Comparing Predicted and Actual numbers of Covid-19 in British Columbia during Omicron Wave

Piyush Agarwal

Department of Mathematics, Simon Fraser University. Email: paa54@sfu.ca

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Abstract

The Omicron wave from Dec, 2021 to Feb, 2022 in British Columbia was predicted to be much larger than what seemed to happen. Demand on healthcare was predicted to be intense during January, 2022. While maximum cases were reported during the Omicron wave in January, hospitalization demand remained moderate and were handled. In this project, we investigate possible reasons for the over-estimation of the Omicron wave. We calculate model estimates when case importations into BC and the booster dose roll-out between December to February are considered. We find that the maximum incidence case reduces by a 4-fold margin when both vaccinations and case importations are considered.

Keywords: Omicron, British Columbia, SIR Model, Covid-19

1 Introduction

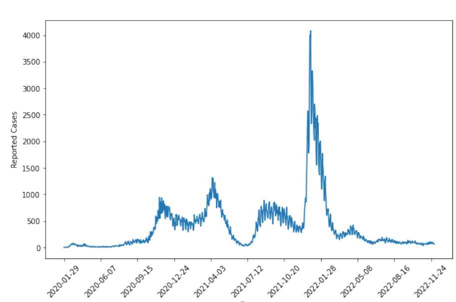
The World Health Organization declared the SARS-CoV-2 variant: B.1.1.529, popularly known as Omicron a variant of concern on November 26th, 2021. Not long after, British Columbia started observing Omicron cases and by Dec 12th, 2021 about 50% of the daily Covid cases were Omicron. Research groups in British Columbia took on the task of predicting the severity and size of the Omicron wave, and using different variants of the SIRS model reached a consensus of a larger wave than ever before in BC.

By late December, they predicted that the demand in healthcare would be extreme in January in the absence of any counter-measures. The doubling time for incident cases was only 3.5 days and only if Omicron was much less severe, the rising case numbers would not lead up to a corresponding extreme hospital demand. However, they accepted large uncertainty in their predictions due to changing health policies and unpredictable public behaviour. With updates from the world, Omicron was found to be less severe and posed less risk of hospitalization as compared to the Delta variant. By late January, the growth rate for Omicron cases had declined and hospital burden had remained low, much lower than the previous predictions. So we ask the question, what did our models miss which led to the much higher predictions as compared to the actual numbers?

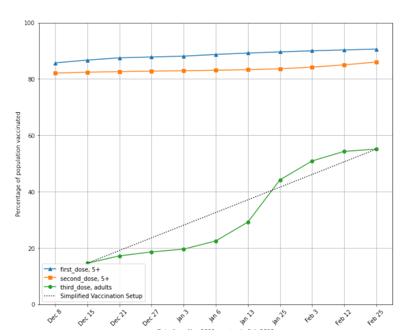
In this project, we try to answer this question with simple modifications to the SIRS model. Our first step is to tune the SIRS parameters to obtain the over-estimated omicron wave from Dec, 2021 to Feb, 2022 with the known epidemic constraints. We then implement our first hypothesis, which is including case importations to the SIRS model. We believe case importations rather than a high transmission rate had a role in the higher growth rates in middle and late December. Considering case importations would lead to a lower transmission rate and hence a lower epidemic size. Our second hypothesis is that the rapid roll-out of the booster dose from Dec, 2021 to Feb, 2022 played an important role in bending the curve. We believe that this brought the fraction of susceptibles down over time which led to a much lower epidemic than what was predicted. The problem was presented and set-up by my supervisor with me performing all further analysis and plotting. I used *solve_ivp* from scipy.integrate to perform numerical integration and *matplotlib* for plots.

2 Data Sets

I used two sets of data for this analysis. I had the daily case data from BCCDC (British Columbia Center for Disease Control) and compiled vaccination data from the daily updates in the newspaper: Vancouver Sun. I used the daily reported case data to compare with the model estimates, and the vaccination data to compute the constant rate of vaccination.



