Estimating COVID-19 Epidemic Growth Rates in Canada

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Executive Summary

Executive summary goes here.

Key modelling choices

Provinces included

It is important to highlight several choices made during this analysis that could influence the reliability of our results. First and foremost, epidemic initial growth rates were only fit for the ten Canadian provinces, excluding the territories of Nunavut, the Yukon, and the Northwest Territories. We excluded Nunavut because the province only reported one case over the entire observation period. Likewise, given the low total case reports for Yukon and the Northwest Territories (23 and 10, respectively), we were unable to get useful fits to the epidemic growth rates there too.

Corrections to the data

Data was given as cumulative case counts, for each day, for each province. We derived interval incidence by differencing that time series with a lag of one.

Next, on some days (eg. 2020-03-25) provinces (eg. Newfoundland and Labrador) reported new COVID-19 cases multiple times. This resulted in repeated observations with differing case reports for that day. To correct this, we added the two case counts together for those days, and removed the duplicated date entirely. Likewise we removed the report for New Brunswick on April 4th, 2020, as it seemed too far an outlier to be realistic.

While we speculated that negative cases, which were observed in multiple provinces, could have been reported to correct earlier totals, we had no guarantees to that end. This informed our decision to remove all days with negative case reports from the data.

In addition, irregular weekend reporting patterns were observed for the provinces of British Columbia and Alberta (22 and 11, respectively). We defined a case of faulty weekend reporting as weekend with zero cases reported on Saturday and Sunday, and nonzero case reports on the days before and after the weekend. For these two provinces, we removed all weekend dates from the time series, and added the reports for Saturday and Sunday to the following Monday if they were nonzero.

Results

We illustrate the parameter estimates of interest below.

Province	Exponential.Growth.Rate	Doubling.Time	Basic.Reproductive.Number
ON	0.1742705891424971	3.977419161607210	1.45557472858525
AB	0.1205228163744577	5.751169790177951	1.31467828287654
QC	0.3333289299195437	2.079469011967403	1.87498434121607
BC	0.0631514137400948	10.975956665240357	1.16476787315206
SK	0.5382167748193190	1.287858745749121	2.42070108134413
MB	0.1920390759493985	3.609406976851870	1.50224620124093
NL	0.9515609832868346	0.728431695639423	3.54076163130229
NB	0.3177029831128150	2.181745899168380	1.83361911036958
NS	0.1128192093641559	6.143875537388466	1.29451887401739
PEI	0.4754895420041773	1.457754838599281	2.25296486889452

Province	Exponential.Growth.Rate	Doubling.Time	Basic.Reproductive.Number
ON	0.0462763176824101	14.97844286827113	1.12077799176347
AB	0.0234813407269747	29.51906318380186	1.06144148721598
QC	0.0623780227909744	11.11204154198100	1.16275069801052
BC	0.0362419359148704	19.12555615649497	1.09464534726642
SK	0.0624895704595297	11.09220587472033	1.16304163266361
MB	0.0632043045925772	10.96677172588257	1.16490582801750
NL	0.0802618285431872	8.63607511990557	1.20942164165288
NB	0.6792832466033772	1.02040965094589	2.80007722968919
NS	0.1107427763337269	6.25907353515433	1.28908664293106
PEI	0.2186609313336410	3.16996354278907	1.57225739413708

How do the results differ among provinces, and why?

British Columbia had the smallest $\mathcal{R}_0$ of 1.164 in the first wave of the pandemic, and the second smallest $\mathcal{R}_0$ of 1.09 during the second wave (second only to Alberta), despite the province containing some of Canada's biggest and most densely populated urban centers, where one would expect transmission to be higher. In the first wave, BC also longest doubling time of almost eleven days. The largest difference between BC and other provinces was the strength and effectiveness of the public health intervention strategy put in place by government officials. These policies and the adherence to them by British Columbians was largely responsible for BC's success in managing the first wave of the pandemic. If we take another densely populated province, Ontario as our prototypical example, one can see that while the two provinces implemented a province-wide state of emergency only one day apart (Ontario: March 17th, 2020, BC: March 18th), British Columbia had far fewer deaths in long term care homes because they managed those facilities more effectively. Indeed, $\mathcal{R}_0$ in Ontario for the first wave was 1.455, much higher than British Columbia. However, the most important takeaway from this for public health officials is not that British Columbia did a good job in managing the pandemic at first. The message is that consistency of public health care interventions matters too. Indeed, COVID-19 cases in British Columbia picked up after that first wave, when BC relaxed their lockdown procedure. Looking at the graph, we can see that the begining of the second wave hit British Columbia just about at the end of May. It is no coincide that the government of British Columbia ended their lockdown on May 19th, 2020. Most other provinces, such as Ontario, follow a similar pattern - control strategies work, but case counts rise when we relax them. Implementing good control measures for a pandemic is not enough - we need to stick by them. Of course, there are economic and other trade-offs when implementing a province-wide lockdown. Thus, a weighted decision is still important in deciding when or if to extend a lockdown. Our point here is that keeping the lockdown in place should be weighted higher, as reducing lockdowns has severe risks.

