This report is a pre-print. It has been subject to internal peer review.

Covid-19 Modelling Aotearoa

Modelling scenarios for changing COVID-19 isolating behaviour and transmission

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This note explains how we use COVID-19 Modelling Aotearoa's (CMAs) Network Contagion Model (NCM) and Ordinary Differential Equation (ODE) model to estimate the impacts of different scenarios of policy induced behaviour change, on future infections, case numbers, and hospitalisations. The behaviour changes we consider include symptomatic testing, case isolation behaviour, household contact testing and quarantine, and general population transmission reduction behaviours.

A note on dates referenced in this report

This report was compiled in late November 2022, following a request for modelling advice from the NZ Ministry of Health COVID-19 modelling steering group. The report considers how transmission of COVID-19 in Aotearoa had changed since earlier in the year, and how it might change in the future. Any references to the 'present' or 'current' situation refers to late November 2022.
Additional key dates and events referenced in this report include:

- 13th September 2022: The NZ Government removed the Covid Protection Framework (CPF). This included the removal of all vaccine mandates, most masking requirements, and the requirement for household contacts of confirmed cases to isolate.
- 22nd November 2022: In this report we model a new Variant of Concern (VOC) becoming the majority of new cases on the 22nd November
- 12 December 2022, 20 January 2023, or 20 April 2023: Dates for different scenarios modelled in this report for when a future policy change of case isolation removal could come into effect.

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Executive Summary

- In order to estimate transmission changes in response to *future* policy changes, it is important to first know how much impact the *current* measures are having; and how much impact *past* changes have made to COVID-19 transmission rates. For example, if most people are still compliant with a policy then changing the policy will have more of an impact than if it is currently followed by only a small fraction of individuals.
- We can use CMAs Network Contagion Model (NCM) model to estimate the changes in the transmission rate that results from changing policies and behaviours. We can also use simulations from the NCM to infer possible retrospective changes in behaviour by comparing model scenarios with observed changes in past transmission rates.
- We can use CMAs Ordinary Differential Equation (ODE) model, in combination with data on cases, hospitalisations, and deaths, to estimate the impact of past changes against a baseline of no change in model parameters. These results indicate that the transmission increase resulting from the September policy change was around 19%; much higher than the previous estimate of 8.5% from CMA in August 2022.
- We have investigated possible changes in community, contact, and case behaviour that could have produced the observed increase in transmission, and conclude that the change in transmission seen in September 2022 is consistent with what would be observed due to a combination of:
    - miscommunication or low compliance of the daily testing requirement for household contacts once contact quarantine was dropped;
    - greater relaxation of COVID-19 transmission reduction measures in work/school/community than anticipated in the scenarios modelled; and
    - some reduction in testing and isolation for cases despite there being no change in policy for them.
- Without data on infection prevalence, or longitudinal behaviour change surveys, it is difficult to make robust inferences about the level of people's transmission reduction behaviour before September 2022, and how these may have changed prior to November 2022. We have used case, hospitalisation, and wastewater data to bound the size of the parameter space related to these changes, however considerable uncertainty remains in our estimates of the impact of future case isolation reductions on overall transmission levels. Our 'best estimates' for the current (November 2022) level of transmission reduction behaviour, lead to an estimated impact of the complete removal of case isolation in the range of a 5% to 15% increase in transmission. These numbers do not include any estimates of

the impact of future community behaviour changes on transmission rate increases.

- Using a baseline of a +19% transmission increase in September 2022, and a new Variant of Concern (VOC) taking over on 22nd November 2022, we have used simulations from the ODE model to illustrate the potential impact of five scenarios for future policy changes (varying between a 0% and 10% increase in Rt) occurring in either December 2022, January 2023 or April 2023. We stress these results are to display the potential population-level impacts of behaviour changes, assuming no other changes in the population occur (such as other new variants). These results also do not consider distributional impacts - i.e. which groups will be most likely to bear more of the burden of this increase.

- These models are a simplified version of the complex dynamics behind transmission increase, which can also be influenced by: new variants, changes in case ascertainment rate (CAR), and change in contacts between age-groups. For example, the ODE model results presented here do not account for any possible change in the case ascertainment rate (CAR) that might be associated with other policy induced behaviour changes. As such, any plots of case numbers will be an overestimate in the scenarios where case testing and reporting has decreased.

- Other than age, the ODE model results do not account for heterogeneity in the population and hence do not give information about the distributional impacts such as *who* will be more, or less, affected by the burden of disease associated with any increase in infections. More details on this can be found in the list of Caveats.

Method

We have used the Network Contagion Model (NCM) to model detailed changes in individuals' behaviour due to changes in public health policy, changes in perceived risk, as well as changes in individual testing and compliance. In August and September 2022, we provided modelling results that considered what the spread of COVID-19 in Aotearoa might look like if changes were made to policy settings that led to changes in behaviour relating to:

- Symptomatic testing and case isolation;
- Quarantine and testing of household contacts;
- Community transmission reduction behaviours, including reducing in-person interactions, mask wearing, improved ventilation, etc.

See Supplementary Material for more details on this past modelling.

Using these NCM simulation results, we can estimate the relative change in effective reproduction number (Rt) that might result from combinations of behaviour changes in response to policy changes. These estimates of the change in the overall transmission level[1] can then be used in the Ordinary Differential Equation (ODE) model to project future infections and cases over longer time periods. Conversely, we can use observed changes in overall transmission to infer what the possible changes in behaviour might have been. **NB**: we do not change the case ascertainment rate or other mixing parameters in the ODE model in response to policy changes, only the overall transmission rate.

Key information gaps and ways to address them

Throughout this report we note that it is very difficult to determine what behaviour changes drove the observed change in transmission rate following September 2022 policy changes, and therefore how much transmission may change with the removal of case isolation. We can propose likely bundles of behaviour change that could lead to the effect size that we have observed up to now. But without knowing 'where we are' it is even harder to model 'where we will go' when a new policy change is enacted.

Some key unknowns are:

- The infection rate currently, and how the case ascertainment rate (CAR) has changed over time.
- Exactly how the transmission rate has changed (although we estimate this with the ODE).
- How different transmission reduction behaviours have changed since September 2022.

Some ways that these information gaps could be addressed in future are:

- A repeated seroprevalence survey
    - Would help to calibrate the ODE and NCM model for the current day, which would mean we are better able to model future changes.
    - Would help to validate the wastewater modelling of CAR.
    - Could also provide valuable information on the prevalence of diseases other than COVID-19.
- A repeated survey on transmission reduction behaviours
    - Would help to narrow down the changes in behaviour that are driving changes in transmission rate. Information on the level of compliance with a policy would inform modelling of the effect of changing this policy.

[1] The overall transmission level is adjusted by changing the *control function* in the ODE model. The *control function* is used as a multiplier to the reproduction number Rt, which in turns affects the number of new daily infections in the model.

Assessing the impact of the 13th September 2022 Covid Protection Framework policy change

We can use data on cases and hospitalisations that have been reported since the Covid-19 Protection Framework (CPF) policy change of 13th September 2022 to estimate the impact of the policy change. From these, we can infer plausible combinations of behaviour changes that might have occurred to produce the subsequently observed increase in transmission.

Estimating transmission increase

Allowing for a gradual transmission increase in mid-September and fitting the ODE model to case and hospitalisation data, we find that the 'best fit' trajectory corresponds to a 19% transmission increase, and that the 95% confidence bands include transmission increases between 10.4% and 29.6%, as shown in **Figure 1**.

