This report is a pre-print.
The methodology of this report has been internally peer reviewed.

Covid-19 Modelling Aotearoa

# Estimating the effect of Covid Protection Framework policy scenarios on the effective reproduction number of COVID-19 in Aotearoa: August 2022

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Information in this report was provided to NZ Ministry of Health on **16th August 2022**, via e-mail and virtual meetings, as part of a rapid response to requests for modelling advice on consequences of changing policy settings for cases, contacts, and community contexts. The deadlines associated with these requests for advice were too short to allow for results and contextual information to be compiled into a report in advance of 16th August. This document collates the results and advice from meetings and emails into a single report.

# Background

This report presents modelling undertaken at the request of, and documents initial advice delivered to, the New Zealand Government by COVID-19 Modelling Aotearoa (CMA) up to mid-August 2022. A second report [1] presents further modelling in response to requests from mid-August to early September. An Addendum [2] to these reports presents findings of sensitivity testing of transmission within households during quarantine.

This modelling estimated the relative change in the effective reproduction number (Rt) for COVID-19 in Aotearoa, across a range of scenarios with different policy settings for:

- isolation requirements for confirmed cases,
- testing and quarantine requirements for household contacts of confirmed cases; and
- community context: transmission reduction behaviours, including mask wearing, reducing in-person interactions, and improved ventilation.

The effect of the different policy settings above were estimated in the context of a range of different background transmission environments.

The scenarios above were investigated using an individual-based Network Contagion Model (NCM) developed by CMA to represent the population of Aotearoa. Simulations estimated the effect of policy changes in the context of a period of decreasing case numbers, following a recent wave of cases, and with a sizable associated pool of individuals with high levels of immunity from past infection.

The effect of these policy changes on the transmission of COVID-19 was estimated by estimating the change in the effective reproduction number, Rt, for each scenario and comparing these values relative to a baseline scenario of no policy change. More explanation of how Rt was calculated, and some of its potential limitations can be found in Appendix A.

## How to use these results

Modelled simulation settings are intended to capture the relative impact of changes in policy settings, as opposed to being a forecast of future cases based on the current situation. The estimated changes to the effective reproduction number (Rt) presented in this work can be used as inputs to models, such as the CMA Ordinary Differential Equation (ODE) model, in order to estimate longer term impacts of policy changes on new infections and hospitalisations.

# Scenario settings modelled

Different settings were modelled for separate policy-related parameter sets intended to capture the effect of different policy settings for:

- community context (transmission reduction behaviour),

- case-isolation;
- and household-contact quarantine.

Each combination of these settings was simulated in the context of three different levels of ‘background transmission’. This helps with quantifying uncertainty and increases the robustness of the estimates of the effect size for the parameters of interest. Every possible combination of settings was modelled as a single scenario. This led to a total of 54 scenarios that were simulated with the NCM.

At the time this work was commissioned, Aotearoa was operating under the COVID-19 Protection Framework (CPF) “Orange” setting[1]. For each of the policy changes described, we have indicated what the current settings were at the time when this modelling was commissioned.

## Community context

`Community context’ captures transmission reduction behaviour at work, school, and in the community that is influenced by CPF settings. This includes mask wearing, people behaving cautiously (such as social distancing), as well as measures to improve ventilation in buildings, such as opening doors and windows.

Two levels of ‘community context’ were considered:

- **CPF Orange**: a best guess at the reduction in transmission due to actions taken under the CPF ‘Orange’ setting in work and school, and community interactions due to people being cautious e.g. improved ventilation, smaller/fewer gatherings, and wearing masks.
- **CPF Off**: all the transmission reductions assumed above removed.

To test the maximum likely effect of transmission-reducing community behavioural changes associated with the CPF being removed (including the removal of masking requirements), we simulated this scenario by completely removing the effect of the ‘community context’ on reduction in transmission. **Table 1** details how these community context settings were parameterised.

| **Setting** | **Modelled as** |
|---|---|
| Community context = CPF Orange | ● 20% reduction in close contact transmission in schools and workplaces, 50% reduction in casual contact transmission in schools and workplaces.<br>● 50% reduction in casual contact community transmission (supermarkets, buses, etc.). |

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[1] More information on the CPF can be found at https://covid19.govt.nz/traffic-lights/history-of-the-covid-19-protection-framework-traffic-lights/

| | |
|---|---|
| | - 10% reduction in close contact community transmission. |
| Community context = CPF Off | No reduction in transmission in any settings. |

***Table 1:*** *Parameterising different community context wearing scenarios*

## Case isolation

Two policy settings were requested to be simulated for case isolation rules:

- 7 days of isolation for confirmed cases, with no test to release required.
- 7 days of isolation for confirmed cases is recommended by official guidance, with the assumption that the guidance is “50% effective”.