Interestingly the maritime provinces for both waves consistently had the highest $\mathcal{R}_0$, shortest doubling times, and biggest exponential growth rates. We attribute this to the extreely low case counts for these provinces, which influenced model fit and made it difficult to estimate these properties exactly.

Between the non-maritime provinces, in terms of $\mathcal{R}_0 > 1$, we observe the following order of increasing $\mathcal{R}_0$ (or transmission) for the first epidemic. $BC < AB < ON < MB < QC < SK$. The order remains for the initial epidemic growth rate, and is inverted for ($< = >$) for doubling time. We can hypothesize that this relationship occured because BC did a very good job, as discussed above, of employing and adhering to public health interventions to curb the pandemic. Other provinces near the bottom of the inequality, Alberta, Ontario and Manitoba, also employed strong public health interventions to curb the pandemic.

For wave 2, the increasing order of $\mathcal{R}_0$ (or transmission) is as follows: $AB < BC < ON < QC < SK < MB$. The order remains for the initial epidemic growth rate (except that $MB < QC < SK$), and is inverted for doubling time, with the exception of SK and MB, which change places (doubling time of SK is still less than doubling time of Maintoba).

Why are Manitoba and Saskatchewan near the top of both inequalities, despite having low population density? This remains an open question in our analysis. One possible explanation is that these increases are due to climate-specific factors of the praries.

It is interesting to note that provinces had $\mathcal{R}_0 > 1$, for both waves indicating a locally asymptotically stable endemic equilibrium, as per the Theorem by van den Driessche and Watmough, as discussed on slide 114 of Lecture 3 for Math 747. Why do we observe this relationship?

Negative binomial models: Ontario, Quebec, Alberta, Saskatchewan, British Columbia, and Manitoba

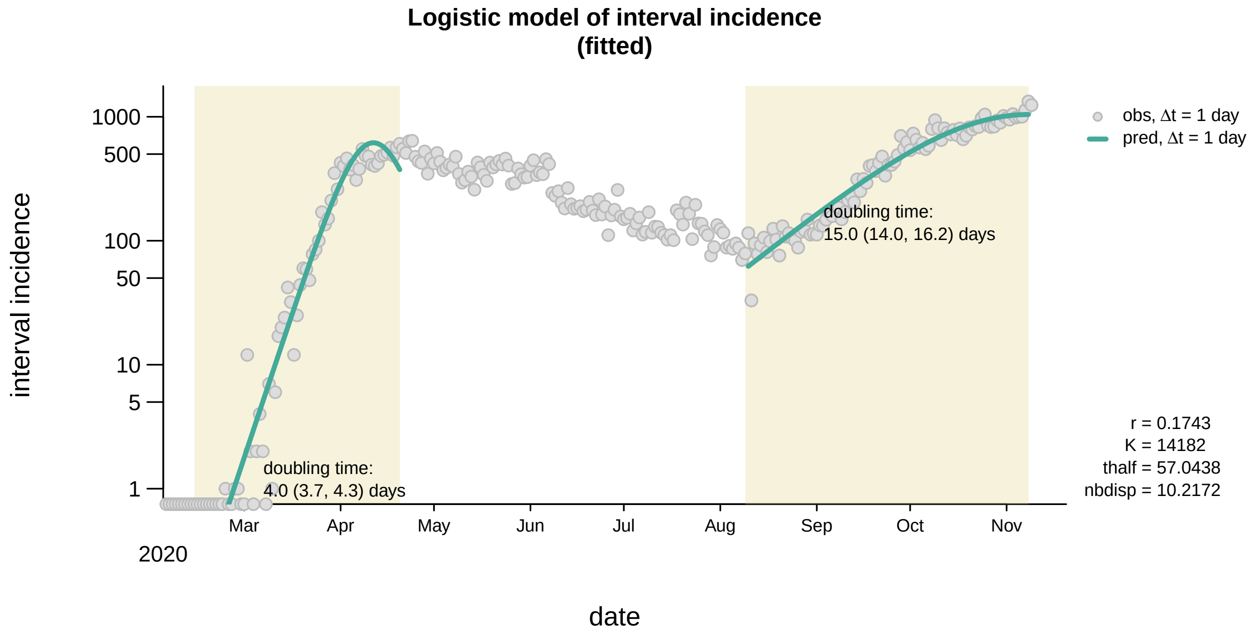
All six provinces were fit with a logistic model of expected cumulative incidence, and a negative binomial model for observed interval incidence. The negative binomial model fit well because the dispersion parameter k was small for both waves (10.217 for Ontario wave 1, for instance). This, switching to a Poission model was not necessary.