Within the period of time considered here (mid-September to late November) we don't believe that the introduction of new variants has significantly influenced increased transmission, as wastewater testing has shown BA.4/BA.5 to make up roughly 90% of infections over September and October. However the share of new variants has been increasing over November and is becoming a more significant factor. This can be seen in **Figure 2** below.

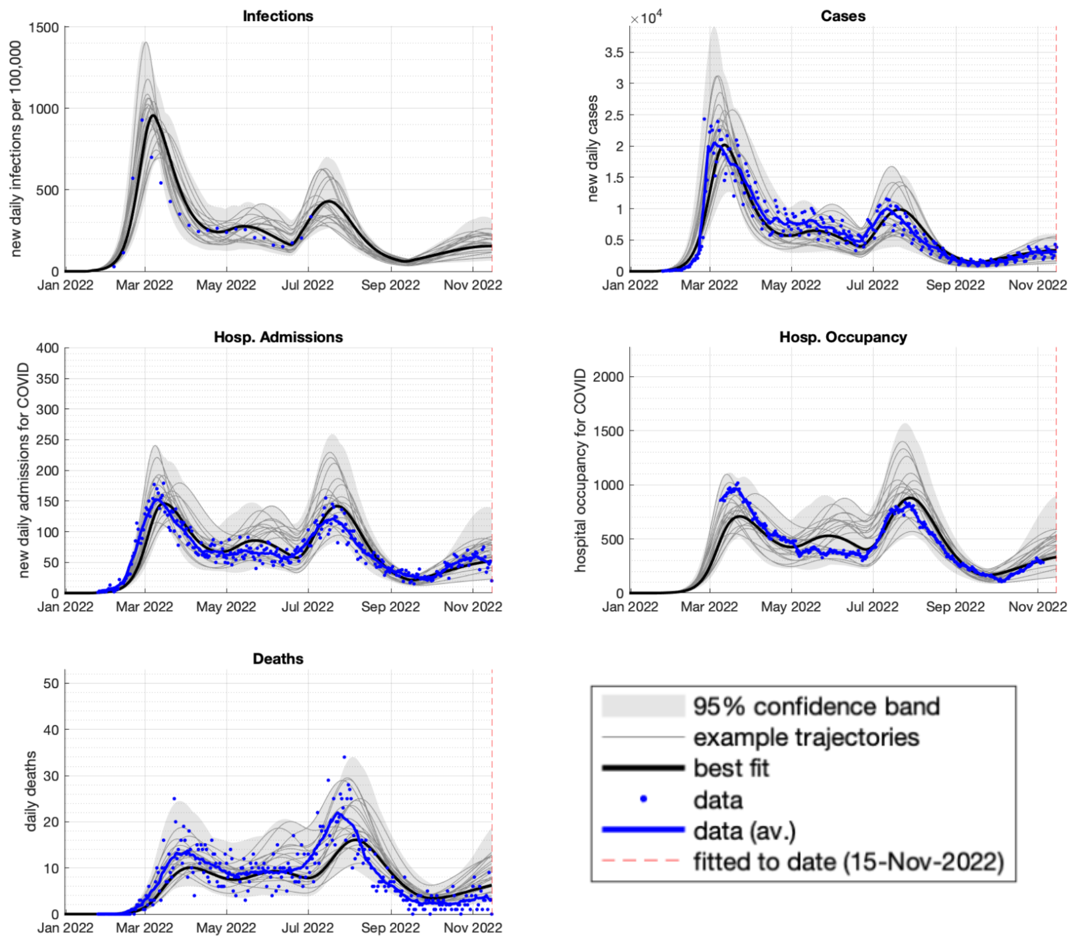

Figure 1: *'Best fit' ODE model results (black line) with a gradual transmission increase in mid-September, and fitting to data (blue points and smoothed line) up until 15th November 2022. Also shown are the 95% confidence bands (grey shaded bands) and example alternative trajectories within these bands (light grey lines).*

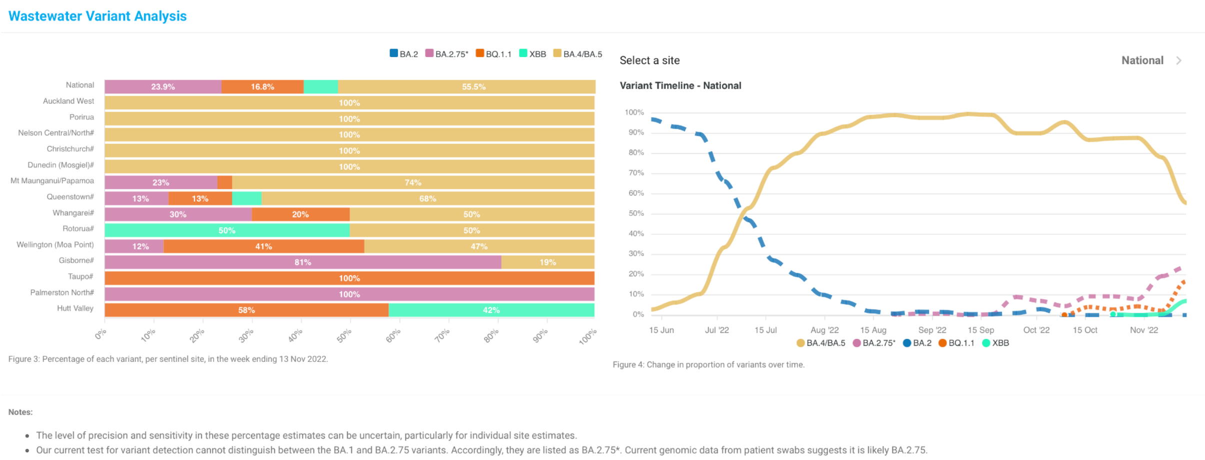

Figure 2: *Screenshot of ESR Wastewater Surveillance Dashboard showing* ***on the left:*** *variant proportions in the week ending 13 November 2022, and* ***on the right:*** *change in proportion of variants over time. https://esr-cri.shinyapps.io/wastewater, accessed 24/11/2022.*

Inferring plausible behaviour changes that could lead to the transmission increase observed after 13th September

In August 2022, we estimated the increase in Rt due to ending the Covid Protection Framework (CPF) and changing household contact quarantine requirements. We also produced a contour plot that looked at the impact on Rt of different levels of compliance with, and effectiveness of case isolation policies on top of the changes from CPF ending and household contact changes. (See Supplementary Material: Past Results for more information.)

From this modelling we can infer possible combinations of behaviour changes for cases, contacts, and the wider community that plausibly lead to the observed ~19% increase.

Household contacts

Although official guidance for household contacts of confirmed cases changed to "daily testing with no requirement to quarantine" on the 13th September, communication of this messaging has not been strong. Based on this, we don't think it's likely that all household contacts of confirmed cases are testing daily. As a result we think that overall household contact testing rates and impact on transmission reductions is probably closest to the modelled scenario of "guidance for household contacts to test only if symptomatic" (see Supplementary Material: Past Results). This was estimated to increase transmission by 5-6%; double the increase of the 2-3% estimated for the "daily testing" policy.

Case isolation and work/school/community transmission changes

If the behaviour change associated with the removal of the CPF was as parameterised and modelled in August[2], we estimate that this would lead to an ~6% increase in overall transmission.