Modelling a move from requiring case isolation to recommending case isolation (the second bullet point above) can be implemented in more than one way. Two contrasting approaches are:

1. The rate of case *detection* is unchanged; all confirmed cases isolate, but with a 50% reduction in the *effectiveness* of their isolation actions to reduce transmission to contacts outside of their dwelling (i.e. the ‘leak rate’ of infections from cases to people outside their dwelling increases.) This assumes a situation where people are equally inclined to, and able to, isolate. This homogeneous effect assumption is likely to be unrealistic.

2. Alternatively, we can assume that a heterogeneous population has people who are more/less inclined to, or able to, isolate. E.g. 50% of the population might isolate with the original isolation efficacy, while the remainder don’t, or can’t, follow guidance to isolate. This is equivalent to a reduction in people becoming confirmed cases, which we model as a reduction in testing and hence reduced case confirmation. That is, a reduced fraction of infected individuals become confirmed cases and hence do not isolate.

Both options were modelled as separate scenarios. **Table 2** details the parameter values that capture how the scenarios for case isolation were simulated. The second approach may better capture a heterogeneous population where people will have different inclination, or ability, to follow guidance to isolate, if isolation is discretionary. This has equity implications which are discussed later in this report.

### Perfect isolation within households assumed for all scenarios

All results presented in this report assume that when a case is isolating at home, all household contacts isolate perfectly from each other. That is, there will be no transmission **within the dwelling** after the first case is detected. An Addendum to this report, *Addendum: Assumption of perfect case isolation within the home*, presents results where the assumption of perfect intra-dwelling isolation is replaced with the assumption of no reduction in transmission within dwelling [2].

| **Setting** | **Modelled as** |
|---|---|
| 7 days no test to release | ● 10% case 'leak' rate<br>i.e. 10% of the infections outside the home that would happen if the case wasn't detected go ahead |
| 7 days 'guidance' (reduced effectiveness of isolation actions)<br>Assuming "follow guidance" is 50% effective for all people. | ● Increase 'leak' rate from 10% (baseline) to 55%<br>i.e. of the 90% of infections that would be prevented by case isolation, only 45% are prevented - on average, across all confirmed cases. |
| 7 days 'guidance' (reduced proportion of cases taking isolation action)<br>Assuming "guidance" is followed by 50% of those who would otherwise be cases and would isolate. | ● Halve the symptomatic testing rate from 70% to 35%; keep case 'leak' rate the same as baseline.<br>i.e. confirmed/reported cases follow isolation guidance but only half the number of cases would be confirmed/reported. This has the consequence that only half the number of household contacts would be identified (increased testing and quarantine). |

***Table 2:*** *Parameterising different case isolation scenarios.*

## Contact quarantine

**Table 3** details how the scenarios for household contact quarantine settings were parameterised. Three settings were simulated for household contact quarantine rules:

- 7 days quarantine; test if symptomatic or on days 3 and 7 (current requirement under CPF Orange).
- 7 days observation; no quarantine; recommendation to test daily.
- 7 days observation; no quarantine; recommendation to test if symptomatic.

| **Setting** | **Modelled as** |
|---|---|
| 7 days quarantine, test if symptomatic or on days 3 and 7 | ● 10% contact quarantine 'leak' rate<br>● Quarantine period of ~6 days after first case in household detected<br>● Increased testing rate for those ~6 days in symptomatic and asymptomatic household contacts |
| 7 days 'observation' with daily testing recommended | ● 100% contact quarantine 'leak' rate<br>● Increased testing rate for those ~6 days in symptomatic and asymptomatic household contacts (higher than the above baseline setting) |
| 7 days 'observation', testing recommended only if symptomatic | ● 100% contact quarantine 'leak' rate<br>● Same testing rate for symptomatic household contacts, no testing for asymptomatic household contacts. |

***Table 3:*** *Parameterising different household contact quarantine scenarios*

## Background transmission

Three levels of underlying background transmission environments were simulated as the context in which the various policy scenarios were applied.

These were used to ensure that any estimates of the effect size for changes in policy were applicable across a range of different background transmission environments in place before the policy change. This could encompass for example, the tendency of people to work from home (when not infected) or to attend events other than work and school interactions. While the different background transmission rates do not make explicit assumptions about different susceptible populations, they do approximate the effects of some of the differences in susceptible population. **Table 4** details how levels of background transmission environment were modelled.

| **Setting** | **Modelled as** |
|---|---|
| Low background transmission | Medium levels of working from home.<br>Reduced numbers of 'close contact' community events (20% reduction).<br>Reduced numbers of 'casual' community contacts (30% reduction). |
| Medium background transmission | BAU levels of working from home.<br>Reduced numbers of 'close contact' community events (10% reduction).<br>Reduced numbers of 'casual' community contacts (15% reduction). |
| High background transmission | BAU levels of working from home.<br>No reduction in close or casual contact community events. |