One would expect though for any reasonable model would have fit well to these data though. This is primary because large numbers of cases were reported on regular intervals, with no faulty weekend case reports for Ontario and Quebec.

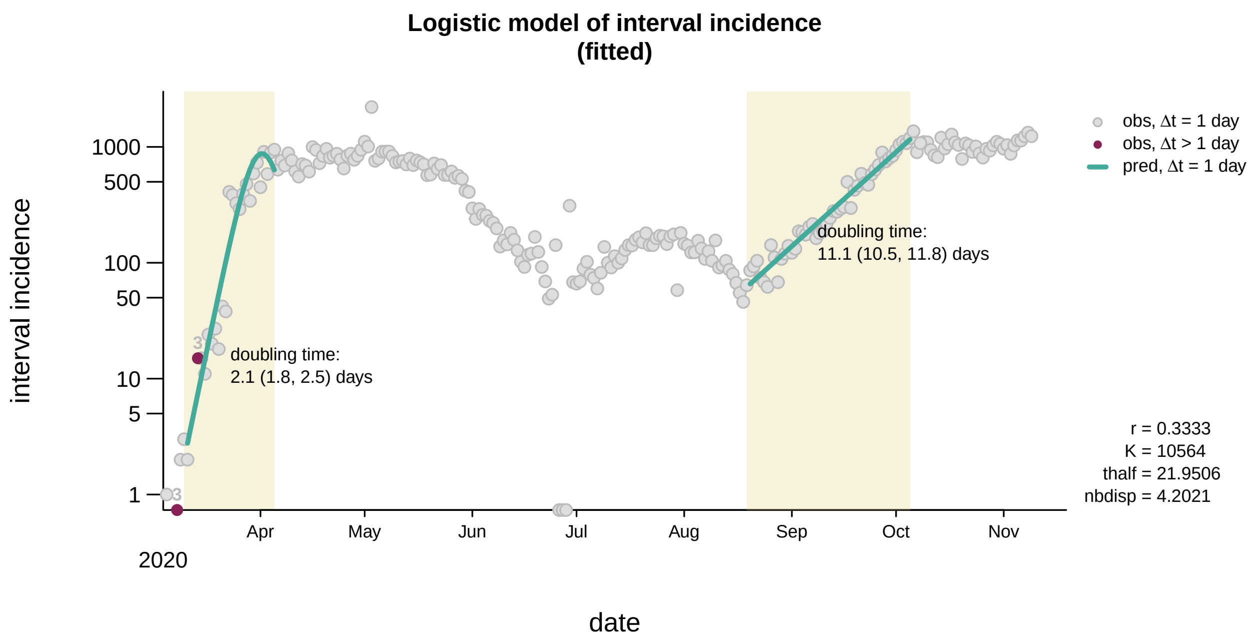
In Alberta and British Columbia, though weekend reporting was faulty, the corrected sums fit the trend of the reports around them, resulting in a good model fit. In addition, Saskatchewan actually saw multiple mini epidemic waves before a big wave starting late October, not just two waves. We chose the biggest two to be the ones to study, but this may not have been the best choice. At least three mini waves occur before what we denote as the first wave, and it may have been better to fit to them.

Selecting the best fitting window for British Columbia was difficult because there were three distinct waves of epidemic there. One epidemic ran dfrom March to April, one from June to September, and one from October to November. I chose the first and final wave to fit models to. British Columbia interval incidence grows subexponentially for a significant chunk of the time series. Thus, the initial epidemic growth rate isn't strongly representative of the initial phase of the second wave, because cases counts grew very slowly for a long time, and then shot up. However, after selecting the appropraiate fitting window, the negative binomial model fit well because the dispersion parameter k was small for both waves (W1 = 3.9931, W2 = 1.822).