(a) Daily Reported Cases in British Columbia



(b) Vaccination Data from Feb 15th onwards

Figure 1. Data sets used for the analysis, (a) Daily Reported Cases (b) Vaccination Records

3 Methods

3.1 SIRS Model

The SIRS Model has been used as a convenient modelling framework to estimate epidemic dynamics. The usual structure is that the population with (size N) has an infected class (I) which spreads the infection to the susceptibles in the population (S) at a rate β. After spending the duration of infection($\frac{1}{\gamma}$), members in the infected class move to the recovered class (R). This would have been the SIR model but we also assume that immunity lapses and the recovered class becomes susceptible to infection after time period $\frac{1}{\delta}$. This gives the following set of equations:

$$\frac{dS}{dt} = -\beta\frac{SI}{N} + \delta R \tag{1}$$

$$\frac{dI}{dt} = \beta\frac{SI}{N} - \gamma I \tag{2}$$

$$\frac{dR}{dt} = \gamma I - \delta R \tag{3}$$

After fixing the parameters β, δ, γ and the initial conditions $S(0), I(0), R(0)$, we obtain a fixed solution using numerical integration. The solution contains information on the size of the infected class over time $I(t)$. Note that the incident cases on day $t+1$ is given by $\beta I(t)S(t)$. So if we can get reasonably accurate parameter values, then we can get a fair idea of how the epidemic will unfold. However this does not tell how severe the infected cases will be or what fraction of infected cases will need care and hospitalization.

In the Omicron wave in British Columbia, we fix $\delta = \frac{1}{180}$, and $\gamma = \frac{1}{5}$ in units of (days)$^{-1}$. Since Omicron could infect fully vaccinated individuals and less than 10% of BC was infected with Covid-19, we assume 70% − 90% of BC susceptible to Omicron ($0.7 \leq s(0) = \frac{S(0)}{N} \leq 0.9$). We had two starting constraints to fix $I(0)$ and β. We were informed that about 50% cases on Dec 12th were Omicron cases, and the rise in Omicron cases was about 20% in mid and late December. Note that we don't discuss $R(0)$ because we show it to be irrelevant in determining $\beta S(t)I(t)$.

3.2 Modification in the SIRS Model

Case Importations

Since we didn't have data of migrations into British Columbia, we just worked with general instances of importations. The modified SIRS model is:

$$\frac{dS}{dt} = -\beta\frac{SI}{N} + \delta R$$

$$\frac{dI}{dt} = \beta\frac{SI}{N} - \gamma I + addition$$

$$\frac{dR}{dt} = \gamma I - \delta R$$

We used four different choices of importations:

- a constant daily addition of 100 cases. so $addition = 100$
- exp. decreasing additions initially 100 and declining at rate 0.05 so $addition = 100e^{-0.05t}$
- a constant daily addition of 100 cases. so $addition = 400$
- exp. decreasing additions initially 400 and declining at rate 0.05 so $addition = 400e^{-0.05t}$

Vaccinations

We assume a constant rate of booster vaccination, with immunity coming in after two weeks of getting vaccinated. The vaccines work at a given efficacy and renders a susceptible individual out of the susceptible class. If v is the efficacy of the vaccine, and b is the constant rate of vaccination, then the SIRS model becomes:

$$\begin{aligned}
\frac{dS}{dt} &= -\beta\frac{SI}{N} + \delta R - vb\mathbb{1}(t > 14) \\
\frac{dI}{dt} &= \beta\frac{SI}{N} - \gamma I \\
\frac{dR}{dt} &= \gamma I - \delta R
\end{aligned}$$

where $\mathbb{1}$ is the indicator function.

4 Results

4.1 Fitting SIRS Model to Initial Data

The goal is to find a reasonable transmission rate (β) (depending on $s(0)$), such that the incident cases predicted by the model matches to real data between Dec 12th, 2021 to Jan 1st, 2022. We first see that the initial size of the recovered class ($R(0)$) doesn't affect the analysis. This is probably because of the large duration of infection induced immunity (about 6 months) as compared to our short interval of interest (20 days). We plot the incidence cases for different initial size of the recovered class (range being large enough) and the probable transmission rates of 0.5, 0.55, 0.6. The number of incident cases remain unaffected with changes in the size of the recovered class.