When combined with the 5-6% increase due to contact quarantine changes, as detailed above, the total transmission increase from these two effects would be expected to be approximately 12%. In that case, the remaining 7-8% of the observed ~19% transmission increase would need to come from changes in case testing and isolation behaviours. This suggests that there would have needed to be a substantial reduction in testing and/or isolation compliance and effectiveness to produce this increase, despite no change in the policy or rules for confirmed cases. In **Table 1** we detail the possible combinations of case isolation effectiveness and compliance reductions that could lead to the required increase (19% contour in **Figure 7**).

[2] 20% close contact and 50% casual contact transmission reductions in school and work. 10% close contact and 50% casual contact transmission reductions in community (see Supplementary Material: Past Results).

Wastewater monitoring can inform what the relative decrease in case ascertainment rate (CAR) has been over this period. From the joint ESR/CMA modelling, the CAR was ~40% in early September and dropped to ~33% in early November. Although many people may be testing and isolating without reporting, we consider this ~20% decrease in case ascertainment rate to be a reasonable upper estimate for the reduction in the proportion of confirmed cases taking actions such as isolating. Once the reduction in confirmation of cases, and hence the reduction in case isolation, associated with this drop in case ascertainment is added to the effects estimated above, it would be necessary to have a decrease in isolation effectiveness of ~40% to produce the observed total transmission increase of ~19%.

If instead, the increase in transmission due to school/work/community behaviour changes associated with the removal of the CPF (e.g. reduced requirements and expectations for mask wearing) was significantly higher than anticipated, then we would need much smaller changes in case isolation behaviour (15% contour in **Figure 7**), or even none at all. Possible combinations of the various factors are detailed in **Table 1**.

Table 1*: Transmission increases due to case isolation and work/school/community behaviour changes that align with the observed overall 19% transmission increase when combined with 'symptomatic testing only' policy for contacts. Bundles of behaviour change in bold (a and b) are two of the more plausible scenarios that align with wastewater CAR decrease estimates.*

Transmission increases in school/work/community due to CPF removal	**Behaviour change for cases in September**		
	Reduction in proportion taking actions	Reduction in effectiveness in actions	
Increase as modelled in August (~6% increase)	45%	0%	
	0%	60%	
	20%	**40%**	***a***
Higher transmission than anticipated (~10% increase)	20%	0%	
	0%	25%	
	15%	**10%**	***b***
Even higher transmission than anticipated (~14% increase)	0%	0%	

How would these inferences change if we overestimated CAR in late August?

We have assumed that prior to the policy change of 13th September 2022, the proportion of symptomatic infections testing positive and isolating, in the NCM, was a constant 70%, and that all confirmed cases isolated effectively for the 7 day isolation period, resulting in only a 10% "leak rate" for transmission beyond their households.

These values define the origin [0%, 0%] on the "effect of case isolation compliance and efficacy" contour plot in **Figure 7** (Supplementary Material: Past results).

Wastewater analysis, however, suggests a decrease in CAR of close to 40% from the peak in March to early September. This lower case ascertainment rate in early September can be accounted for in this analysis by translating the contour plot to an effective lower assumed case ascertainment rate (driven by lower rates of symptomatic testing in the NCM) for early September. Any assumed changes in the efficacy of isolation for confirmed cases can be similarly accounted for.

In **Table 2** we give an example of the behaviour change needed if, by early September the proportion of symptomatic infections taking action (testing and isolating) had reduced by 30% and the effectiveness of the isolation had reduced 25% from the default values assumed earlier in the year at the peak CAR (i.e. 70% of symptomatic infections taking action, and 90% effective isolation). We note that in order to produce the same overall reduction in transmission when fewer cases are isolating, the further reduction in September must be larger.

Table 2*: Transmission increases due to case isolation and work/school/community behaviour changes that align with an overall 19% transmission increase when combined with 'symptomatic testing only' policy for contacts IF the proportion of symptomatic infections taking actions had already decreased by 30% and the effectiveness of the isolation had reduced 25% from those associated with peak CAR levels (model defaults). Bundles match the bundles in Table 1 (a and b) but with different starting points prior to the September 13th policy changes. Bundle c is the most plausible based on wastewater estimates.*

Transmission increases in school/work/ community due to CPF removal	**Behaviour change for cases in September**		
	Reduction in proportion taking actions	Reduction in effectiveness in actions	
Increase as modelled in August (~6% increase)	55% reduction (in addition to an August level of 30% below the model defaults)	50% reduction (in addition to an August level of 25% below the model defaults)	
Higher transmission than anticipated (~10% increase)	20% reduction (in addition to an August level of 30% below the model defaults)	20% reduction (in addition to an August level of 25% below the model defaults)	***c***

Potential impact of future case isolation policy changes

CMA has also been asked to model the trajectory of the outbreak for scenarios where a case isolation policy change results in various increases in transmission at three future dates. These scenarios include the residual effects of the observed median increase in transmission of 19% due to the September 2022 policy changes, as well as the introduction of a new variant of concern (VOC) on 22nd November.

Estimating the impact of changes in case isolation

It is important to note that what could happen in response to changes in the future is dependent upon what changes have already occurred. For example, if the September change was entirely due to the contact changes and community transmission changes, then removing the case isolation requirement would have a bigger impact than if the change in September was driven mostly by people not testing or isolating any more. All scenarios for the impact of changes in the future need to be considered in conjunction with estimates of what changes have already occurred.

Whether the increase in transmission in response to removing case isolation requirements is small or large will depend on how much effect testing and isolation are having at the moment. Specifically, how many people are staying home when symptomatic, testing if they get symptoms, and how well they are isolating if they test positive.

When inferring plausible behaviour changes that could lead to the transmission increase after the 13th September policy change, we found that many different combinations would all produce the observed increase. Specifically, in **Tables 1** and **2**, we highlighted three bundles of behaviour change (***a***, ***b***, and ***c***) that gave the same transmission increase effect size, but from very different combinations of case, contact, and community behaviour changes. These bundles are summarised in **Table 3**. Using the contour plot from past results (**Figure 7**), and the results from the estimates of the changes in September, we can estimate the impact on overall transmission due to a complete removal of case isolation behaviours (a 100% reduction in case testing and isolation effectiveness). The results for the three selected bundles are given in **Table 3**. Different combinations of past behaviour changes will produce different estimates for the impact of case isolation reduction or removal.

Table 3: *Three selected bundles of case isolation and work/school/community interaction changes that match the observed +19% transmission increase, along with the impact of a future change that lead to a 100% reduction in case testing and isolation effectiveness .*

Scenario Bundle	***Description***	***Transmission increase after case isolation removal***

a	People were still testing and isolating well at the end of August but there was a large reduction in case isolation behaviours in response to the policy changes in September.	***+8%***
b	People were still testing and isolating well at the end of August and most of the change in September was due to school/work/community behaviour changes, and not much relaxation of case isolation.	***+12.5%***
c	People had already reduced their testing and isolation by the end of August, and then there was some further relaxation of cases and school/work/community behaviour (similar to that in bundle b) in September.	***+5%***

Consequences for estimates of the impact of future changes in community interactions

As we saw in our analysis of the changes in September, it is very difficult to estimate the impact of the removal of transmission reduction (protective) behaviours at work, school and in the community that are induced by COVID-19 related policy changes. If a change in policy can be interpreted as a message that the risk from COVID-19 has reduced, we should expect to see increases in community transmission, including increases in contacts and attending high transmission risk events. Consequently, if a significant fraction of the observed 19% increase in transmission from 13th September 2022 was due to induced behaviour changes other than those effects directly modelled and directly linked to policy changes then it is suggestive that future increases in transmission could also be higher than those presented here. That is, we would again expect to see additional increases in transmission due to behavioural changes induced by the removal of case isolation. These should be considered a significant unknown.