***Table 4:*** *Parameterising different levels of background transmission*

## Choosing a baseline scenario

At the time of commissioning, Aotearoa was operating under the COVID-19 Protection Framework (CPF) "Orange" setting[2]. We looked at three different baseline scenarios: each with the same settings for the various policy parameters, but a different level of "background transmission" to capture different levels of Reff before the policy change (details in **Table 5** below[3]). In the plots in the results section, the baseline setting for each policy dimension presented is indicated by an asterisk (*).

| **Policy related parameter sets** | **Baseline scenario setting** |
|---|---|

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[2] More information on the CPF can be found at https://covid19.govt.nz/traffic-lights/history-of-the-covid-19-protection-framework-traffic-lights/

[3] Table 5 details the levels for each of the modelled policy settings that relates to the COVID-19 Protection Framework (CPF) "Orange" setting across Aotearoa. The "CPF Orange" level of the "Community Context" policy setting models the transmission reduction behaviour in workplaces, schools, and the community that was taking place under level "Orange" of the CPF in July 2023.

| | |
|---|---|
| Community context | - CPF Orange |
| Case isolation | - 7 days no test to release |
| Contact quarantine | - 7 days quarantine, test if symptomatic and days 3 and 7 required |

***Table 5:*** *Selected policy related parameter settings for the 'Baseline scenario'. There are effectively three different baselines, as simulations were run for three different levels of 'background transmission' (High, Medium, and Low).*

# Results: comparison using effective reproduction number, Rt

To compare the effect of different policy settings on the spread of COVID-19 through the NCM we simulated transmission under each scenario and calculated the change in the effective reproduction number, Rt, relative to a baseline of no policy changes.

For each of the 54 scenarios modelled, we used the time series of new infections (both confirmed and unconfirmed) to calculate a time series of Rt[4]. More details on the Rt calculation can be found in **Appendix A**.

## How to interpret relative differences in Rt

- For each scenario we have looked at the maximum relative change in Rt, relative to a chosen baseline scenario with the same level of background transmission.
- We only looked at the first few weeks of the simulations after a change in policy settings, as we are considering the instantaneous change in Rt due to the different policy settings. Alternative models within COVID-19 Modelling Aotearoa, such as the Ordinary Differential Equation (ODE) model can be used to project the effect of a short term change in growth rate, due to a single event like a policy change, into a longer term projection of cases.
- The maximum measured change in Rt is intended to provide a best guess at the maximum **instantaneous/short-term** effect changes in policy settings may have

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[4] When calculating Rt from observed data it is generally necessary to estimate the actual number of infections from the observed number of confirmed cases. However, calculating Rt from confirmed cases can lead to different estimates of the effect size, since different policy scenarios can lead to different fractions of total infections being recorded as confirmed cases. When analysing the simulation results we are able to use the number of infections directly.

on infection transmission. Over longer time periods, infection dynamics mean that lower or higher growth rates will be observed.

## New infections

The new infection time series for all scenarios are presented in **Figure 1** below. These plots show the new daily infection trajectories for a range of policy changes in the context of a period of decreasing case numbers, following a recent wave of cases. In all simulated 'baseline' cases (i.e. current CPF Orange restrictions remain) the time series for new infections are on a downward trajectory. This is due to decreasing spread in the context of a shrinking susceptible population, and no changes in transmission settings or behaviour, and without the introduction of new variants. Scenarios where restrictions are removed have higher peaks for new infections, following any policy change. Over longer times, all scenarios modelled revert to the background behaviour of decreasing infections due to depletion of the susceptible population.