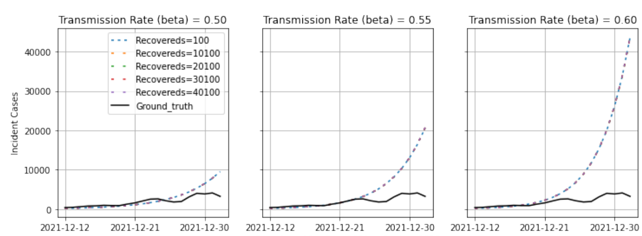


Figure 2. Demonstration of Size of Recovered Class being irrelevant in the Analysis

We see that the incident cases overlap for the different sizes of the recovered class and so we don't have to worry about the recovered class size in further analysis.

We will now try to find the transmission rate (β) with the constraints that omicron cases were half of the total cases on Dec 12th, 2021 and the growth rate of the epidemic was estimated to be about 20%.

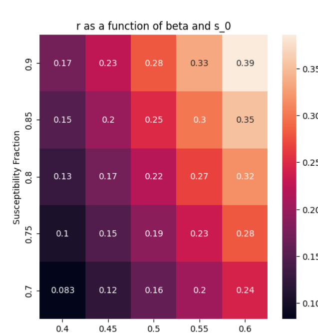


Figure 3. Mean Growth Rate r as a function of transmission rate β and initial susceptibility fraction s_0

Note that imposing the growth rate as a starting constraint is difficult so we impose it as a satisfying criteria. If the chosen parameters leads to a very different growth rate, we reject the parameter. In the above heatmap, we plot the mean of the growth rate of the epidemic from Dec 12th, 2021 to Jan 1st, 2022. We accept those choices of (β, s_0), which satisfy $0.17 \leq r \leq 0.23$. This gives us the following list: $(0.4, 0.9)$, $(0.45, 0.80)$, $(0.45, 0.85)$, $(0.45, 0.9)$, $(0.5, 0.75)$, $(0.5, 0.80)$, $(0.55, 0.75)$. Let us now plot the dynamics of the epidemic from Dec 12th to Jan 1st for the selected parameter list.

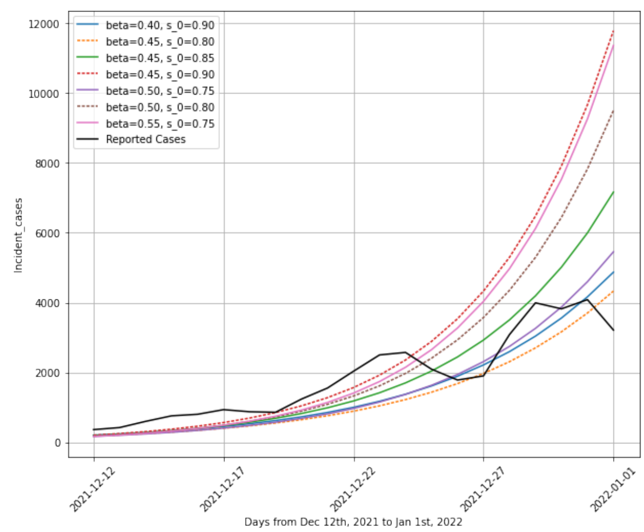


Figure 4. Daily Incident Cases as a function of transmission rate (β) and initial susceptibility (s) from Dec 12th, 2021 to Jan 1st, 2022

By late Dec-early January, testing limits had breached in British Columbia with PCR tests prioritized for those 65 years and older or with underlying medical conditions. Let us observe the growth of the epidemic for each of scenario till about mid-February. Clearly the number of reported cases