ODE model results

In **Figures 3-5** we present ODE model trajectories fitted to data until November 15th for forward scenarios with the addition of a new variant of concern (VOC) becoming the main variant on 22 November 2022 and a policy change, occuring on either 12 December 2022, 20 January 2023, or 20 April 2023. The mechanism of the increase due to the VOC (i.e. immunity evasion from prior infection and vaccination) is independent of the mechanism associated with the increase due to policy or behavioural changes (an increase in the control function that captures non-pharmaceutical interventions).

To cover the range of potential combinations for changes in the past and the future, we have produced ODE model trajectories for scenarios with a range of increases in transmission. In all plots the legend for the series notes the percentage point increase in transmission due to the future behavioural or policy change [0%, 2.5%, 5%, 7.5%, 10%]. This increase is additional to the 19% increase in September, and is measured relative to the transmission rate *before* the September change, in order to aid comparison of effect sizes. Potential combinations of case and community behaviour that would line up with each of these four transmission increases for bundles *a, b*, and *c* (from **Tables 1** and **2**) are described in **Supplementary Material: Future Scenario Detailed Descriptions**.

New VOC, 12th December 2022 policy change

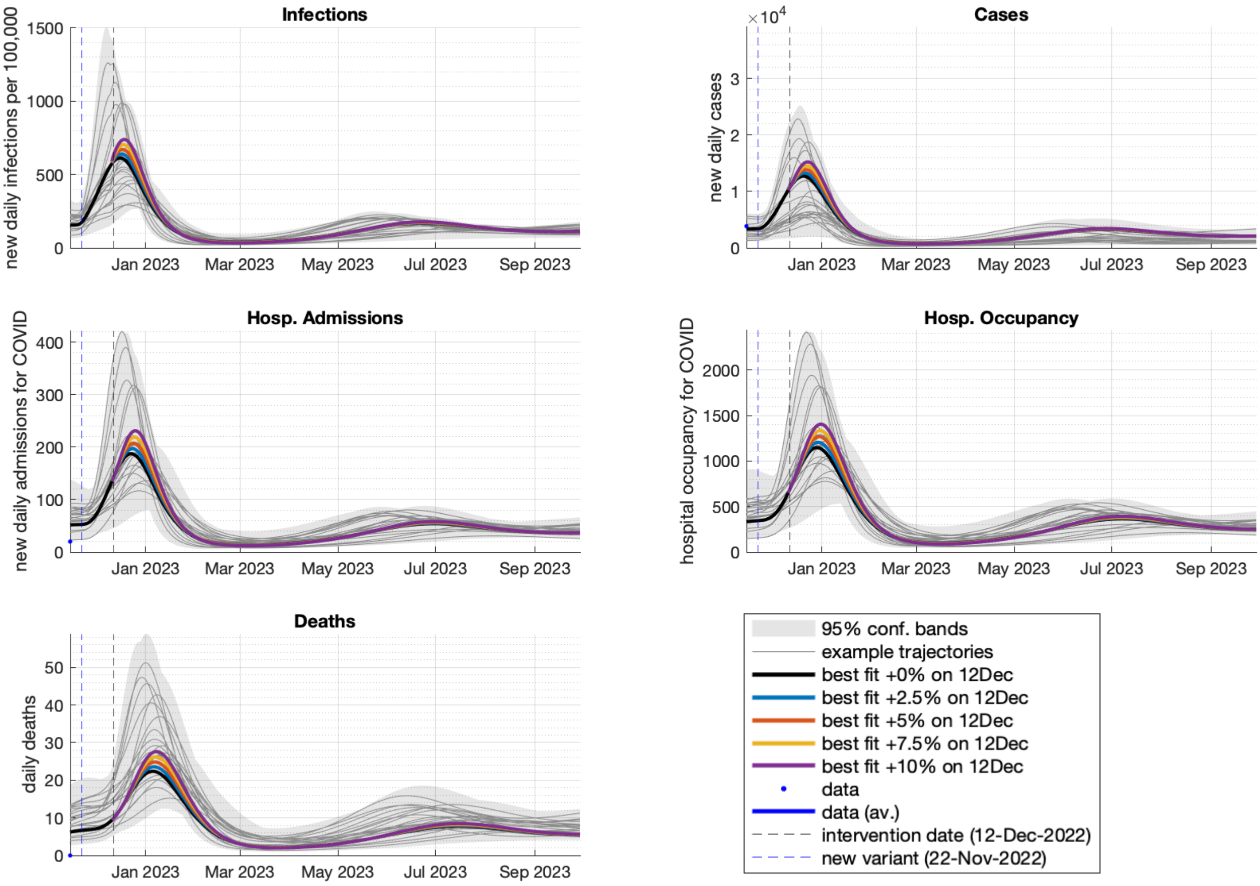

Figure 3: *Solid thick lines show the ODE model 'best fit' trajectories, fitting to data until 15th November 2022, for five scenarios including one with no change (+0%) and four with increases in transmission (2.5%, 5%, 7.5%, 10%) resulting from a policy change on 12 December 2022. A new VOC becomes dominant on 22nd November 2022. The 95% confidence bands (grey shaded bands) and example alternative trajectories (light grey lines) are shown for the scenario with the highest transmission change (+10%).*

