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Modelling support for the continued elimination strategy

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Executive Summary

- We model the effects on the risk of COVID-19 border reincursions of a wide variety of different border policies, including changes in managed isolation requirements for travellers as well as different testing regimes for frontline border workers.
- A more detailed modelling study and risk analysis of a specific policy change would be recommended before any implementation.
- One potential change in policy that could be considered is to replace the current requirement for 14 days in MIQ with 7 days in MIQ followed by 7 days in home isolation (including a second PCR test) for arrivals from countries with low prevalence of COVID-19 such as Australia.
- However, any increase in the number of arrivals from high-prevalence countries, for example due to an increase in MIQ capacity or repurposing of existing MIQ capacity, will lead to an increase in the risk of border reincursions.
- Weekly PCR testing of frontline border workers helps to ensure most border reincursions are detected before they grow too large. Supplementing this with an additional weekly rapid test would be an extra safeguard that decreases the risk of a large outbreak.

Abstract

We use modelling to investigate whether travellers arriving into New Zealand from countries with a low/medium COVID-19 prevalence could spend part of their quarantine period at home, rather than the full 14 days in managed facilities. We use a quarantine facility model of COVID-19 transmission and testing to compare the risk of releasing infectious travellers under varying combinations of mandatory quarantine (in managed isolation and at home) and testing schedules. A stochastic branching process model of COVID-19 transmission and testing is then used to estimate the risk of community outbreaks being seeded in frontline workers in comparison to a case seeded in a general member of the public and estimate the likely size of an outbreak at the time of detection. Finally, we use the model to investigate the length of time at different Alert Levels that would be needed to bring outbreaks of different sizes under control.

Introduction

Aotearoa New Zealand has successfully pursued a strategy of eliminating community transmission of COVID-19 (Baker et al. 2020, Wilson et al. 2020a). The maintenance of Aotearoa New Zealand's COVID-19 free status is currently reliant on stringent border controls, effective quarantine of arrivals from overseas and compulsory testing to minimize the risk of seeding new community outbreaks (Steyn et al. 2020a). Despite having one of the strictest surveillance systems in place globally to manage the risk of importing cases from overseas, Aotearoa New Zealand has experienced a number of cross-border incursions that are cause for concern: eight re-incursions have been reported since August 1st 2020, including a large Auckland outbreak (Wilson et al 2020b) and it is highly likely that there have been more undetected re-incursions (Steyn et al. 2020b).

MIQ facilities pose a risk of seeding community outbreaks through two main routes of infection (Steyn et al. 2020a). Firstly, there are risks associated with international travellers themselves. A traveller could catch the virus during their stay in a MIQ facility and leave the facility while still infectious and undetected, providing opportunity for onward transmission in the community. A smaller risk is that an infectious traveller could present an unusually long virus incubation period and leave a quarantine facility while still infectious and undetected. Well-managed 14-day quarantine, with minimal contact between travellers outside family groups, and tests on day 3 and day 12 provide a very good safeguard against infected travellers initiating community outbreaks (Steyn et al. 2020a). Secondly, there is also a risk that a frontline worker, for example someone working in a MIQ facility, airport or port, could become infected via a contact with an international traveller or via environmental transmission, inadvertently seeding a community outbreak. This risk can be significantly reduced by scheduled weekly testing of all frontline workers combined with symptom checks by trained professionals (Steyn et al. 2020a).

Reducing the length of stay in MIQ facilities for travellers arriving from low COVID-19 incidence countries and/or allowing some of the isolation period to be completed at home (with appropriate safeguards such as compulsory testing and use of digital technologies to ensure adherence, Wilson et al. 2020b) pose a new set of risks. The risk of a non-infected traveller acquiring the virus in home quarantine is much smaller because there is no risk of mixing with other infected travellers outside a family group. However, the risk of an infected traveller transmitting the virus to a member of the general public while isolating at home is much higher than while isolating in a MIQ facility. In home quarantine, contacts of an infected person may include household members and members of the general public (e.g. via casual contact at supermarkets or while accessing other essential services). Members of the general public are likely to have a lower awareness of symptoms and take longer to get tested than frontline workers, increasing the risk of onward transmission in the wider community.