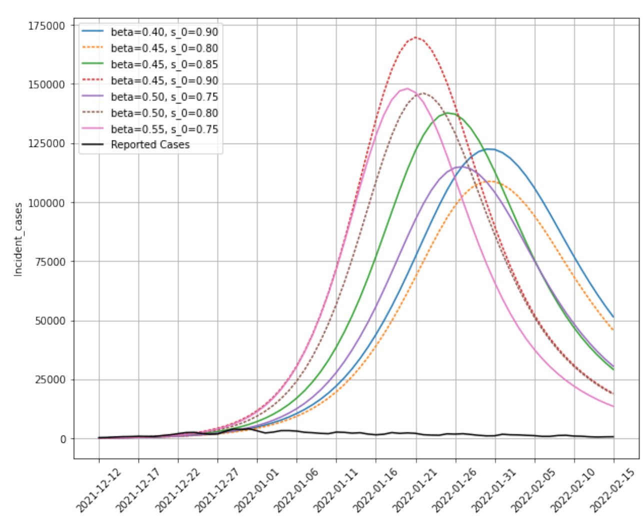


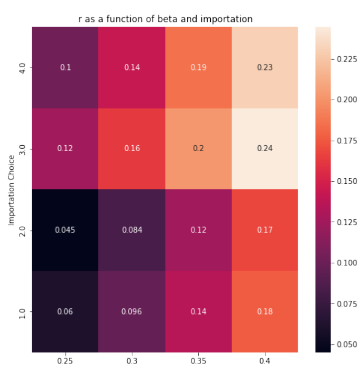
Figure 5. Daily Incident Cases as a function of transmission rate (β) and initial susceptibility (s) from Dec 12th, 2021 to Feb 15th, 2022

dwarf in comparison to what could have been possible sizes of the epidemic. Also, these estimates of the epidemic are consistent with the estimates from the **BC Covid-19 Modelling Group** with the peak in mid-January, and the projected incident cases at the same order of magnitude. Then this begs the question, can we explain the events that unfolded during the omicron wave due to which the reported cases were far less as compared to model estimates. We can review this question in largely two ways:

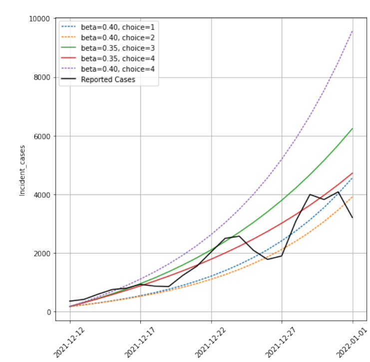
1. Was the omicron wave in BC actually this big as the model predicts? Or did we miss major events like policy changes, booster doses or effects like case importations due to which the model predictions got inflated?
2. Were there a large number of infections which went unreported? This could be due to testing capacities or even low severity of omicron which led to more asymptomatic cases.

4.2 Case Importations

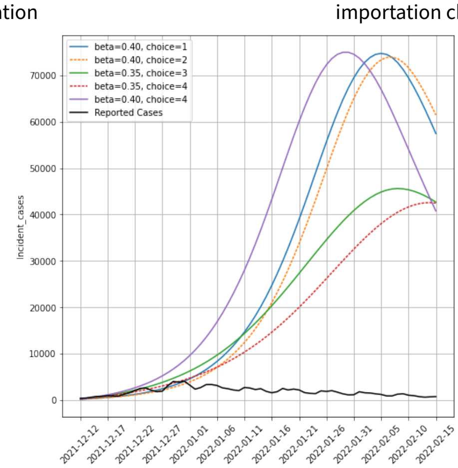
The SIRS model considered a closed BC population with no inflow or outflow of infected cases. So it is plausible that including inflow of omicron cases into BC drives the transmission rate lower leading to a much smaller epidemic size. Note that the susceptible size remains the same and is unaffected by case importations. We introduce importations through four simple ways described in methods. We check if we can achieve a growth rate (r) of about 20% by considering the transmission potential β from $[0.2, 0.4]$ and then consider the dynamics for those parameters with growth rate $0.17 \leq r \leq 0.23$ from Dec 12th, 2021 to Jan 1st, 2022 and then Dec 12th, 2021 to Feb 15th, 2022.