New VOC, 20th January 2023 policy change

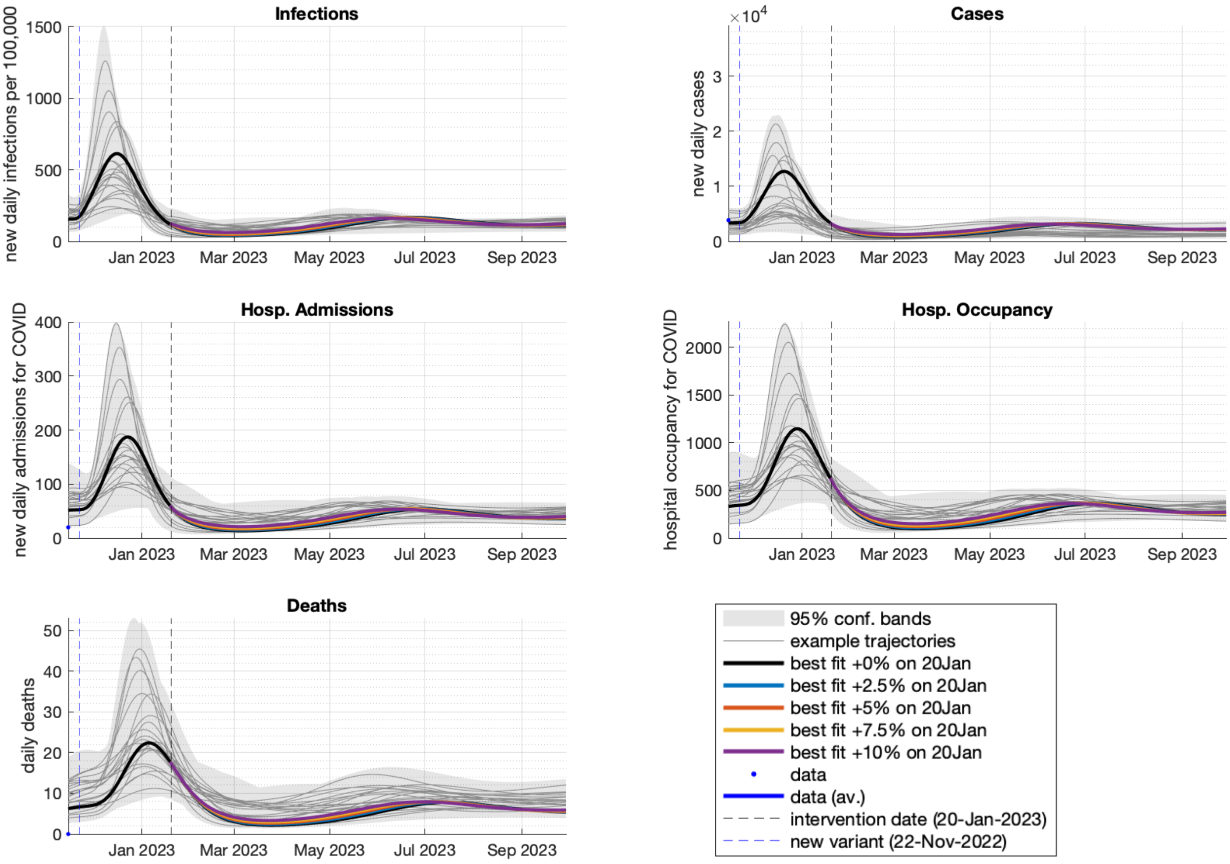

Figure 4: *Solid thick lines show the ODE model 'best fit' trajectories, fitting to data until 15th November 2022, for five scenarios including one with no change (+0%) and four with increases in transmission (2.5%, 5%, 7.5%, 10%) resulting from a policy change on 20 January 2023. A new VOC becomes dominant on 22nd November 2022. The 95% confidence bands (grey shaded bands) and example alternative trajectories (light grey lines) are shown for the scenario with the highest transmission change (+10%).*

New VOC, 20th April 2023 policy change

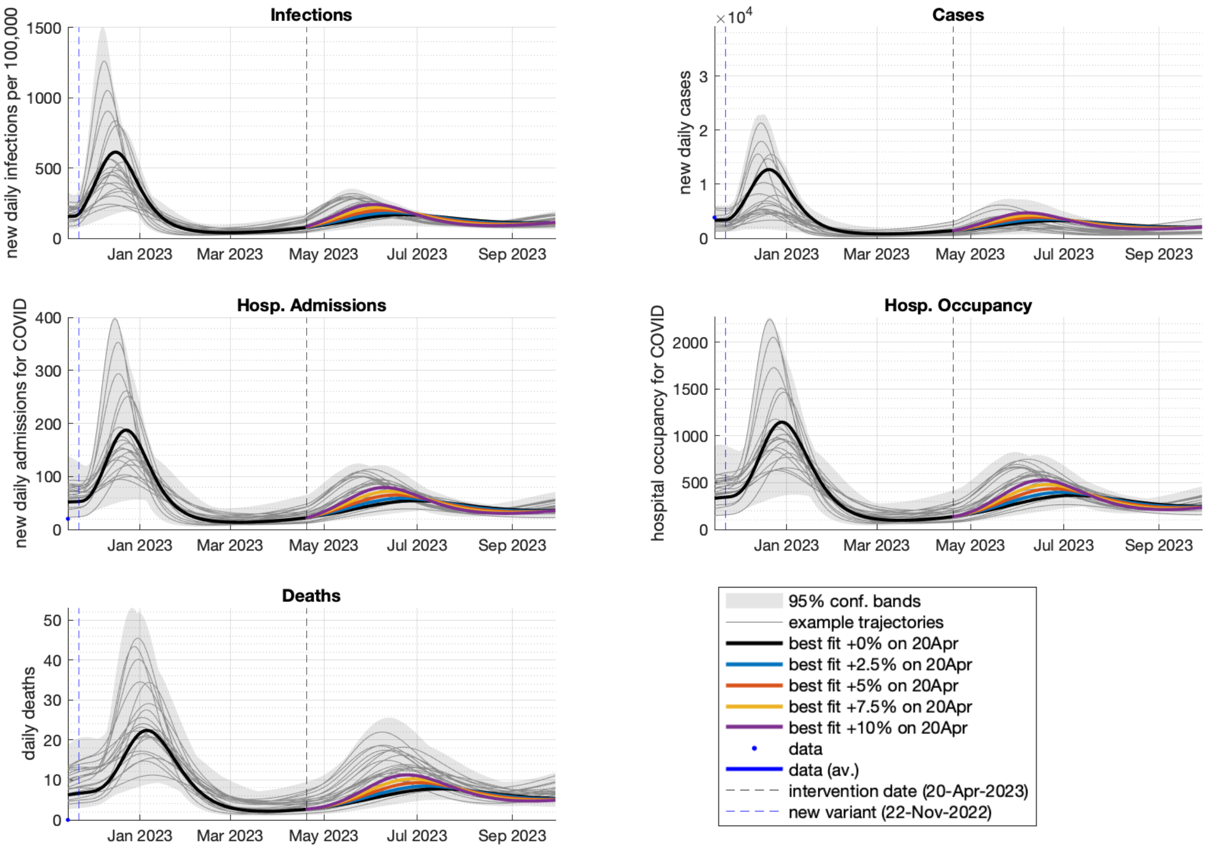

Figure 5: *Solid thick lines show the ODE model 'best fit' trajectories, fitting to data until 15th November 2022, for five scenarios including one with no change (+0%) and four with increases in transmission (2.5%, 5%, 7.5%, 10%) resulting from a policy change on 20 April 2023. A new VOC becomes dominant on 22nd November 2022. The 95% confidence bands (grey shaded bands) and example alternative trajectories (light grey lines) are shown for the scenario with the highest transmission change (+10%).*

Important considerations for interpreting the ODE model trajectories

The trajectories from the ODE model are illustrations of possible patterns of infections (and the knock-on effects on reported cases, hospital admissions, hospital occupancy and deaths) in the future. We emphasise that they are *potential* patterns which result from specifying changes in transmission resulting from specified behavioural changes in the population as a response to national policy changes. They are not predictions of what will happen. An example of a behavioural change was the end of the CPF in September 2022, which resulted in more relaxed behaviours leading to higher transmission of infection (see **Figure 1**, estimated 19% increase in transmission). The trajectories plotted here explore the impact of a potential relaxation in measures in either December 2022, January 2023 or April 2023. Specifically, these forward trajectories do not include the effect of any additional variants of concern, despite extending significantly into the future.

A key conclusion to draw from these plots is that if background transmission is increasing, and policies are changed that result in an increase in transmission rate, then we see higher peaks of infections and hospitalisations.

As expected, larger relaxations in behaviour lead to larger increases in transmission (see purple lines compared to black lines in **Figures 3**, **4** and **5**). The dynamics for the plots show that the behaviour change in April 2023 causes higher infections (**Figure 5**, top-left panel) for several months, peaking around early June 2023, with higher peaks progressively for 2.5%, 5%, 7.5% and 10%.

It is worth noting that the ensemble of trajectories represented by the confidence bands are all consistent with the data, but vary substantially, especially in the near term, with large overlaps in the confidence bands. As an example, the peak in hospital occupancy for the 12th December change (**Figure 3**, middle-right panel) varies between 500 and 2400 for the +10% scenario, and between 400 and 2200 for the +0% scenario.