This report is structured around the three pillars of the elimination strategy to provide modelling support for refining and improving the Elimination Strategy from a public health perspective. In the "Keep it out" section, we investigate the effect of different border and MIQ policies, for example what would happen if travellers arriving from countries with a low/medium COVID-19 prevalence could spend part of their quarantine period at home. We used a quarantine facility model (Steyn et al. 2020a) of COVID-19 transmission and testing to compare the risk of releasing infectious travellers under varying combinations of mandatory quarantine (in MIQ and at home) and testing schedules. In the "Prepare for

it" section, we use a branching process model (Plank et al. 2020) of COVID-19 transmission and testing to estimate the risk of community outbreaks being seeded in frontline workers in comparison to a case seeded in a general member of the public and estimate the likely size of an outbreak at the time of detection. We compare different frontline worker testing regimes and community scenarios. In the "Stamp it out" section, we use the model to investigate the length of time at different Alert Levels that would be needed to bring outbreaks of different sizes under control.

Keep it out

There are two key routes for a COVID-19 reincursion into New Zealand. An infected arrival could pass through border control measures while still infectious without being detected or a frontline worker could become infected. With minimal border control, for example, testing on arrival with not mandatory quarantine, most reincursions would be initiated by infected arrivals. With stricter measures, such as those currently in place, frontline workers are actually the predominant source of reincursions. Under our current border measures, 14 days of managed isolation, we have had one detected reincursion due to a traveller leaving quarantine whilst still infectious, six detected reincursions due to infected frontline workers, and one reincursion (the Auckland August outbreak) with unknown source (see Table A1). Most reincursions initiated in frontline workers are likely to be small, as regular testing means they will typically be spotted quickly. Reincursions initiated by arrivals, however, are not as likely to be spotted quickly and hence more likely to lead to large outbreaks.

We estimate the risk of a reincursion from both these sources under different border policies relative to the risk under the current 14-day MIQ. We combine these risks to estimate the proportion of reincursions initiated by each source. Reincursions are grouped by the infection generation of the individual in which they were first detected. Reincursions detected in generation 1, i.e. the frontline worker or released infected traveller, are likely to have generated few additional infected individuals. Reincursions detected in generation 2 or later are more likely to have generated larger numbers of cases, as the virus has been circulating in the community for longer. Results are given first as the number of expected reincursions per 1000 infected travellers, and secondly as the number of expected reincursions per month at the current rate of infected arrivals. The latter is a product of travel volume and overseas prevalence of COVID-19 and may be affected by other variables.

Risk of an infectious traveller entering the community

For the risk posed by infected international arrivals entering the community, we model testing, isolation and transmission of COVID-19 within MIQ facilities to estimate the probability of an undetected infectious traveller entering the community after completing quarantine requirements. We consider 4 different border policies:

- Baseline: 14-day stay in MIQ, tests at day 3 and 12
- 7 day stay in MIQ plus 7 days home isolation, tests at day 5 and 12
- 7 day stay in MIQ, test at day 5
- Test on arrival (quarantine/self-isolation free travel)
- Open borders, no testing, no quarantine.

We use a quarantine facility model (Steyn et al 2020a) to estimate the probability of an undetected case leaving quarantine while still infectious. Simulations are initiated with a single seed case, representing an infected international arrival entering a quarantine facility. We use a small effective reproduction number $R_0 = 0.1$ to model limited opportunities for contacts among individuals within an MIQ facility. Individuals that are infected during their stay in quarantine could be at any point in their stay. Tests have a sensitivity which depends on time since infection and derived from a linear interpolation of the false negative rates reported in Kucirka et al. (2020). All international arrivals undergo scheduled tests with symptom checks, which we assume reduces the false negative rate after symptom onset. We assume that all cases that are detected in quarantine or in self-isolation are completely isolated and not released until fully recovered.

