures in Japan, which necessitate adherence to contact tracing to detect clusters.

Among children or younger adults, the proportion of asymptomatic infected people might be larger than among elderly people. However, the proportion of asymptomatic cases in children or younger adult remains uncertain. Less susceptibility among children

[3–5] might imply a higher proportion of asymptomatic cases in children. In this sense, 3/23 among the elderly might be the lower bound of the proportion for the general population. Overall, sensitivity analysis showed similar estimation with base case. Therefore, we might conclude that the obtained results were robust to some extent.

Fortunately, two weeks had already passed since the study period. Therefore, the delay in reporting had almost disappeared. If timely estimation is necessary, meaning estimation using data from a day prior, we used adjusted delay for reported data [8, 18, 19].

We used the minimized sum of the absolute values of discrepancies for the bootstrapped epidemic curve and the fitted values, instead of the minimized sum of squared residuals such as maximum likelihood estimation based on a normal distribution. In general, minimization of the sum of the absolute values is more robust than minimization of the sum of squares because the absolute value is less sensitive than squared values to the effects of outliers [20–22]. The daily epidemic curve sometimes shows spikes because of the day of the week and other reasons. Especially, there were few patients per day reported during the early stage of the outbreak. Therefore, spikes might be considerably large. These spikes were probably outliers. They might affect the estimator too much. For this reason, we prefer minimization of the sum of the absolute values to minimization of the sum of squared values when analyzing daily data in the earlier stage of the outbreak.

Moreover, we chose non-parametric approaches using actual data in preference to parametric approaches assuming a particular distribution. Such an assumption might affect results through miss-specification. Therefore, we prefer to use the actual distribution of incubation periods or epidemic curves without any unnecessary or restrictive assumption.

Under-ascertainment of cases might be another topic for COVID-19 studies in Japan [23]. However, if some under-ascertainment randomly, it would not be expected to affect the results of the estimated reproduction number. For that reason, our obtained R_0 is expected to be comparable to those of other countries. Therefore, under-ascertainment might not be hinder estimation of the reproduction number.

In fact, the number of tests per 1,000 residents was 0.509 in Japan on April 9 and 6.63 in the US on April 8 [24]. However, the numbers of patients at that time were 3,906 in Japan and 396,710 in US [25]. Therefore, the incidence per 1,000 residents can be inferred as 0.0325 in Japan and 1.21 in US assuming a US population of 327.75 million. Based on those results, the positive rate was 6.39% in Japan and 18.25% in the US. Consequently, the positive rate in Japan was much lower than US. The insufficiency of test examinations might not lead to fewer patients in Japan. Particularly, the positive rate in Korea was 120%. Therefore, the number of patients might be greater than the number of test examinations. If insufficient test examination was the reason for under-ascertainment, then under-ascertainment might be severer in Korea than Japan.

The present study has some limitations. The first point was that even though we evaluated VECSC, the respective effects of voluntary event cancellation and school closure cannot be discerned. To do so, one would have to develop a model with several age classes. School closure mainly affects the contact pattern among schoolchildren; voluntary event cancellation mainly affects pattern among adults. Therefore, a study of those age groups might elucidate the effects of these policies separately. That stands as our challenge for future study.

The second point was under-ascertainment, as described above. Although it probably did not affect the results heavily, an important concern is that under-ascertainment might not occur randomly. Especially, under-ascertainment might occur less among severe patients than among mild patients. If this were the case, then the reproduction number might be overestimated if a virus mutates to present higher pathogenicity. Alternatively, under-ascertainment might occur less in less-affected areas than in more heavily affected areas. To characterize under-ascertainment, a complete survey of antibody titer and symptoms must be conducted. That also stands as a challenge to be undertaken after the current ongoing outbreak has ceased.

A third point is estimation of the outcomes or necessary medical resources for the care of COVID-19 patients. We particularly examine how policies affect the effective reproduction number. Therefore, we ignore prediction of the entire course of the outbreak and its outcomes such as the number of deaths. Nevertheless, outcomes are expected to be a primary concern for modelling. Moreover, collapse of medical services can be expected to lead to worse outcomes even if the reproduction number remains unchanged. Prediction of the effects of severe policies including lockdowns is expected as a future challenge for our research.

Conclusion

Results have demonstrated that VECSC can reduce the infectiousness of COVID-19 considerably: approximately to one. However, the figure is probably larger than one. Outbreaks might continue for a long time. Therefore, lockdown policies are expected to be as effective as VECSC if they are executed carefully. After VECSC, the reproduction number escalated again beyond that before VECSC. Similar phenomena might occur after a lockdown. We hope that results of the present study can contribute to governmental policy-making related to lockdown measures or other countermeasures to combat the spread and destruction of COVID-19.

The present study was based on the authors' opinions. The results or implications do not reflect any stance or policy of professionally affiliated bodies.