Caveats

On estimating changes in Rt

- Inferring different changes in Rt, with different levels of change in case and contact isolation behaviour, is only suitable for a relatively short time period following the policy changes that cause these behaviour changes. This modelling focuses on the effect on Rt in the short-term. These results are not suitable to apply when considering different scenarios in the longer term, as over time other factors (such as more behaviour changes, changing disease variants) will become significant.
- There are a number of complex factors that influence the Rt, including introduction of new variants with different levels of infectivity, changing travel patterns, increasing numbers of large community events, and reduced case ascertainment and contact tracing. These are not captured in current modelling.

Distribution of impacts

- The results presented here use an age structured ODE model to produce forward trajectories. Beyond the age structure, this model assumes a homogeneous population. The results presented here do not account for the fact that the impact of changes in case isolation requirements, or other policy changes related to COVID-19 protections will be experienced differently by different groups.

- Those groups who are better able to follow public health guidance to avoid infection will benefit from higher infection rates that occur in more vulnerable populations of people who are less able to follow this guidance. An increase in infection rates in these more vulnerable populations will lead to a decrease in the overall number of people susceptible to infection resulting in a decrease in average risk of infection overall. In this situation those who are more able to follow public guidance have had their risk of infection lowered due to the higher infection rates in more vulnerable populations.
- To incorporate additional population heterogeneity in the modelling results, would require using a model that has better/more detailed representation of the population than the ODE currently does, for example the NCM model. However using a more detailed model generally means increased running time and requires knowledge about additional input parameters.

On using the current ODE model to forecast into 2023

- In the ODE model, behavioural changes modelled through the control function are only one of the factors affecting case numbers. In particular, the control function in the ODE model does not distinguish between age-groups, and the case ascertainment rate (CAR) has not been adjusted to reflect the reduction in testing and reporting that the policy changes would have produced. Other confounding factors still being investigated are the time- and age-dependent CAR and the age contact matrix.
- We have predicted fourth dose uptake using projections provided by the Public Health Agency. These projections are in need of updating, as since they were produced the data have already shown a reduction in uptake compared to the projections. In addition, the projected fourth doses are only given to those aged 50 and over, through until the end of July 2023, when the projections are relatively flat (i.e., no further individuals are being vaccinated). Hence the model does not assume younger age groups will be offered a second booster vaccine in these illustrations.
- Data are not available on infection rates in the community (we use historical border worker testing as a proxy for community infection rates, to fit the model up until July 2022). The lack of data makes the model less robust, as since July we fit to only case and hospitalisation data, and CAR thus has a large impact on the assumed infection rate in the population. Ideally, empirical infection prevalence estimates would be used to ground-truth the model and ensure we are not in an epidemiologically unfeasible area of parameter space with the model fit.
- The ODE model assumes no new variants arriving with an immune escape different to the current BA.5 strain. **Figure 2** shows BA.5 reducing in occurrence throughout November, with BA.2.75 and BQ.1.1 increasing in occurrence. Thus a

new strain may take over as the dominant strain with higher immune escape, similar to the way in which BA.5 became the main strain observed in mid 2022. If this occurs the dynamics of the outbreak will likely alter, with higher transmission resulting from a lower population immunity level to the new strain. Hence we stress that the forecasts shown here are illustrative, and not predictive.

Supplementary Material: Future Scenario Detailed Descriptions

Here we give some examples of the combinations of case isolation (and sometimes work/school/community transmission) that could produce the scenarios of transmission increases.

With all of these, if there was any behaviour change associated with the policy shift, due to relaxation of behaviour in school/work/community interactions, then the increases could be even higher.

Scenario Bundle 'a'

If the changes in September line up with Bundle '***a'*** from **Table 1**, the transmission increase scenarios could be produced by a number of combinations of reductions in cases taking action and in reductions in the effectiveness and/or compliance of the isolation. Here we give one example for each.

Additional 2.5% transmission increase (+21.5% relative to August)
Could be produced by (21.5% on the contour plot in **Figure 7**):

- A further 30% reduction in cases taking action (50% relative to August), and a further 10% reduction in the effectiveness of the isolation relative to now (50% reduction relative to August already).

Additional 5% transmission increase (+24% relative to August)
Could be produced by (24% on the contour plot in **Figure 7**):

- A further 30% reduction in cases taking action (50% relative to August), and a further 35% reduction in the effectiveness of the isolation relative to now (75% reduction relative to August already).

Additional 7.5% transmission increase (+26.5% relative to August)
Could be produced by (26.5% on the contour plot in **Figure 7**):

- A further 30% reduction in cases taking action (85% relative to August), and a further 45% reduction in the effectiveness of the isolation relative to now (85% reduction relative to August already).

Additional 10% transmission increase (+29% relative to August)
Could not be produced by case isolation changes alone (29% on the contour plot in Figure 7). Would need to be:

- No case isolation or testing and thus no household contacts.

- AND increases in community transmission due to behavioural relaxations, leading to ~2% overall transmission increases.

Scenario Bundle ‘b’

If the changes in September line up with Bundle ‘***b’*** from **Table 1**, the transmission increase scenarios could be produced by a number of combinations of reductions in cases taking action and in reductions in the effectiveness and/or compliance of the isolation. Here we give one example for each.

Additional 2.5% transmission increase (+21.5% relative to August)
Could be produced by (17.5% on the contour plot in **Figure 7**):
- A further 5% reduction in cases taking action (20% relative to August), and a further 15% reduction in the effectiveness of the isolation relative to now (25% reduction relative to August).

Additional 5% transmission increase (+24% relative to August)
Could be produced by (20% on the contour plot in **Figure 7**):
- A further 10% reduction in cases taking action (25% relative to August), and a further 40% reduction in the effectiveness of the isolation relative to now (50% reduction relative to August).

Additional 7.5% transmission increase (+26.5% relative to August)
Could be produced by (22.5% on the contour plot in **Figure 7**):
- A further 30% reduction in cases taking action (45% relative to August), and a further 40% reduction in the effectiveness of the isolation relative to now (50% reduction relative to August).

Additional 10% transmission increase (+29% relative to August)
Could be produced by (25% on the contour plot in **Figure 7**):
- A further 50% reduction in cases taking action (65% relative to August), and a further 55% reduction in the effectiveness of the isolation relative to now (75% reduction relative to August).

Scenario Bundle ‘c’

If there had already been a 30% reduction in cases testing and isolating, and then the changes in September lined up with Bundle ‘***c’*** from **Table 2**, the transmission increase scenarios could be produced by a number of combinations for case behaviour for lower increases, but to see the higher increases there must also be some behaviour change leading to increased transmission rates in school/work/community. Here we give one example for each increase in transmission level.

Additional 2.5% transmission increase (+21.5% relative to August)

Could be produced by (25% on the contour plot in **Figure 7**):

- A further 20% reduction in cases taking action (in addition to the 20% reduction in September, so 70% reduction relative to model defaults), and an additional 20% reduction in the effectiveness of the isolation (in addition to the 20% reduction in September, so 65% reduction relative to model defaults),

Additional 5% transmission increase (+24% relative to August)

Could be produced by (27.5% on the contour plot in **Figure 7**):

- No case isolation or testing and thus no household contacts.

Additional 7.5% transmission increase (+26.5% relative to August)

Could not be produced by case isolation changes alone. Would need to be:

- No case isolation or testing and thus no household contacts.
- AND increases in community transmission due to behavioural relaxations, leading to ~2.5% overall transmission increases.