As an example, we predict that for every 1000 infected travellers arriving at the border, an 80 additional travellers would be infected within MIQ facilities. There would be 869 positive tests and 211 infected people would leave without testing positive, though many of these may be no longer infectious.

Risk of a frontline worker being infected

Since early August, approximately 270 infected individuals have been detected in MIQ facilities. Excluding the port worker, which is related to freight rather than international travellers, five small reincursions have been started by a frontline border worker being infected through environmental transmission, contact with people who had not at that point tested positive, or the source is unknown. So the rate of reincursions from frontline workers detected at generation 1 is approximately 18 per 1000 infected travellers under the current 14-day MIQ system (see Table A1). We assume that 50% of the risk posed to frontline workers occurs during an infected traveller's arrival into New Zealand and transfer to MIQ, i.e. contacts that occur at the airport, transport to MIQ, check-in procedures at the facility, etc. The remainder of the risk is spread evenly over the 14-day stay and is proportional to length of stay. All border workers have weekly PCR tests with symptom checks. Under this assumption, decreasing the quarantine period to 7 days reduces risk to frontline workers to 75%, i.e. the number of reincursions detected at generation 1 would fall to approximately 14 per 1000 infected arrivals. If an arrival does not undergo any quarantine but is tested on arrival, the risk to frontline workers is assumed to be reduced to 10%, representing the still-present risk to nurses administering the test, airport and customs staff, etc. If there are no border control measures, we assume the risk to frontline workers drops to 2%. This represents the ongoing risk for cabin crew, airport workers and similar.

Risk of a case being detected in the community

Once an infected person, either an arrival or a frontline worker, has entered the community we use the community spread model (James et al., 2020) to estimate the number of infected individuals when the first case is detected. Frontline workers are tested weekly with accompanying symptom checks to reduce the false negative rate of clinical cases. In addition to the weekly scheduled tests, testing is also triggered by onset of symptoms, with a short delay from onset to testing (average 2 days), representing increased awareness of Covid-like symptoms. In the 7 day MIQ plus 7 day home isolation scenario, arrivals are tested on day 5 of their home isolation with symptom checks to reduce the false negative rate. Home isolation is assumed to be partially effective at preventing onward transmission of the virus: individuals in home isolation have a transmission rate that is 50% of individuals in the wider community. All international arrivals have an increased awareness of symptoms and therefore have a short delay from symptom onset to testing (average 2 days) during home isolation and after entering the community. The general public have a lower probability (30%) of being tested following development of symptoms, and those that do get tested have a longer delay from symptom onset to testing (average 6 days). An infected individual who is in the community for their full infectious period is assumed to cause, on average, 2.5 secondary cases (i.e. $R_0 = 2.5$). Subclinical members of the general public do not get tested.

In the 3.5 months since 1st August, approximately 270 cases of COVID-19 have been detected in international travellers. Using the MIQ model, we estimate that 325 individuals with COVID-19 have arrived in New Zealand. These travellers have initiated 5 reincursions in frontline workers (we exclude the August outbreak as it was initiated before August 1st and its origin is unknown, and we exclude the Jet Park nurse case as this was caused by exposure to an individual infected during the August outbreak rather than an international arrival) and one reincursion initiated by an international arrival. These were all detected in generation 1. With our current MIQ arrangements and volume and profile of travellers the model predicts 1.9 generation 1 reincursions per month (approximately 75% through frontline workers) and one generation 2+ reincursion every 2-3 months (approximately 20% through frontline workers), which is in agreement with Steyn (2020).

Results

A comparison of the different border policies is shown in Table 1. Reducing the stay in MIQ to 7 days, whether or not this is followed by 7 days home isolation, slightly reduces the rate of reincursions detected at generation 2 or more. Both-7 day MIQ scenarios result in more detections at generation 1,

noting that a case detected during the home isolation period is counted here as a reincursion detected at generation 1. For 7-day MIQ with no home isolation or subsequent testing, a large number of reincursions go undetected, as the majority of these do not generate further cases, but there is a two-fold increase in the frequency of reincursions detected at generation 2 or more.