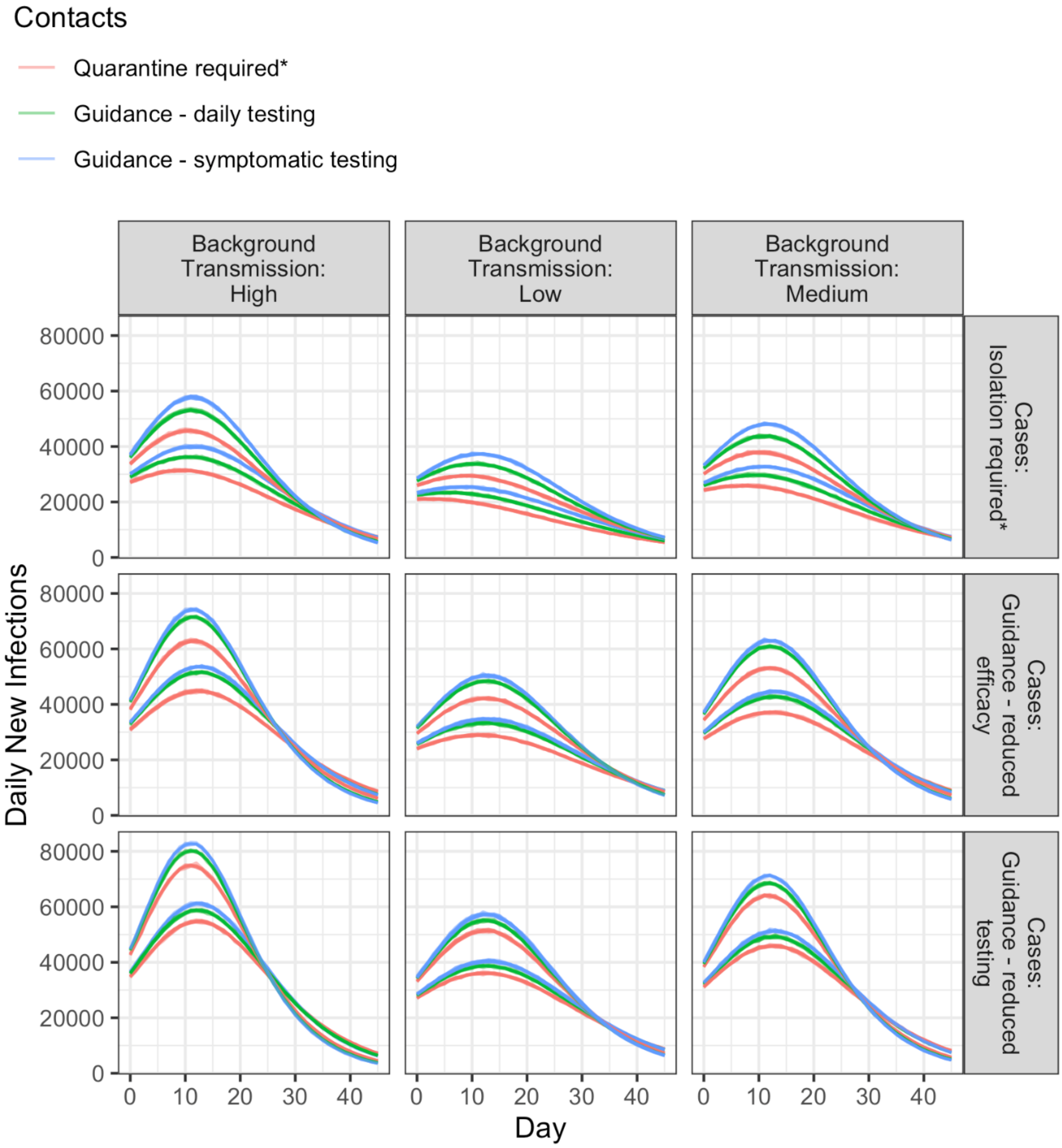

**Figure 1:** *New infection timeseries for all scenario realisations. Day 0 occurs after the policy changes specified in each scenario have come into effect. The plots are gridded with different levels of background transmission horizontally, and different case isolation policies vertically. Time series are coloured by the household contact quarantine policy. For each policy dimension, the baseline setting is indicated by an asterisk (*). Note that there are two series with the same colour in each individual plot. These correspond to the two different community context settings, the series with a higher peak is the scenario that has community context = "CPF Off" (community transmission reduction behaviours removed), and the series with the lower peak is the scenario with community context = CPF Orange.*

## Rt time series

**Figure 2** shows the time series for the effective reproductive number, Rt, calculated for each scenario. In the context of decreasing background infections, for all policy scenarios, Rt eventually drops below 1 (the point at which an outbreak is decreasing). This happens at different points in the simulated period for different scenarios.