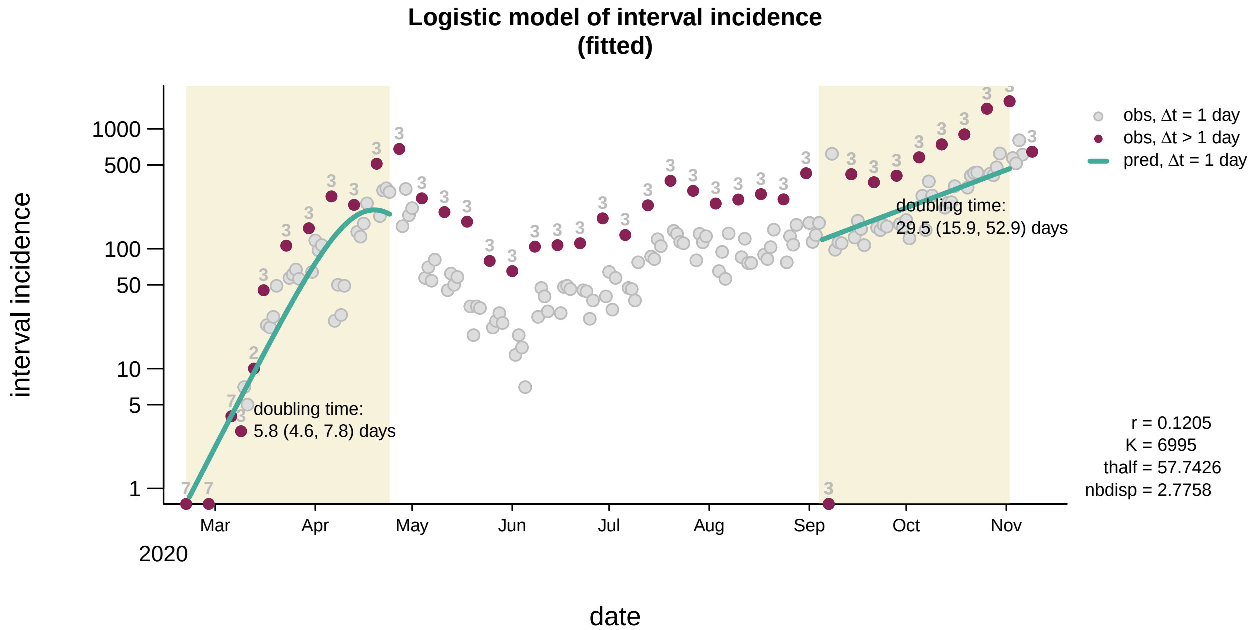
Ontario



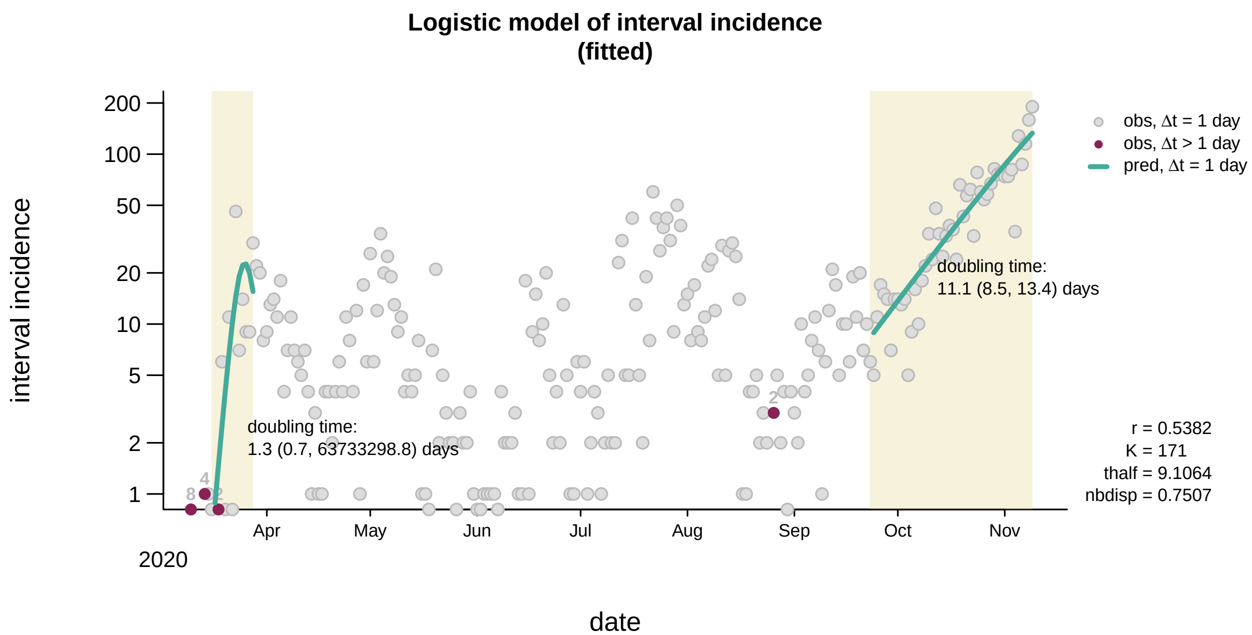
Quebec



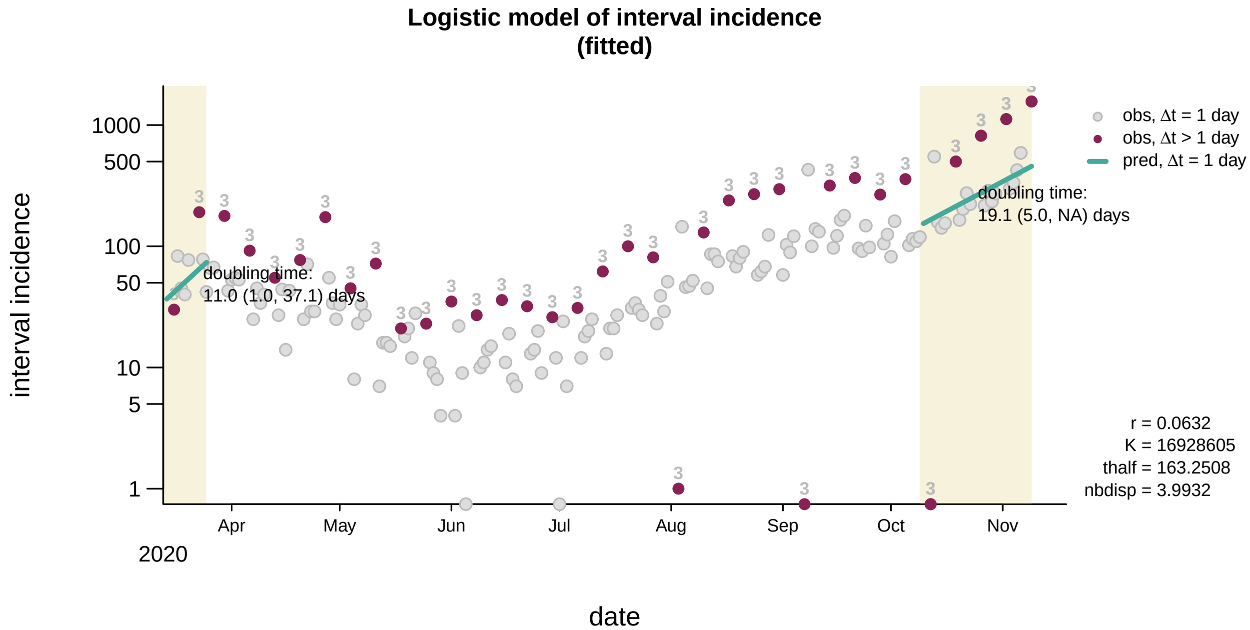
Alberta



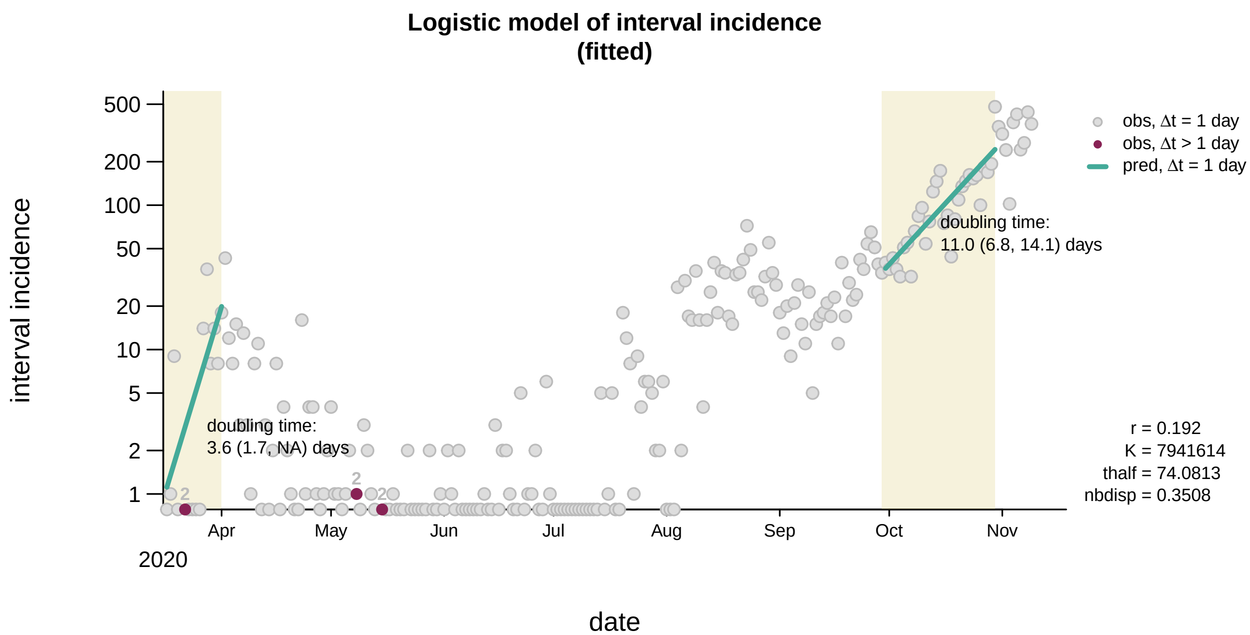
Saskatechewan



British Columbia



Manitoba



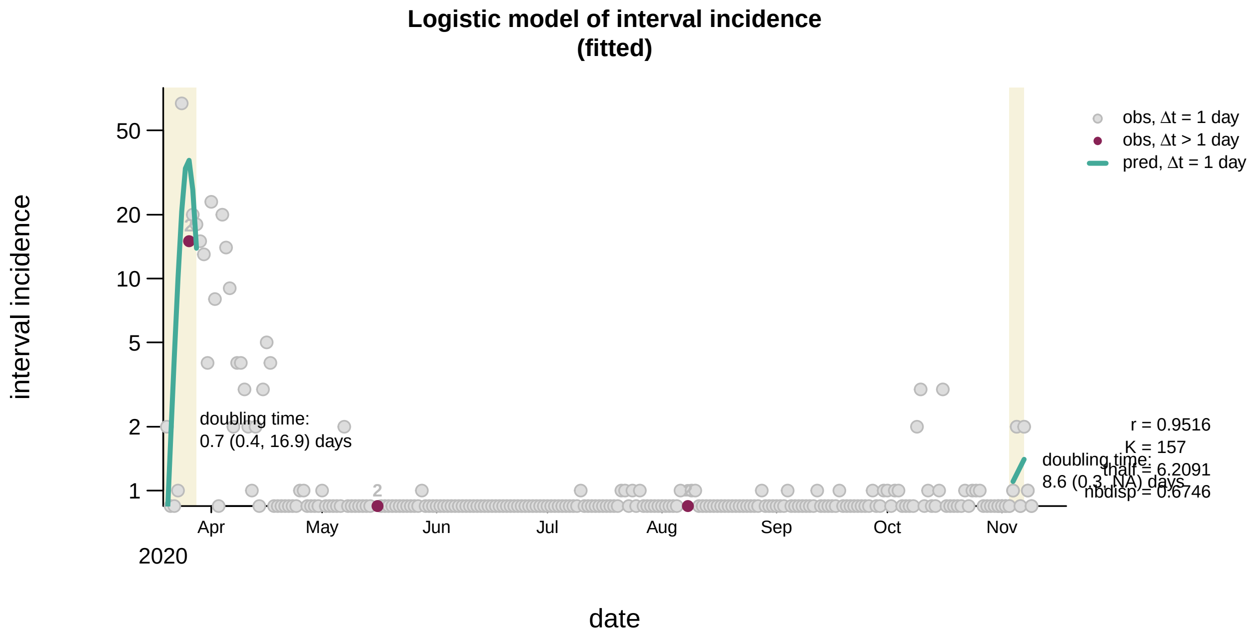
Poisson Models: Newfoundland and Labrador, Nova Scotia, New Brunsiwck, and Prince Edward Island

There was only one real epidemic wave in Newfoundland and Labrador. However, the dispersion parameter k for the fitted model was 0.674, much below the threshold value as defined in the vignette, which explains why the negative binomial model fit well. We fit the second wave to a mostly flat second epidemic wave consiting of less than 5 cases at peak, which explains the poor fit of the model, as demonstrated in the corresponding plot below. It is unclear if growth rate has any practical interpretation, given the poor model fit that produced it.