(a) Growth Rate varying with transmission rate β and choice of importation



(b) Daily Incident Cases as a function of β and importation choice from Dec 12th to Jan 1st



(c) Daily Incident Cases as a function of β and importation choice from Dec 12th to Feb 15th

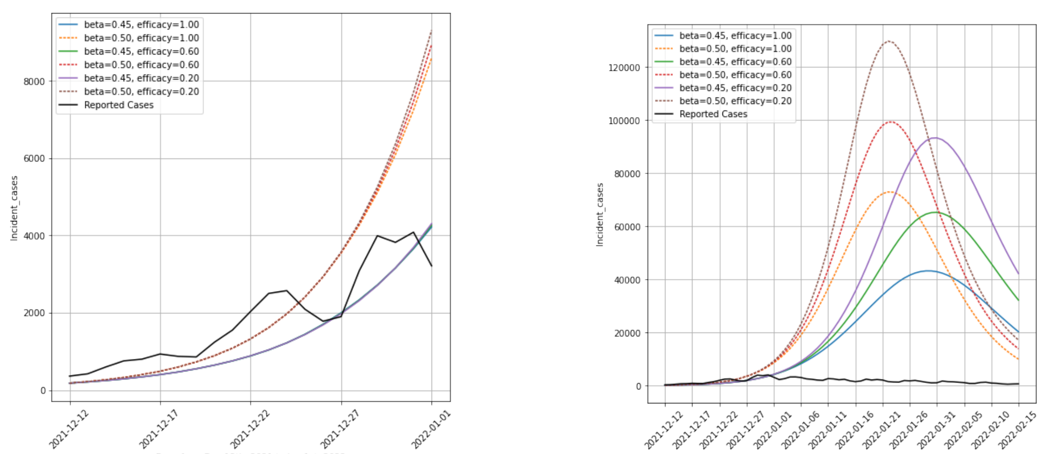
Figure 6. Importation cases every day: choice 1: 100, choice 2: $100e^{-0.05t}$, choice 3: 400, choice 4: $400e^{-0.05t}$

In the closed population, the range for β was $[0.45, 0.55]$ with the peak for new cases being around $150,000$. Considering importations, the dynamics still matches for the first 20 days(Dec

12th to Jan 1st) but the transmission rate and the peak are dragged down, with β in $[0.35, 0.40]$ and peak being around $40,000$ when $\beta = 0.35$ and $70,000$ when $\beta = 0.40$. Note that $\beta = 0.35$ is achieved when 400 importations are considered which might be too high. Still, on including a lower and a more plausible bar of 100 importations causes the peak cases to reduce to half which is a significant change. So the plausibility that ignoring case importations led to a bloated transmission rate and hence higher peaks cannot be ruled out. We could make better judgement if provided with an enhanced understanding of the travel landscape and correct estimates of the number of infected case importations into British Columbia.

4.3 Vaccinations

The booster dose was rapidly rolled out in British Columbia following the beginning of the Omicron wave. We will now see whether vaccines played a role in downsizing the omicron wave. We consider the initial susceptible fraction $s_0 = 0.8$, and $\beta = 0.45, 0.50$. Since the booster dose started rolling out in early December, we consider the effect of vaccines beginning after two weeks of our initial date, so Dec 26th, 2021.