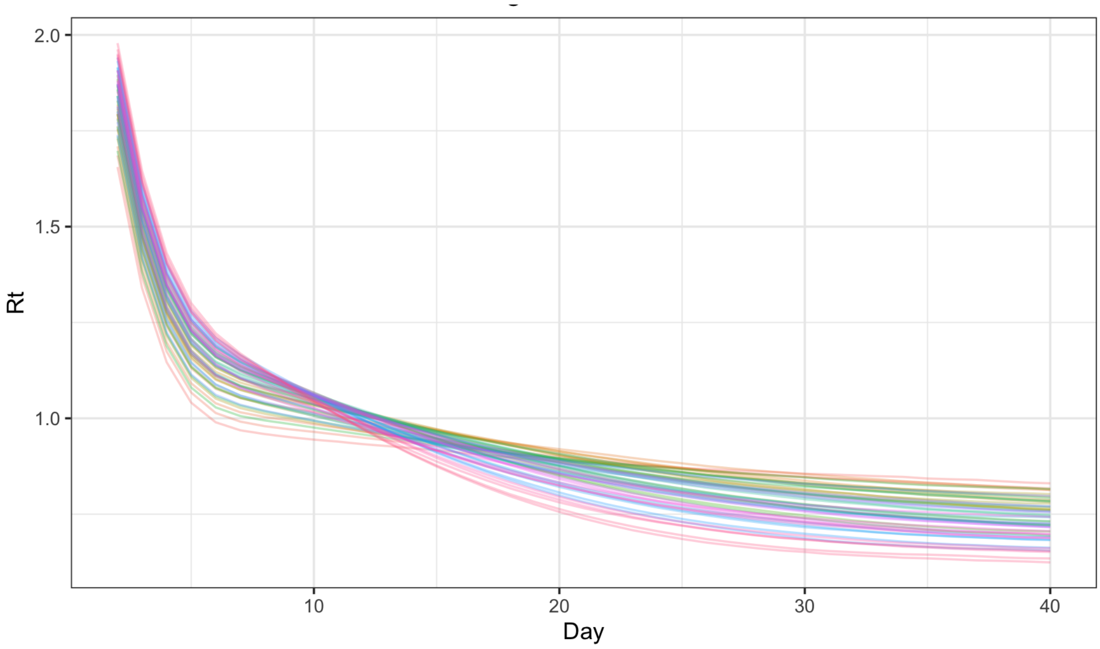

**Figure 2:** *Estimated Rt through time for all scenarios simulated, each scenario a different colour. Time is measured relative to when any corresponding policy change has taken effect, allowing for an initialisation period.*

## Comparing effects of changes in policy on Rt

**Figure 3** below shows the maximum fractional increase in the effective reproduction number (Rt) of each scenario, relative to the baseline scenario for the three different background transmission levels modelled. Any pair of simulation results that are compared in this report (to produce a fractional increase in Rt) have the same background transmission setting. We do not compare between simulations with different levels of background transmission.

We see from **Figure 3** that the background transmission level makes a difference to the relative increase in Rt due to policy changes. Specifically, the effect size from policy changes is larger when the background transmission is lower. Further investigation shows that the impact of a policy change for different levels of background transmission all result in similar absolute increases in Rt. This means that the fractional increase in Rt is higher when 'background transmission' is lower (lower Rt at baseline). This results in, at most, approximately 2.5 percentage point difference in the effect size of different policies on the fractional change in Rt.