Scenario	Reincursions detected at gen 1				Reincursions detected at gen 2+			
	Per 1,000 infected travellers			Per month**	Per 1,000 infected travellers			Per month**
	Arrivals	Staff	Total	Total	Arrivals	Staff	Total	Total
14 day MIQ	4.2	15.7	19.9	1.9	2.5	0.68	3.2	0.3
7 day MIQ + 7 day home isol	113.1* (incl day 12 +ves)	11.8	124.9	12.1	1.3	0.51	1.8	0.2
7 day MIQ	24.5	11.8	36.3	3.5	5.3	0.51	5.9	0.6
Test on arrival	91.8	1.6	93.3	9.1	42.5	0.07	42.6	4.1
No testing or MIQ	493.0	0.3	493.3	47.9	77.5	0.01	77.5	7.5

Table 1: Reincursion rates under different border control measures. *Includes travellers testing positive in home isolation on day 12 after arrival, **assumes current rate of infected arrivals. These rates will change slightly with different community scenarios (see Table A2 spreadsheet).

Example scenario - Trans-Tasman travel bubble

In the last 6 months (1st June to 30th October 2020), approximately 31% of arrivals into New Zealand were from Australia (16224 out of 52889). The prevalence of COVID-19 in Australia over this period was estimated at 12 cases per 100,000 (5 cases per 100,000 in the last month), although this average masks significant spatial and temporal variations. The prevalence of COVID-19 in recent arrivals from Australia to New Zealand was 6 cases per 100,000 (1 case out of 16224 travellers), accounting for only 0.38% of all cases arriving (1 out 262 cases). Allowing Australian travellers to enter with no MIQ, home isolation or testing requirements would give an estimated 3 reincursions detected at generation 1 and 0.5 reincursions detected at generation 2 or later per 100,000 travellers.

Allowing quarantine-free travel with Australia would free up 31% of beds in MIQ for travellers from other countries, most of which have a higher prevalence of COVID-19 than Australia. If this capacity were filled by additional arrivals from countries following the current profile, this would increase the number of infected arrivals by 45% from 495 per 100,000 arrivals to approximately 717 infected individuals per 100,000 arrivals. We assume this gives a corresponding 45% increase in risk from MIQ resulting in 2.8 generation 1 and 0.45 generation 2+ reincursions per month (assuming current MIQ capacity).

If trans-Tasman travel remained at the current level of approximately 1,000 arrivals per month, the total expected number of generation 1 reincursions would be 2.8 per month and 0.5 generation 2 or later reincursions per month. Approximately 1% of these would be from Australian arrivals, the remainder would be from the increased MIQ risk.

If trans-Tasman travel returned to pre-COVID levels of 44,000 Australian arrivals per month, we would expect the number of generation 1 reincursions per month to increase to 4.1 and the number of generation 2 or later reincursions per month to increase to 0.7. Approximately 30% would be caused

by arrivals from Australia. This number would increase further when travel by New Zealanders to and from Australia was included.

Table 2 also shows results for allowing arrivals from Australia to enter the country with a 7-day stay in MIQ and using the spare MIQ capacity for either more Australians or travellers from other countries

Scenario	Monthly reincursions detected at generation 1	Monthly reincursions detected at generation 2+
Current MIQ	1.93	0.3
Trans-Tasman bubble (1000 arrivals per month), spare MIQ capacity used for other countries	2.79	0.45
Trans-Tasman bubble (44,000 arrivals per month), spare MIQ capacity used for other countries	4.12	0.66
Australia 7-day MIQ (spare MIQ capacity Aus only)	1.93	0.31
Australia 7-day MIQ (spare MIQ capacity current profile)	2.28	0.37

Table 2: Monthly recursion rates for a range of different MIQ scenarios. Rates include changes due to the new scenario and any knock-on effects on the existing risk from MIQ.