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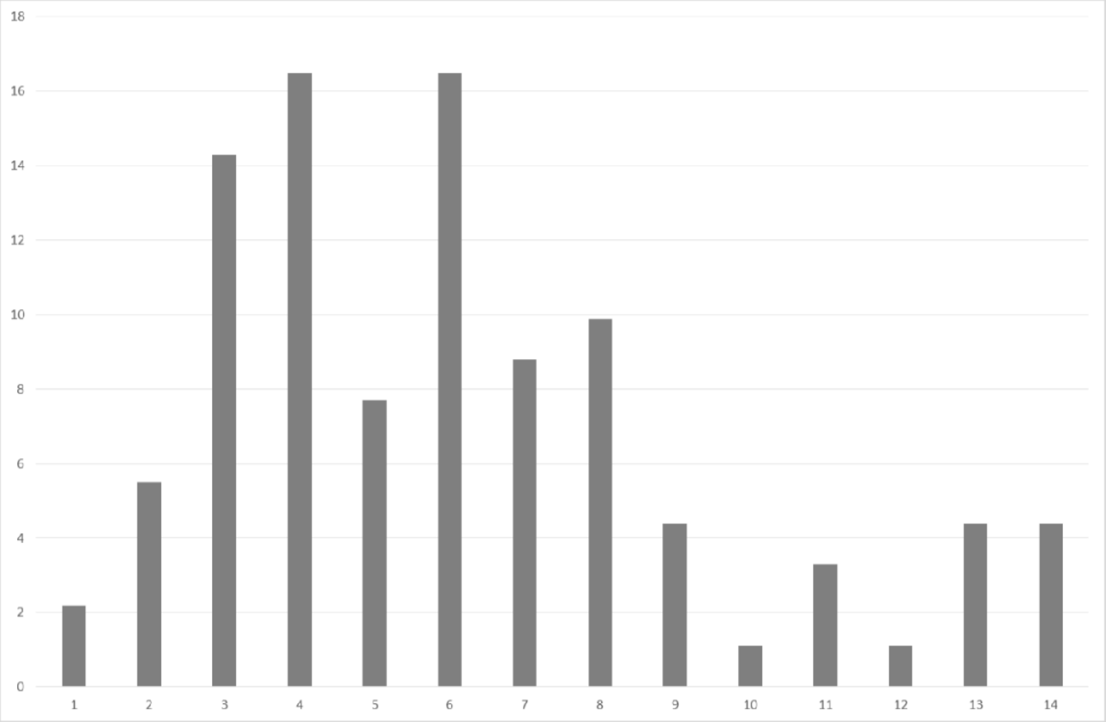
Figure 1: Empirical distribution of incubation period published by Ministry of Labour, Health and Welfare, Japan

(%)

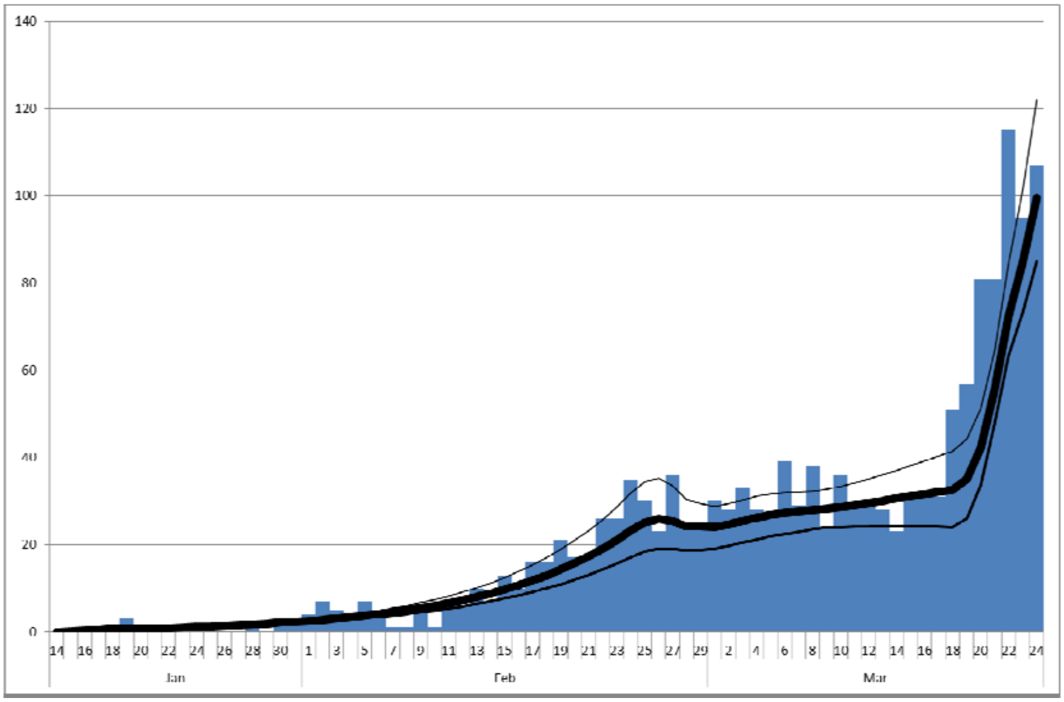


(days)

Notes: Bars showeddistribution of incubation period among 91 cases whose exposed date and onset date were published by Ministry of Labour, Health and Welfare, Japan. The patients whose incubation was longer than 14 days were included as bars on 14.

Figure 2: Observed epidemic curve of COVID-19 patients and predicted epidemic curve from the model based on the estimated reproduction number

(patients)



Note: Bar indicated the observed epidemic curve and bold line indicates the predicted line based on the estimated reproduction numbers. Thin lines indicate range of the best fit line at each bootstrapping iteration.