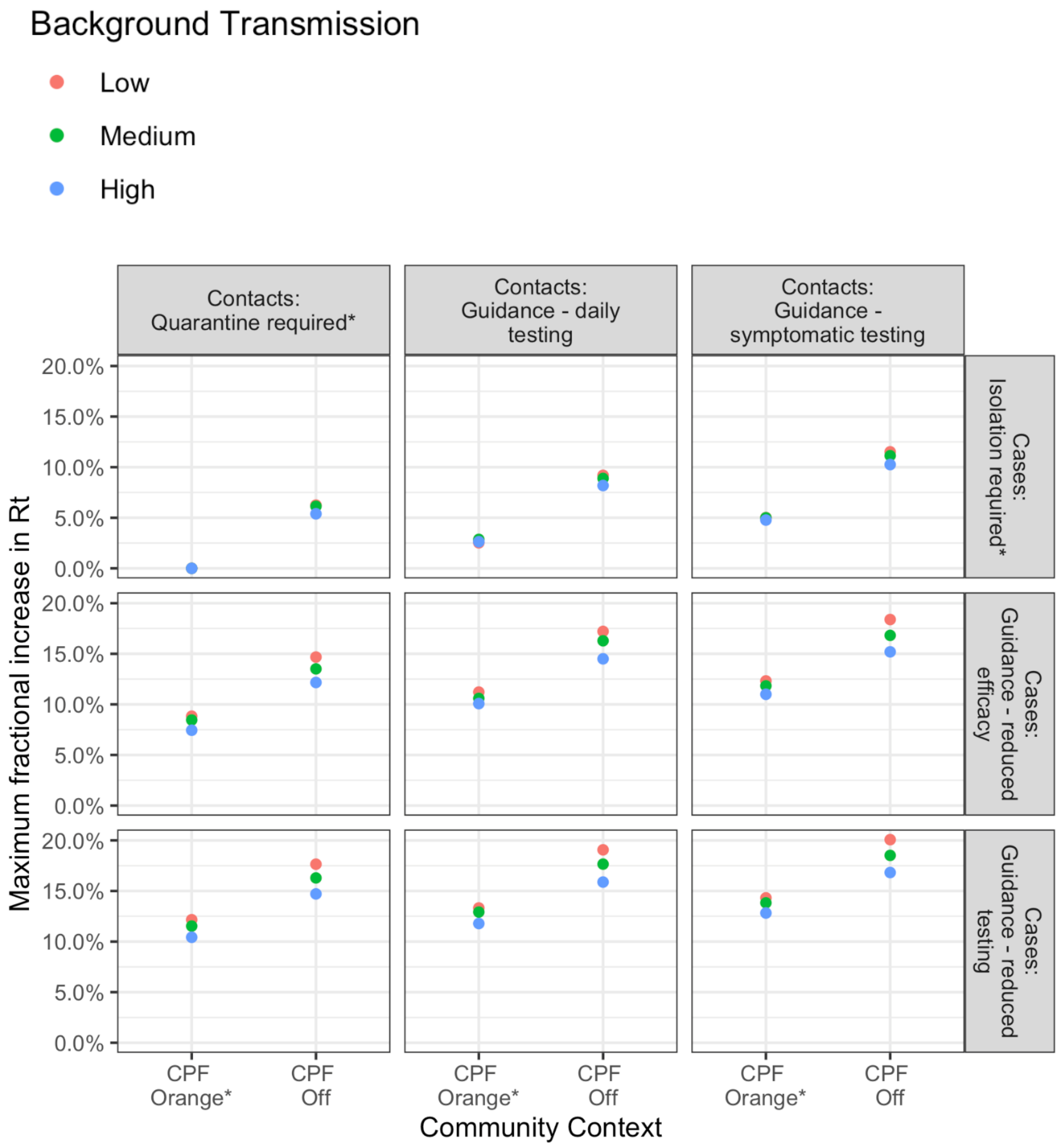

**Figure 3:** *Maximum fractional increase in Rt relative to the baseline scenario for all case isolation, contact quarantine, and community context policy setting combinations across the three different background transmission levels modelled (low, medium, high). The colour of the dot indicates which of the three background transmission levels was used for all simulations. Each column of charts has the same scenario setting for household contacts; each row of charts has the same scenario setting for case isolation. Each facet in the grid presents the results for simulations with the same policy setting for cases and contacts, and the x-axis separates two different policy settings for community context. The different coloured series show how the maximum fractional increase in Rt relative to the baseline for each scenario changed depending on the background transmission context. For each policy dimension, the baseline setting is indicated by an asterisk (*)*

Although we expect the effect of different interventions (policies regarding community context, household contact quarantine, case isolation) to be somewhat interdependent, it is possible to estimate the approximate single-factor effect size due to each of the changes in these settings. As illustrated in **Figure 4**, within-group effect sizes are approximately the same magnitude, even when compared between groups (i.e. in conjunction with different combinations of other effects).

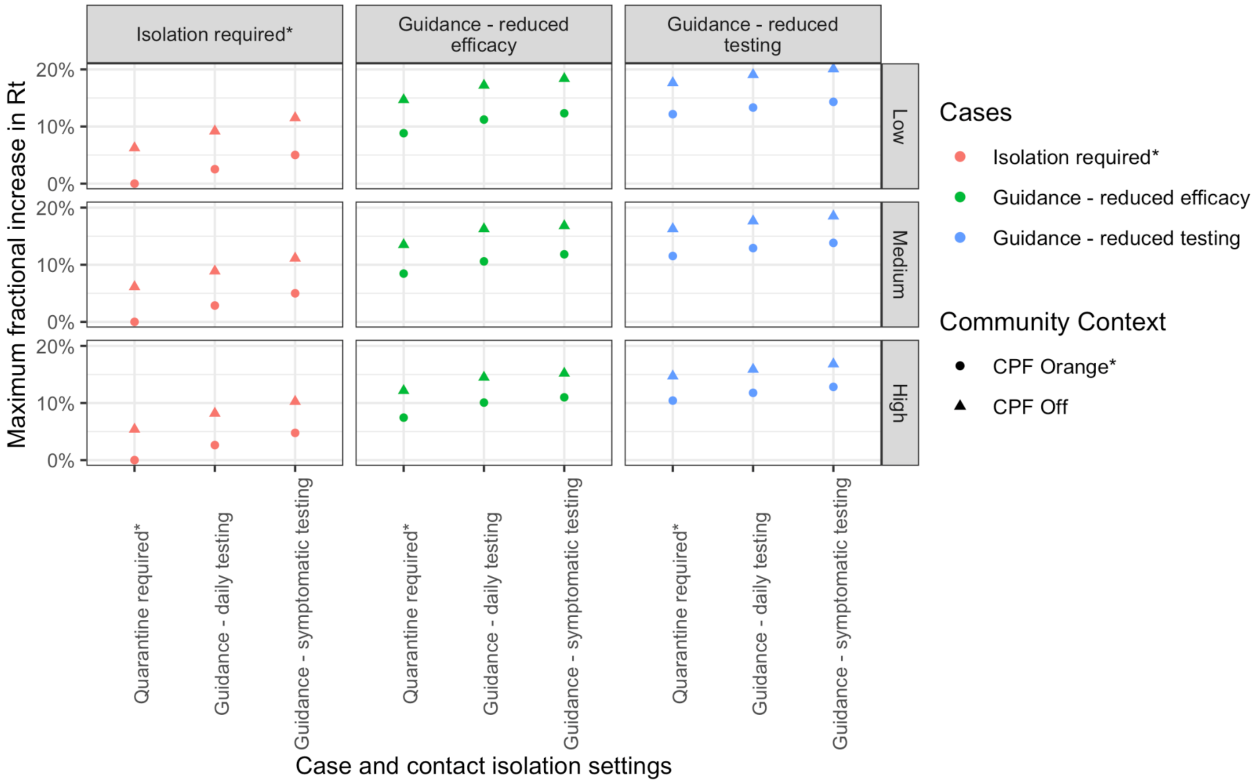

**Figure 4:** *Plot of relative change in Rt for each combination of policy changes compared to baseline scenario. For each policy dimension, the baseline setting is indicated by an asterisk (*). The step change between different levels of one policy dimension (for example, changing the case isolation policy) is roughly the same across other policy dimensions and background transmission levels.*