Prepare for it

Reincursions that are detected at the first generation i.e. in a frontline worker or an international arrival released from MIQ, are very likely to be small provided frontline workers are tested frequently. Reincursions detected at generation 2 or later are likely to be much larger. We use the branching process model to predict the expected size of a reincursion under different community scenarios. The size at detection is the total number of infectious individuals (clinical and subclinical) when the first case is detected.

The probability of a reincursion being detected at generation 1 or later (Table 3) also changes with the behaviour of the community, though these changes are small. Table A2 (excel spreadsheet) shows the arrival risks of Table 3 for each of the different community scenarios. We consider the following scenarios all assuming a 14-day stay in MIQ:

- Baseline: $R_0 = 2.5$, 3 days on average from symptom onset to testing, PCR testing, probability of case detection in the general public $p_{detect} = 30\%$.
- Frontline workers get a weekly PCR test and an additional weekly rapid test (with 50% of the sensitivity of PCR).
- Frontline workers get a rapid test (with 50% of the sensitivity of PCR) twice weekly.
- Reduced $R_0 = 2$
- Increased detection in general public $p_{detect} = 50\%$
- Fast testing. General public tested 3 days after symptom onset on average.
- Combination $R_0 = 2.2$, $p_{detect} = 40\%$, fast testing.

Here $R_0$is the expected number of secondary infections. It does not include any effects of contact tracing or self isolation as the model is simulating the period prior to detection of the first case when there is no contact tracing.

Probability of generation 1 reincursions with N infected individuals at time of detection						
Scenario	N=1	N = 2-10	N = 11-20	N = 21-50	N = 51-100	N>100
Baseline	67%	30%	3%	1%	0%	0%
Alternate PCR and rapid test (twice weekly)	81%	18%	1%	0%	0%	0%
Rapid tests (twice weekly)	67%	30%	2%	1%	0%	0%
Reduced R_0	72%	25%	1%	1%	1%	0%
Increased detection	67%	30%	2%	1%	0%	0%
Faster testing	66%	31%	3%	1%	0%	0%
Combination	67%	29%	3%	0%	0%	0%
Probability of generation 2+ reincursions with N infected individuals at time of detection						
Scenario	N=1	N = 2-10	N = 11-20	N = 21-50	N = 51-100	N>100
Baseline	0%	32%	18%	31%	19%	1%
Alternate PCR and rapid testing (twice weekly)	0%	30%	17%	33%	19%	0%
Rapid tests twice weekly	0%	34%	17%	29%	20%	0%
Reduced R_0	0%	50%	20%	18%	10%	3%
Increased detection	0%	52%	15%	18%	13%	2%
Faster testing	0%	43%	24%	15%	17%	1%
Combination	0%	50%	17%	24%	7%	1%

Table 3: Distribution of number of infected individuals at time of detection for reincursions detected in generation 1 (frontline worker or international traveller) and for reincursions detected in generation 2 or later, for a range of frontline worker testing regimes and community scenarios. All scenarios assume 14-day stay in MIQ; changing the border policy has only a small effect on these results (see Table A2).