(a) Daily Incident Cases as a function of β and vaccine efficacy from Dec 12th to Jan 1st

(b) Daily Incident Cases as a function of β and vaccine efficacy from Dec 12th to Feb 15th

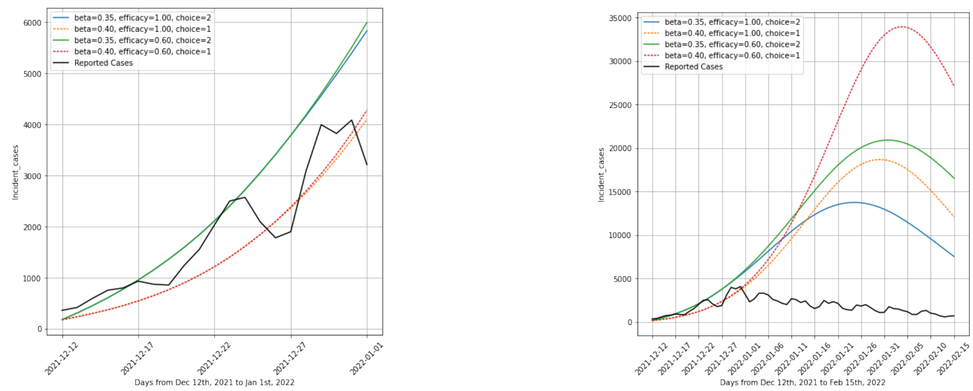
Figure 7. Effect of Vaccinations on the daily incident cases in British Columbia

We see that the final effect of vaccinations is quite similar to case importations though the cause is very different. Vaccinations reduced the number of susceptibles over time instead of altering the transmission rate. If the vaccines are highly effective ($\nu = 1$), we see almost a four-fold reduction in the maximum number of incident cases. Also, if the vaccines are even only slightly effective (efficacy$= 0.2$), we see some change in the maximum incidence from the unvaccinated case. Since we have reductions in the peaks for both importations and vaccinations it becomes interesting to see what happens when we consider importations and vaccinations together.

4.4 Case Importations and Vaccinations

After including a daily of 100 infected case into BC, we could reduce transmission rate to 0.4 which led to a massive reduction in the daily infected cases. We will now see the reductions in the daily cases when we introduce vaccinations as well. We consider the efficacy of vaccinations at $\{1, 0.6\}$ and daily case importations at 100, 400. Since initial growth rates are unaffected by vaccinations, we use transmission rates from importations. $\beta = 0.4$ for 100 daily importations, and $\beta = 0.35$ for

400 daily importations.



(a) Daily Incident Cases in BC from Dec 12th to Jan 1st

(b) Daily Incident Cases in BC from Dec 12th to Feb 15th

Figure 8. Effect of Vaccinations and Case Importations on the daily incident cases in British Columbia

Even on considering vaccinations and importations both, the dynamics of the modelled epidemic and the reported cases still compare well for the initial period. In the longer duration, the peak cases (among all scenarios) has reduced to 35000 which is a significant reduction from our starting point. Though, reported cases pale in comparison to the model estimates in the longer duration, we know that reported cases were affected by the capacities in testing. So it seems that the two modifications are plausible explanations for the low actual epidemic size as compared to the initial model outputs.

5 Discussion and Conclusion

We see that case importations and booster dose roll-out prove to be plausible explanations behind the over-estimation of the epidemic size. This analysis can be made concrete by considering hospitalization numbers on the model predicted infected cases. Hospitalization data being more accurate than the reported case data will present a clearer picture over what really happened. Incorporating travel data to construct a more precise case importation function will also be a very useful step in this direction.

For the purposes of the project, I focused on just the first set of questions we raised earlier, as to making modifications in the model to match the predicted numbers to actual numbers. But we worked little on considering what the actual number of infected cases. There would have been many asymptomatic infections among the young in BC which were never accounted for. We also didn't consider the initial immunity due to vaccination and previous waves which would have rendered a lower susceptible population to the Omicron variant.

6 Acknowledgement

I want to first thank the Math 561 class, especially my classmates Alireza and Jonah, whose thought process intrigued me and motivated me to question things further. I want to thank Dan for interlacing concepts with stories and things happening in the research circles, presenting us with the bigger picture ideas and even motivating us in our shortcomings. I want to thank my supervisors Cedric and Caroline, Caroline for setting me up with the entire project and giving me objects to play with. I also want to thank my group and my housemates for their constant support.