If we approximate the effects of changing each intervention as independent, we find the following heuristics:

| **Intervention** | **Policy change from baseline** | **Percentage point change in Rt (from baseline)** |
|---|---|---|
| Removal of community transmission reduction behaviour | CPF Orange → CPF Off | +5 % |

| | | |
|---|---|---|
| Reduced case isolation | 7 days isolation requirement → 7 days isolation guidance only | +11% |
| No contact quarantine | Quarantine required, day 3 and 7 testing → No quarantine required but daily testing | +2.5% |
| No contact quarantine | Quarantine required, day 3 and 7 testing → No quarantine required and only testing if symptomatic | +5% |

These values can be used to inform the choice of a change in growth rate or change in control function in models such as the CMA ODE model which can then be used to project trajectories for future infections and cases from a range of baselines and over longer time periods, possibly including effects such as the introduction of new variants.

A significant finding from the simulated scenarios is that if quarantine requirements for household contacts are removed but are replaced with high frequency testing, such as daily use of rapid antigen tests, then much of the effect of a quarantine policy can be recovered (changing to this setting only results in a +2.5% increase in Rt from baseline). This is because infected (and infectious) household contacts are only active in the community for a short period of time before they test positive and subsequently become a confirmed case themselves, requiring them to isolate. This protection is reduced, however, if only symptomatic individuals are advised to test, due to an estimated 30-40% of infections being asymptomatic, but still infectious.

## Equity concerns

We have modelled the shift of case isolation requirements to “guidance only” in two ways. One that assumes a reduced isolation efficacy, but an equal ability/proclivity to follow guidance for all individuals. The other approach assumes that the ability/proclivity to isolate is unevenly spread throughout the population. We believe that the reality will be a mix of the two. In this work we do not assign ability/proclivity to isolate to any specific part of the population, but do note that heterogeneity in ability/proclivity to isolate has equity implications.

It is clear from existing literature for other respiratory illnesses, and from emerging international evidence for COVID-19, that shifting from *'requirements'* to follow transmission-limiting behaviours to *'guidance'* disproportionately affects those who do not have the ability to choose to follow the guidance. Lower income jobs tend to be less adaptable to working from home [3], while increased reliance on income means that lower income individuals will feel more pressure to work while sick, especially in jobs without sick leave provision [4]. There is also international evidence that workers feel pressure from employers to return to work before they have fully recovered [5].

For adults, factors which make it harder to follow guidance include being in precarious employment, doing a job that requires on-site work (hence unable to work from home), workers without sick leave, people in casual work, people with caring responsibilities, people in precarious housing, and people with disabilities.

For children, many of these same factors apply, as it depends whether a parent or carer is able to stay home to look after them.

It is therefore likely that increased infections resulting from a shift from requirements to guidance would be concentrated in these more vulnerable communities. Increased infections in these communities will reduce the total susceptible population throughout Aotearoa, thereby decreasing the infection risk for those communities where more people are able to follow isolation guidance.

# Limitations and considerations

### Analysis produced under urgency

- We have had limited time to design, run and analyse the results of these simulations. This report is not a comprehensive study, but advice given to inform decision-makers in real-time.

### Potential interaction effects between interventions modelled

- The heuristics presented above attempt to capture some estimate of effect sizes due to policy changes across a range of background transmission settings (baseline Rt). However, different policy changes will interact and will have different consequences in different contexts. The above numbers should be treated as applying broadly rather than being a precise prediction for a specific scenario at a specific time.

### Some modelling caveats

- We assume daily testing of household contacts for ~6 days. This is because NZ data indicates that confirmed cases test positive a mean of ~2 days after symptom onset and the quarantine period for household contacts ends 8 days after symptom onset for the first case in the household, but can only begin when the first case tests positive

- As noted, the Community context effect on transmission reduction behaviour under CPF Orange has been modelled as different levels of transmission reduction in different contexts. The change to *Community context = CPF Off* has been modelled as though the transmission reductions of *Community context = CPF Orange* disappear overnight. For example a 20% reduction in close contact transmission outside the home switches to no reduction (i.e. a 25% increase in close contact transmission outside the home).

# References

[1] Harvey, E. et al. (2023) *Estimating the effect of changes in case isolation on the effective reproduction number of COVID-19 in Aotearoa: September 2022*, https://covid19modelling.blogs.auckland.ac.nz/estimating-the-effect-of-changes-in-case-isolation/

[2] Harvey, E. et al. (2023) *Addendum: Assumption of perfect case isolation within the home when estimating the effect of a change in case isolation policy*, https://covid19modelling.blogs.auckland.ac.nz/addendum-assumption-of-perfect-case-isolation-within-the-home/

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[5] Wall, T. (2022) *Covid: one in 10 in England told to work despite signs of infection* theguardian.com, https://www.theguardian.com/world/2022/jul/09/covid-one-in-10-in-england-told-to-work-despite-signs-of-infection, retrieved 9 August 2022.