Stamp it out

To predict the time needed to eliminate an outbreak with N infected individuals when the first case is detected, we use the single-seed outbreak model of James (2020). To investigate the consequences of different sized outbreaks, we run the model with case detection suppressed until N individuals (clinical and subclinical) have been infected. When the first case is detected, the Alert Level is raised and community testing rates and transmission rates change accordingly. The model outputs are relatively insensitive to the transmission parameters before the outbreak is detected. When the first case is detected, we assign reporting dates to all infected individuals; any individuals that would have reported before this date are re-assigned a reporting date randomly over the next four days to represent for the backlog of case reporting after the first positive case is discovered. The key model input is the expected number of secondary cases caused by a case R_0 during the high alert level, without case isolation or contact tracing. During the Auckland August outbreak the best estimate of R_0 under alert level 3 was 0.75. During alert level 3, we also assume fast onset to testing (3 days), high case detection rate (90% for clinical individuals and 50% for subclinical individuals), and low superspreading rate ($k = 0.7$). We assume that Alert level 3 continues for at least 5 days and until 15 cases or less have been reported over a 5 day period. This triggers a switch to Alert Level 2.5 with $R_0 = 0.75$ to reflect the more effective contact tracing despite higher transmission rates. As this is still less than 1, the outbreak will continue to decline and will eventually be eliminated. Note that this value for R_0 under Alert Level 2.5 represents the use of Alert level 2.5 towards the end of an outbreak, when cases are declining and contact tracing is enabling most cases to be quarantined early. Using Alert Level 2.5 at the beginning of an outbreak would likely not be as effective and would lead to a higher value of R_0. Alert Level 2.5 continues until 7 days after the final case has been isolated. We record the number of days spent at each alert level and the associated cost and size of the outbreak (reported cases only) with mean and IQR for each output.

We test a number of scenarios for transmission during the high alert level period corresponding approximately to a range of contact tracing measures and alert levels, each of which are modelled via the estimated reduction in R_{Eff} found by Plank (2020). In all scenarios, Alert Level 2.5 (with a reproduction number of $R_0 = 0.75$) was used at the end of the high alert level period.

- Transmission similar to Alert level 3 of the August outbreak with manual contact tracing only $R_0 = 0.75$
- Transmission similar to Alert level 3 with manual contact tracing plus 80% uptake of QR codes - 5% reduction to $R_0 = 0.71$
- Transmission similar to Alert level 3 with manual contact tracing plus 80% uptake of a bluetooth contact tracing app - 25% reduction to $R_0 = 0.63$
- Transmission rates similar to Alert Level 4 (March/April) $R_0 = 0.5$
- Transmission rates similar to a very optimistic Alert Level 2.5 $R_0 = 1$. Although this is higher transmission than expected in AL2.5 at the end of an outbreak we believe it is highly optimistic for AL2.5 at the start of an outbreak.

Costs for each level are those given in James (2020) and we assume costs for Alert Level 2 and 2.5 are the same. In the final two scenarios, the cost of the high alert level period is different from the first three scenarios.

		Size of outbreak when first detected				
		30	40	50	75	100
$R_0 = 0.75$ Manual	Days at L3 Days at L2.5	5 (5, 5) 42 (31, 49)	6 (5, 5) 41 (31, 47)	9 (5, 10) 41 (32, 50)	23 (21, 27) 28 (20, 34)	27 (24, 30) 28 (19, 35)