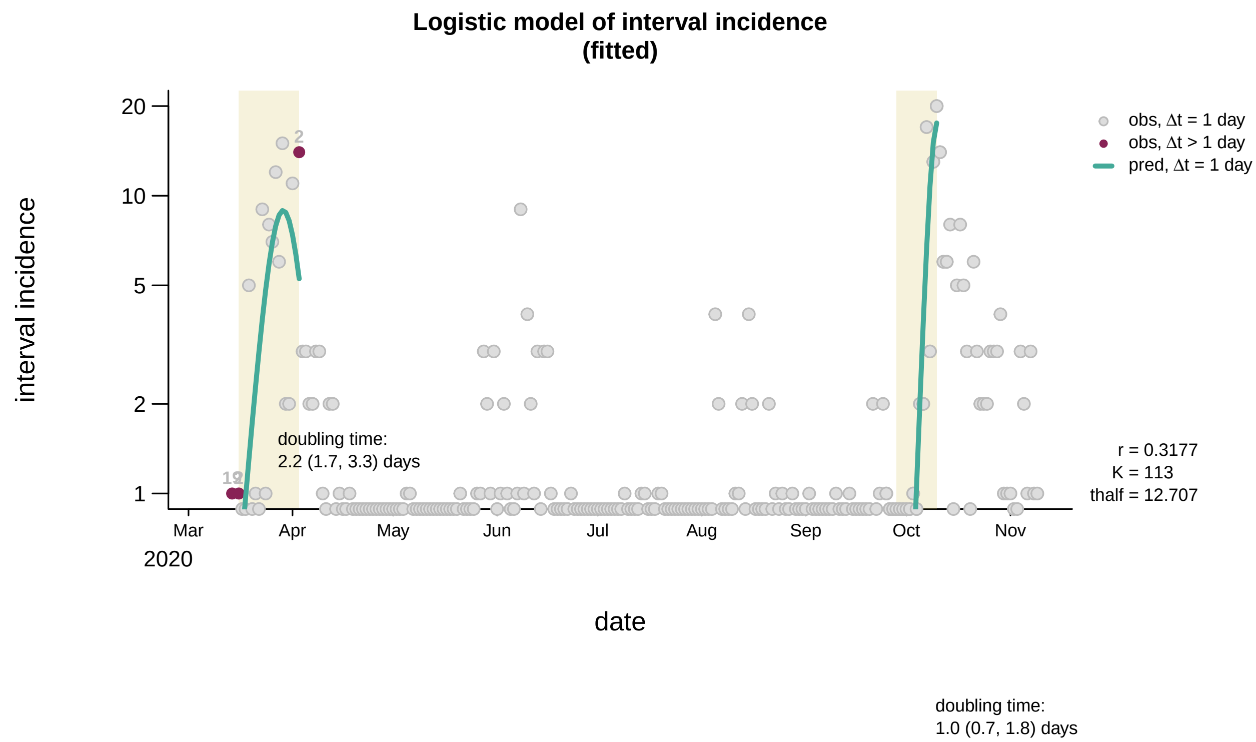
For the rest of the provinces and waves, the dispersion parameter for a fitted negative binomial model exceeded the threshold value as defined in the vignette. Therefore, Poision models fit better to the data.

New Brunswick has a very small wave in between the two epidemic waves we fit. We didn't fit to it because to the other two were much larger in magnitude. Also, the second wave in Nova Scotia is tiny, which could impact our model fit. Prince Edward actually had four epidemic waves, the final three being very similar in size. Our estimates of epidemic growth rates are valid and useful insofar as we consider the waves we picked to the ones of interest.