[6] Cori, A. et al. (2013) *A New Framework and Software to Estimate Time-Varying Reproduction Numbers During Epidemics*, American Journal of Epidemiology, Volume 178, Issue 9, Pages 1505–1512, https://doi.org/10.1093/aje/kwt133

[7] Vattiatio, G et al. (2022) *Modelling the dynamics of infection, waning of immunity and re- infection with the Omicron variant of SARS-CoV-2 in Aotearoa New Zealand*, https://www.covid19modelling.ac.nz/waning-of-immunity-and-re-infection-with-omicron/

[8] Gostic, KM. et al. (2020) *Practical considerations for measuring the effective reproductive number, Rt*. PLoS Comput Biol 16(12): e1008409. https://doi.org/10.1371/journal.pcbi.1008409pmid:33301457

# Appendix A: Calculation and interpretation of Rt estimates and important limitations

The effective reproduction number of a disease, Rt, *"is the average number of secondary cases that each infected individual would infect if the conditions remained as they were at time t."* [6].

This is an easy to understand metric to describe the likely near-term future transmission of infection at a point in time, as well as provide feedback on how effective interventions have been to reduce the transmissibility of the disease in the measured population (from looking at how Rt changed after these measures were introduced).

The Rt estimate values in this report are calculated using the estimate_R function of the EpiEstim package developed by Cori et al. [6]. This function requires the following inputs:

**New infection timeseries**

For each of the 54 scenarios modelled, we ran 10 realisations. We then calculated the pointwise/daily median time series of new infections for each scenario. This median time series was used as the new infection time series input into the estimate_R function.

**Serial interval distribution**

The estimate_R function developed by Cori et al. [6] requires as an input the distribution of the serial interval of infection (the time between a parent case first experiencing symptoms and a child case first experiencing symptoms).

We approximated this by constructing a discrete probability distribution of the serial time being within t and t-1 days, using a continuous probability distribution of the generation time as in [7]. This is a Weibull distribution with a scale parameter of 3.7016, and a shape parameter of 2.826. These give a mean generation time of 3.3 days and a standard deviation of 1.3 days. The resulting serial interval discrete distribution is plotted in the figure below.

There are some limitations associated with this choice. For example there are issues with assuming the serial interval and generation interval are interchangeable. Gostic, KM et al. [8], discuss in more detail the issues with assuming the two have the same distribution. However for the purposes of a first approximation of the relative effect of a policy change, where there are a number of other unknowns, we consider these limitations acceptable.

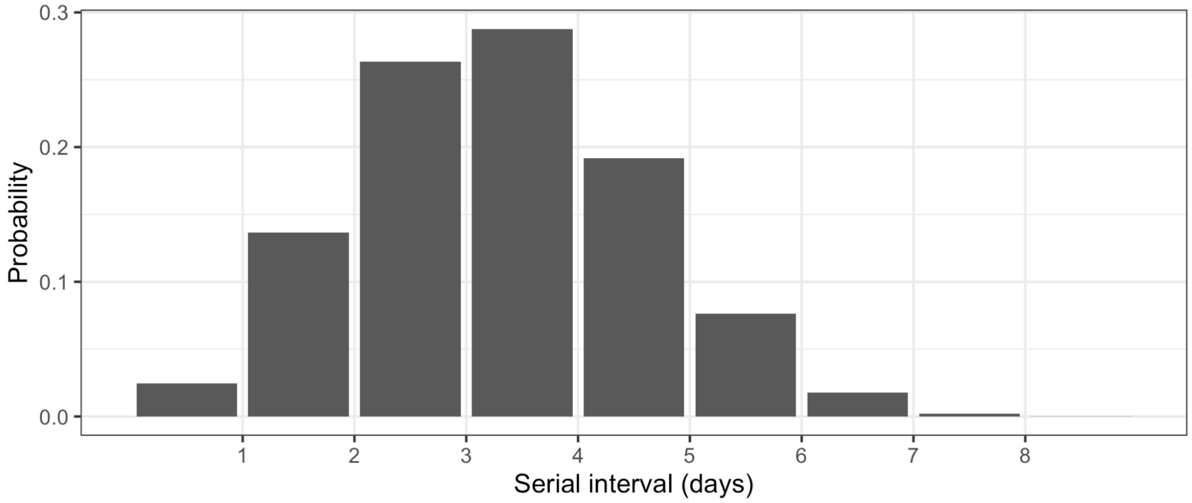

**Figure 5:** *Discrete probability distribution of serial interval length in days. The probability of the serial interval = 0 days is zero, the most likely length is 4 days.*