tracing only	Cost $bn Size	1.9 (1.6, 2.1) 66 (45, 82)	1.9 (1.6, 2.1) 83 (63, 98)	2.1 (1.8, 2.4) 100 (78, 118)	2.5 (2.2, 2.7) 147 (123,169)	2.8 (2.4, 3.1) 191 (157, 218)
$R_0 = 0.71$ Manual + QR codes	Days at L3 Days at L2.5 Cost $bn Size	5.1 (5, 5) 39 (30, 43) 1.8 (1.6, 1.9) 57 (39, 67)	5.9 (5, 5) 41 (32, 48) 1.9 (1.6, 2.1) 76 (56, 92)	9 (5, 10) 38 (29, 47) 2.0 (1.7, 2.3) 93 (70, 110)	20 (18, 25) 30 (20, 38) 2.4 (2.1, 2.6) 130 (106, 147)	25 (23, 27) 27 (19, 32) 2.6 (2.3, 2.8) 168 (142, 190)
$R_0 = 0.63$ Manual + bluetooth	Days at L3 Days at L2.5 Cost $bn Size	5.1 (5, 5) 37 (27, 43) 1.7 (1.5, 1.9) 52 (37, 64)	5.5 (5, 5) 40 (31, 46) 1.9 (1.6, 2.0) 68 (52, 79)	8 (5, 8) 37 (28, 44) 1.9 (1.6, 2.1) 80 (64, 92)	19 (18, 23) 26 (17, 34) 2.2 (2.0, 2.4) 113 (95, 130)	24 (22, 26) 26 (17, 30) 2.5 (2.2, 2.7) 152 (127, 175)
$R_0 = 0.5$ AL4	Days at L4 Days at L2.5 Cost $bn Size	5.1 (5, 5) 34 (26, 41) 1.9 (1.6, 2.1) 45 (34, 54)	5.4 (5, 5) 35 (28, 41) 1.9 (1.7, 2.1) 56 (43, 65)	8 (5, 10) 35 (26, 41) 2.2 (1.9, 2.5) 73 (57, 84)	17 (16, 20) 26 (17, 32) 2.8 (2.5, 3.0) 97 (83, 102)	21 (19, 23) 21 (15, 23) 3.0 (2.8, 3.2) 125 (110, 141)
$R_0 = 1$ Optimistic AL2.5	Days at L2.5* Days at L2.5 Cost $bn Size	5.1 (5, 5) 44 (34, 52) 1.8 (1.5, 2.0) 83 (58, 101)	6.1 (5, 5) 46 (36, 53) 1.9 (1.6, 2.1) 109 (76,134)	15 (5, 24) 47 (35, 57) 2.2 (1.8, 2.4) 158 (104,187)	34 (27, 42) 37 (25, 45) 2.4 (2.1, 2.7) 252 (174,303)	43 (35, 51) 34 (26, 42) 2.6 (2.3, 2.9) 365 (264, 431)

Table 4: Size and cost of reincursions detected at generation 2 or later for a range of sizes at first detection and contact tracing measures. Size at first detection includes all infected individuals (clinical and subclinical). Total outbreak size is reported cases only. Costs are in $NZ billion. Mean (interquartile range) over 200 simulations given for each result. *Days at level 2.5 until 15 cases reached.

Table 4 shows the length of time needed at each Alert Level, the total cost of controlling the outbreak, and the overall outbreak size in each scenario, depending on the size of the incursion when it was detected and the Alert Level was first raised. The different scenarios are modelled via differences in the effective reproduction number. These are modelling estimates of the effect of different Alert Levels and contact tracing effectiveness, but there is considerable uncertainty in the exact effect these have on R_0.

Discussion

We have used a model of COVID-19 transmission to investigate the effect of different border policies for international arrivals to New Zealand, different testing regimes for frontline border workers, and different responses to emergent community outbreaks. This approach allows the risk of border reincursions occurring through different routes, and the cost of controlling them, to be evaluated. One option that could be considered is to replace the current requirement for 14 days in MIQ with 7 days in MIQ followed by 7 days in home isolation (including a second PCR test), especially for arrivals from countries with low prevalence of COVID-19 such as Australia. However it is important to note that we have carried out a broad comparison of different policy settings; before any implementation is considered, we recommend that a more detailed modelling study of a specific policy change should be carried out. It is also important to consider the consequences of utilising any managed isolation and quarantine capacity that is freed-up by policy changes for travellers from high-risk countries.

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Appendix

Reincursion	Date	Type	Infection source	Outbreak size
Auckland Aug cluster	11th Aug	Unknown. Assumed frontline worker	Unknown	180
Rydges worker	16th Aug	Frontline worker	MIQ environmental transmission (lift)	1
Jet Park nurse	13th Sept	Frontline worker	Known infected person (Auckland cluster)	1
International arrival	19th Sept	Infected arrival	MIQ environmental transmission (rubbish bin)	3
Port worker	17th Oct	Frontline worker	Contact with international ship crew	4

Chch Sudima 1	2nd Nov	Frontline worker	Unknown	1
Chch Sudima 2	3rd Nov	Frontline worker	Unknown	1
Defence Force	4th Nov	Frontline worker	Unknown	6

Table A1: Known reincursions of COVID-19 during the period Aug 11th - October 31st