Additional 10% transmission increase (+29% relative to August)

Could not be produced by case isolation changes alone. Would need to be:

- No case isolation or testing and thus no household contacts.
- AND increases in community transmission due to behavioural relaxations, leading to ~5% overall transmission increases.

Supplementary Material: Past Results

Mapping different levels of community transmission reductions and household contact policies to transmission changes

In August 2022 CMA used the Network Contagion Model (NCM) to estimate the change in transmission levels due to

- the shift away from the Covid Protection Framework, and
- relaxation of household contact quarantine requirements[3].

The shift away from the Covid Protection Framework was modelled by assuming that the shift would lead to transmission increases in all community interactions due to perceived reduction in risk and thus the relaxation of the transmission reduction behaviours. We implemented this as two levels of 'Community context'[4]:

- **CPF Orange**: related to a best guess at the transmission reductions taking place in work[5] and school[6], and community[7] interactions due to people being cautious e.g. improved ventilation, smaller/fewer gatherings, masks, etc.
- **CPF Off**: all the transmission reductions assumed above removed.

Three settings were simulated for household contact quarantine rules:

- ***7 days quarantine; test if symptomatic or on days 3 and 7***
- ***7 days observation; no quarantine; daily testing***
- ***7 days observation; no quarantine; daily testing while symptomatic***

The change in Rt for specific combinations of behaviour change for community and household contacts are given in **Table 4**, with the full set of combinations given in the original report. All changes in Rt are relative to a baseline of the CPF Orange settings in place in August:

- Community context = CPF Orange
- Household contacts = 7 days quarantine, test on day 3 and 7
- Case default values = 7 days isolation implemented as a *10% leak rate over the whole infectious period after detection,* 70% of symptomatic infections testing and isolating.

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[3] *Estimating the effect of Covid Protection Framework policy scenarios on the effective reproduction number of COVID-19 in Aotearoa*, Harvey, E., O'Neale, D., Patten-Elliott, F., Priest Forsyth, E., COVID Modelling Aotearoa, 16th August 2022.

[4] In the initial analysis and report this setting was labelled as 'mask requirements' for brevity, but this is not specifically only the impact that masks themselves were having

[5] 20% reduction in close contact transmission, 50% reduction in casual contact transmission

[6] 20% reduction in close contact transmission, 50% reduction in casual contact transmission

[7] 10% reduction in close contact transmission, 50% reduction in casual contact transmission

Table 4: *Change in Rt for selected combinations of community transmission and household contact rules relative to the **Baseline scenario settings**.*

Community context	Household contacts	Change in Rt*
CPF Orange	7 days observation, guidance to test daily, no quarantine required	2.5% - 2.9%
CPF Off	7 days quarantine; test if symptomatic or on days 3 and 7	5.4% - 6.2%
CPF Off	7 days observation, guidance to test daily, no quarantine required	8.2% - 9.2%,
CPF Off	7 days observation, guidance to test daily if symptomatic, no quarantine required	10.3% - 11.5%,

In August it was decided that a 8.5% increase was the best estimate for the impact of the CPF change in September. However, case data since then show that this is an underestimate.

ODE model predictions using an 8.5% increase in Rt produce the infection, case, hospitalisation, and death timeseries shown in **Figure 6**.

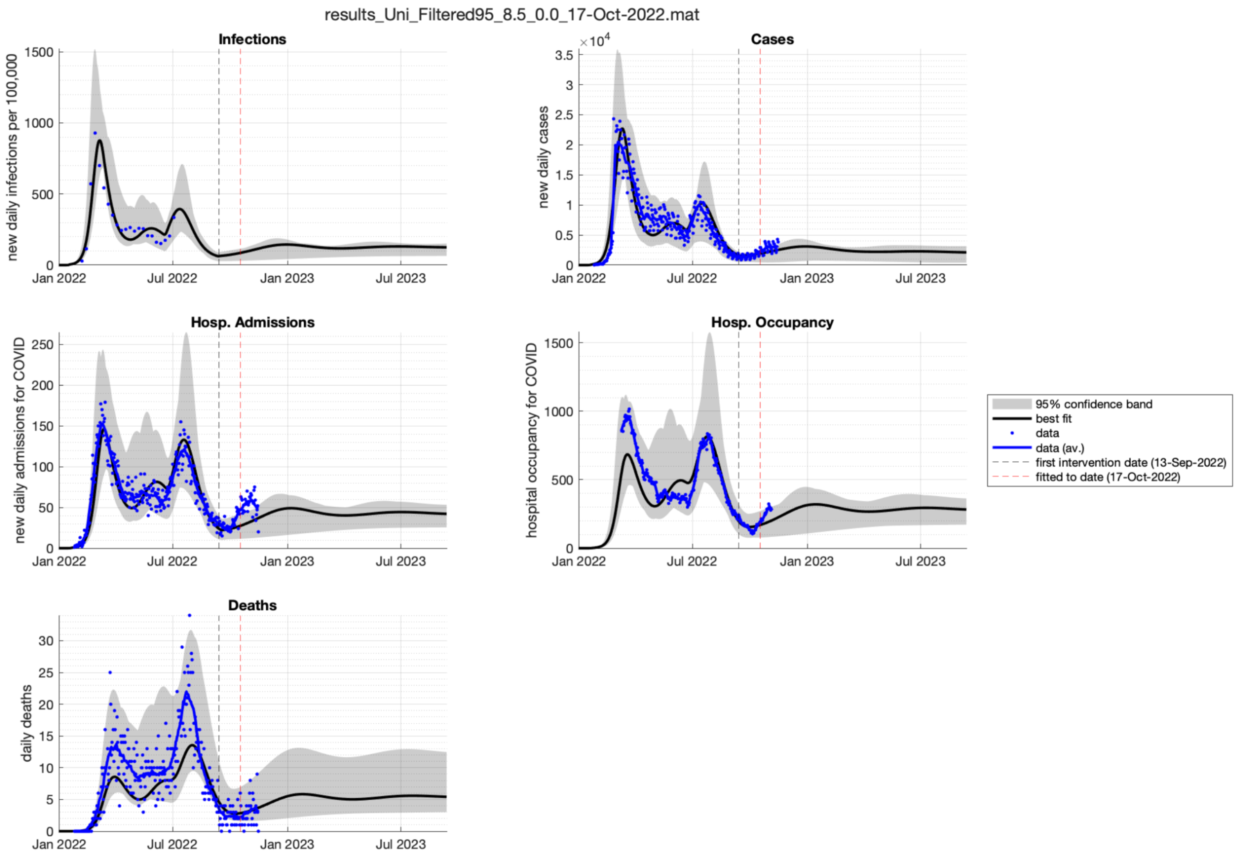

Figure 6: *ODE model results using an **8.5%** transmission increase on 13th September. Observed reported cases and hospital admissions increase outside of the model's 95% confidence interval bands after the 13 September policy changes.*

Mapping different levels of case isolation compliance to transmission changes

In September 2022 CMA used the NCM to investigate the potential transmission increases due to changing isolating behaviours of **confirmed cases**.[8]

The following contour plot considers how Rt could change with different levels of compliance with case isolation policy, relative to a baseline of the CPF orange settings in place in August 2022.