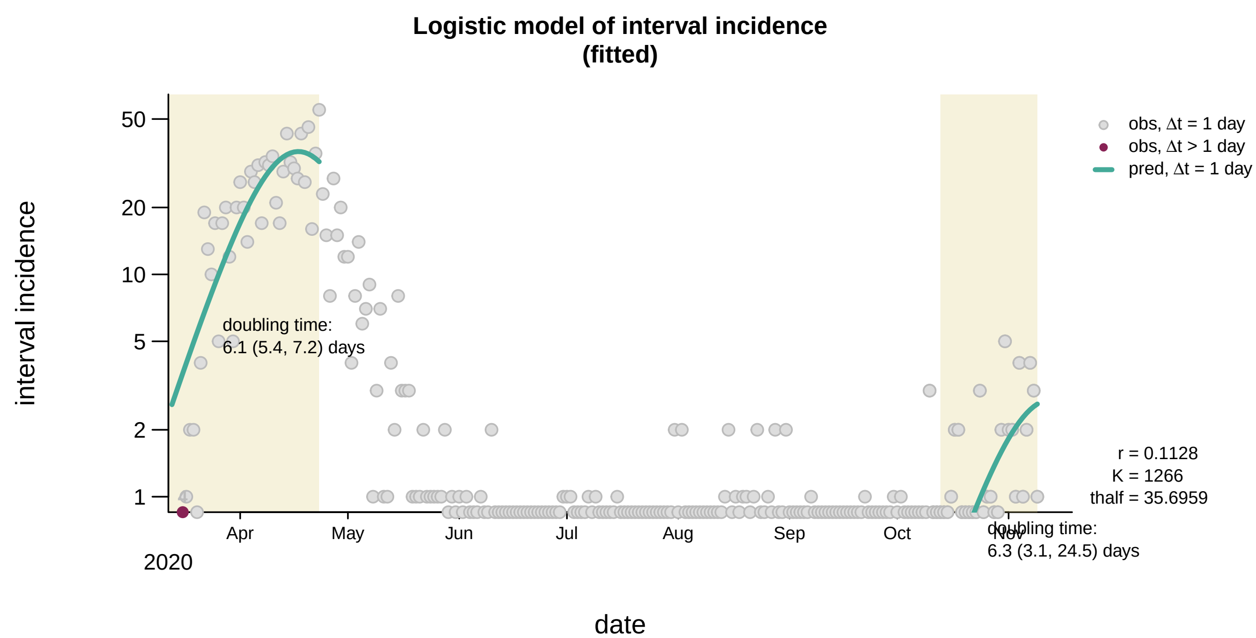
Newfoundland and Labrador



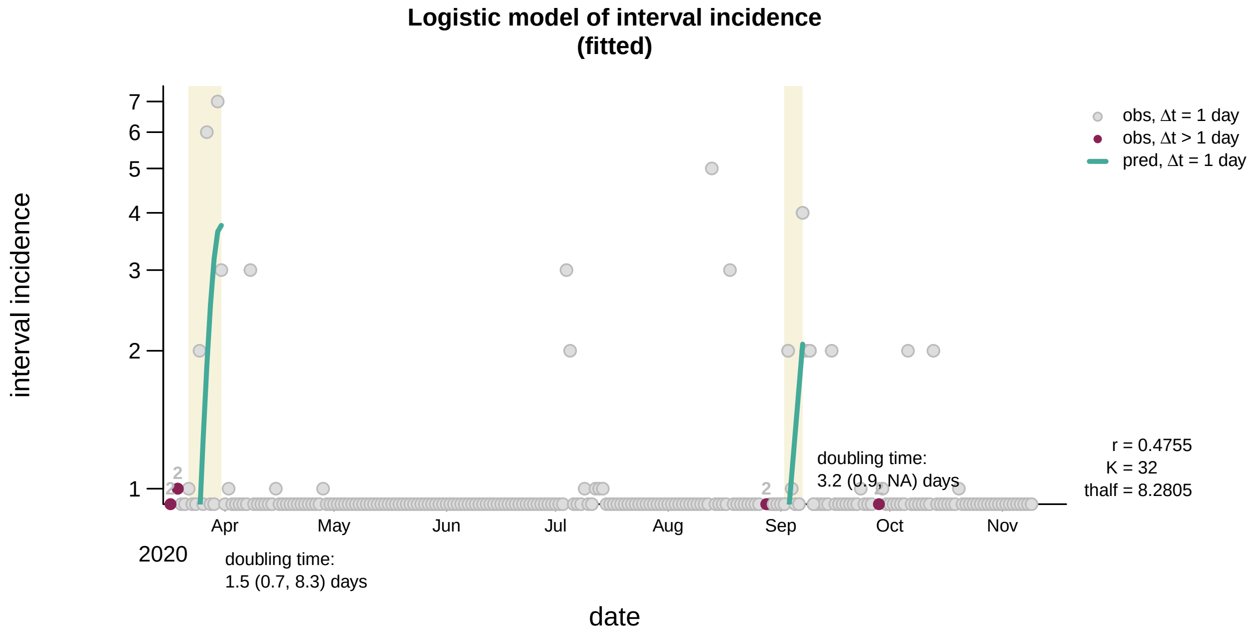
New Brunswick



Nova Scotia



Prince Edward Island


Logistic model of interval incidence
(fitted)
interval incidence
7
6
5
4
3
2
1
obs, Δt = 1 day
obs, Δt > 1 day
pred, Δt = 1 day
doubling time:
3.2 (0.9, NA) days
r = 0.4755
K = 32
thalf = 8.2805
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
2020
doubling time:
1.5 (0.7, 8.3) days
date