Baseline scenario settings (CPF Orange August settings):

- Community context = CPF Orange
- Household contacts = 7 days quarantine, test on day 3 and 5
- Cases = 7 days isolation

[8] *Estimating the effect of changes in case isolation on the effective reproduction number of COVID-19 in Aotearoa*, Harvey, E., O'Neale, D., Patten-Elliott, F., Priest Forsyth, E., COVID Modelling Aotearoa, 15th September 2022.

All scenarios in the contour plot include:

- Moving from CPF Orange to CPF Off. This results in behavioural changes (including mask requirements being removed) that increase transmission in work, school, and community settings.
- Household contact isolation policy being changed to no contact isolation requirement, and contacts only advised to test if symptomatic.

Our previous modelling estimated that these two changes, with no change in requirements or behaviour for confirmed cases, produced an 11.4% change in Rt relative to the baseline scenario, which is our best guess for the situation in August 2022. **This means that the value at the origin (0,0) is 11.4%**

Case isolation behaviour varies in two ways in the scenarios plotted:

1. **Proclivity to change behaviour:** the proportion of symptomatic infections who would take some sort of action to reduce transmission (including those who test positive but also those who take action based on symptoms).
2. **How much people change behaviour:** how effective the action people take is (specifically, the reduction in transmission outside the household for those people taking action).

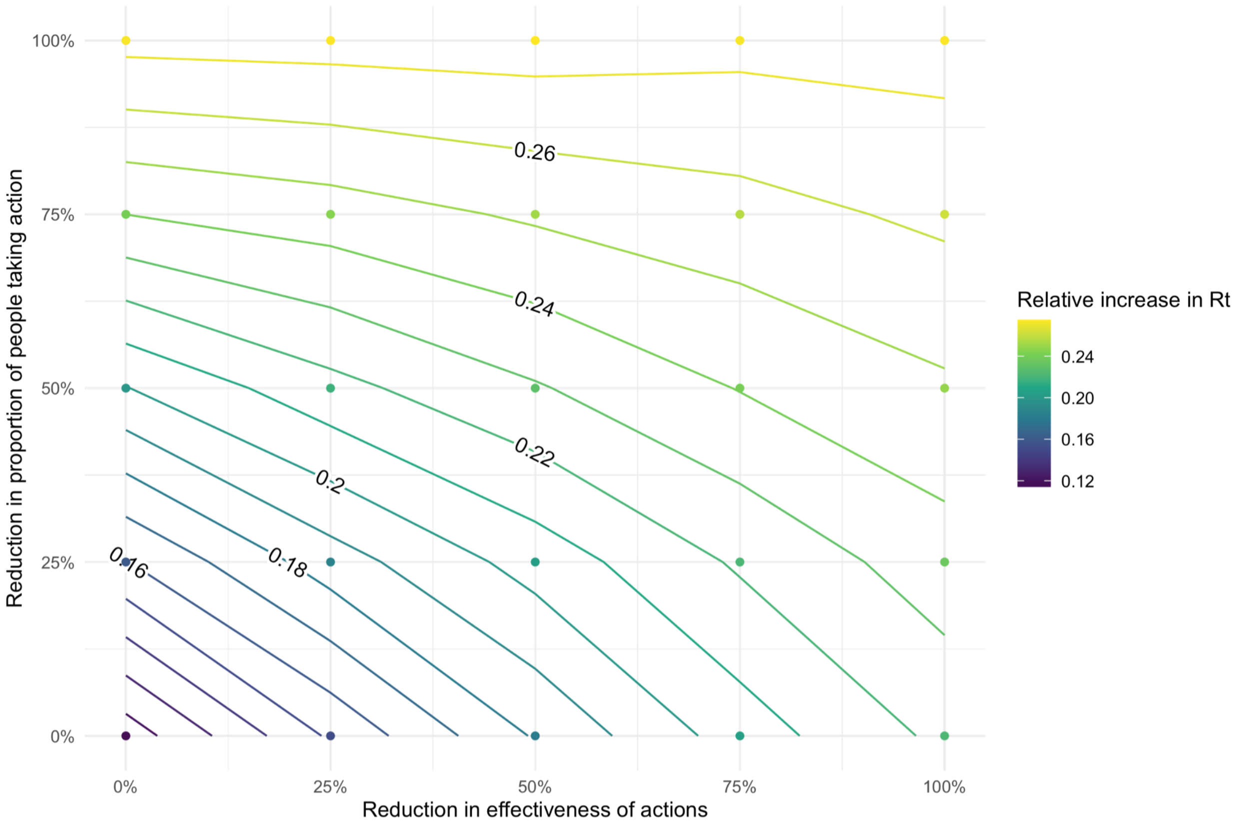

Figure 7: *Contour plot showing the* ***relative increase in Rt*** *due to a change in case isolation behaviour factors compared to an August 2022 baseline. The value at the origin of this plot is 11.4%, which is the estimate of increase in Rt due to ending the CPF and changing household*

contact quarantine requirements to 'guidance to test if symptomatic'.The locations of the 16 specific scenario results are plotted as dots. In general, we find that a large fraction of people taking some action leads to a smaller increase in Rt than a small fraction of people taking a highly effective action.

Table 5: *Estimated percentage increase in Rt relative to baseline, for simulations when changing case isolation behaviour factors.*

		Reduction in effectiveness of actions				
		0%	**25%**	**50%**	**75%**	**100%**
Reduction in proportion of people taking action	**0%**	11.4%	15.2%	18.1%	20.5%	22.2%
	25%	16.0%	18.5%	20.4%	22.1%	23.5%
	50%	20.0%	21.7%	22.9%	24.0%	24.8%
	75%	24.0%	24.5%	25.2%	25.6%	26.2%
	100%	27.3%	27.4%	27.5%	27.3%	27.4%

Using the contour plot

Estimating a change in Rt from predicted levels of behaviour change

Table 6 below gives an example of how to estimate change in Rt if there was a 60% reduction in proportion of symptomatic people taking action, and a 30% reduction in the effectiveness of those actions.

All changes are relative to August 2022, and include policy changes from *CPF Orange* to *CPF Off*, and *no contact isolation requirement*, and *contacts advised to test daily only if symptomatic*.

Table 6: *Interpretation of plot values and translation to NCM model parameters*

	Value	**What this represents in terms of real world behaviour changes**	**Corresponding model parameter change**
Y-axis value	60%	A 60% reduction in the proportion of symptomatic people taking action to prevent transmission, compared to the baseline (as in August 2022)	A 60% reduction from 70% of symptomatic people taking action to reduce transmission, to 28% of symptomatic people taking action.

X-axis value	30%	A 30% reduction in effectiveness of actions taken by symptomatic people that do take action –*see Y-axis value*– compared to baseline (as in August 2022)	A 30% reduction from 90% of transmission prevented as a result of case behaviour, to 63% of transmission prevented. An increase in leak rate from 10% to 37% in model parameters.
Contour value	0.23	We estimate Rt would increase by 23% compared to the baseline scenario, for a case isolation policy change with the corresponding parameter values (30%,60%) as described in the rows above	N/A (Rt is estimated from the new infections timeseries produced by the model, it is not a model parameter)

Inferring potential levels of behaviour change from observed change in Rt

If we want to infer what level of behaviour change has occurred for a particular change in Rt, we can read off the possible combinations of behaviour changes that produce a certain contour line on the plot.

This assumes that the policy changes from *CPF Orange* to *CPF Off (includes removing mask requirements)*; and *no contact isolation requirement, only advice to test if symptomatic*, have been modelled accurately.