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Economic comparison of the use of Alert Levels 3 and 4 in eliminating the Auckland August outbreak: a cost-effectiveness analysis

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Alex James[1,2], Rachelle N. Binny[2,4], Shaun C. Hendy[3,4], Audrey Lustig[2,4], Nicholas Steyn[1,3,4], Michael J. Plank[1,4]

1. School of Mathematics and Statistics University of Canterbury, New Zealand.
2. Manaaki Whenua, Lincoln, New Zealand.
3. Department of Physics, University of Auckland, New Zealand.
4. Te Pūnaha Matatini: the Centre for Complex Systems and Networks, New Zealand.

Executive Summary

- We compare the economic costs of containing the Auckland August outbreak of COVID-19 using Alert Level 3 to those that might have been incurred from the use of Alert Level 4.

- We estimate the effectiveness of Alert Level 3 using data from the actual August outbreak. The effectiveness of a putative regional Alert Level 4 is less certain, but we consider an optimistic estimate based on what was achieved in the March-April outbreak, as well as a more pessimistic estimate, which reflects the higher transmission rates observed in August.

- We use a decision-making model for de-escalation of alert levels based on observations of weekly case numbers, which is a simpler decision-making criterion to that used in New Zealand and likely underestimates the duration of Alert Level 4 periods that would be used in practise.

- To achieve the same likelihood of elimination, we find that both the optimistic and pessimistic Alert Level 4 period has a shorter duration than the period needed at Level 3.

- To achieve the same likelihood of elimination, the optimistic Alert Level 4 controls have a lower economic cost than the Alert Level 3 controls.

- To achieve the same likelihood of elimination, the pessimistic Alert Level 4 controls come at a comparable economic cost to the Alert Level 3 controls.

- This analysis does not take into account the longer term economic costs of these measures, nor does it consider social, or health impacts that might differ between strategies.

Abstract

We consider the economic costs of the different alert level options in controlling the Auckland August outbreak. We use a branching process model of disease transmission, which can model the effects of the alert levels on disease dynamics, together with daily cost estimates for each level. With a strong criterion for relaxing alert levels, i.e. very few cases in the days immediately before lowering the level, the time spent at a more restrictive alert level will be longer, but the probability of the outbreak being eliminated is very high. With weaker criteria for relaxation, the time spent at the more restrictive alert level will be much shorter, while the chance of a recurrence is much higher. Furthermore, the reduced activity that is allowed at higher alert levels is more effective at reducing transmissions and brings infection rates under control more quickly. In achieving the same likelihood of elimination, we find that a highly effective and stringent alert level is needed for a shorter duration that comes at a lower economic cost. On the other hand, if the more stringent alert level is less effective, then it comes with a comparable economic cost to achieve a given outcome to the more moderate alert level that was used in the Auckland August cluster.

Introduction

On 11 August 2020, after Aotearoa New Zealand had gone 102 days without the detection of community cases of COVID-19, a South Auckland resident was diagnosed with the disease, having developed symptoms five days earlier. As this case had no known links to the border, its discovery indicated that there was a potentially large outbreak in progress and there had been undetected community transmission occurring possibly for almost two weeks. From August 12 through to August 30, Auckland was subject to a regional Alert Level 3 restriction, while the rest of the country was subject to Level 2. Travel into and out of the Auckland region was restricted. By the end of September, the resulting 'Auckland August' cluster was largely contained, having grown to involve a further 178 cases that were either epidemiologically or phylogenetically linked to the August 11 index case.

The New Zealand Alert Level system for COVID-19 responses was established in March 2020 at the start of the initial outbreak. The control measures available range from Level 1, which is essentially "business as usual" domestically, with strong restrictions at the border that allow only citizens and residents to enter the country, and even then after a 14 day government stay in managed isolation facilities. Under the Oxford COVID-19 Government Response Tracker, New Zealand's Alert Level 1 scores just 22% on the stringency index, which are among the most relaxed restrictions in the world (Hale 2020). New Zealand's Alert Level 4 lies at the other end of the spectrum. The Oxford Tracker has rated this at over 96%, making it one of the most stringent set of measures in the world. At Alert Level 4 only essential businesses, such as supermarkets and hospitals, remain open while all hospitality premises, schools and other businesses are closed. There is no mixing permitted between households, and any exercise must be undertaken locally. At Alert Level 3, rated at 70-80% stringency, more businesses are open but they must operate in a fully contactless manner, while schools remain closed apart from children of essential workers and hospitality premises remain closed.

The more targeted approach taken by the government in August is in contrast to the March-April outbreak, where all of New Zealand was placed under Alert Level 4 restrictions from March 25 to April 27. This reflects the relatively contained nature of the August cluster to within the Auckland region, which likely resulted from a single seed case, while the March-April outbreak was seeded multiple times by international travellers returning to many parts of the country. The decision to impose Alert Level 3 rather than Level 4 may also have been informed by the difficulties in maintaining differential restrictions across Auckland territorial boundaries. Nonetheless, the regional Alert Level 3 restrictions, though less stringent than March-April's Alert Level 4, proved highly effective in containing this new outbreak.

Indeed, the two Alert Levels impose quite different economic and social costs, but also have different effects on the COVID-19 transmission rate. More severe restrictions may have led to a faster containment and elimination of the 'Auckland August' cluster, which, although coming with a higher daily economic cost, may have led to lower costs overall, if the duration needed at Level 4 was substantially less than the duration needed at Level 3 to achieve the same outcome. It is therefore worth considering whether Alert Level 4 may have had less severe costs overall than the Level 3 restrictions that were used in achieving the same result.

In this paper, we investigate the economic costs of the different Alert Level options in achieving the same outcomes. To do this we use the established branching process model of disease transmission for a single seed outbreak (James, 2020), which models the effects of the alert levels on disease dynamics exogenously. We have previously considered the effect of the timing of measures in controlling and eliminating New Zealand's March-April outbreak (Binny, 2020). Of the three counterfactual scenarios considered in that work, it was found that an earlier start to Alert Level 4 would have resulted in the greatest reduction in numbers of cases and deaths. However, we did not consider how the duration or strength of the Alert Level restrictions affected the outcome nor did we account for any economic losses. The work reported here is a first attempt to address these factors.

To do this we use a simple decision-making model for relaxing Alert Levels based on weekly detected case numbers. With a strong criterion for relaxing Alert Levels, i.e. very few cases in the days immediately before lowering the Level, the time spent at the higher alert level will be longer but the probability of the outbreak being eliminated is very high. With weaker criteria for relaxation, the time spent at the more restrictive Alert Level will be much shorter but the chance of a recurrence is much higher. Additionally, the time spent at a high Alert Level is also dictated by the how effectively transmissions are reduced. The reduced activity that is allowed at Alert Level 4 is more effective at reducing transmissions and brings infection rates under control more quickly than Alert Level 3.

The New Zealand Treasury has recently estimated the cost in loss of economic activity at each alert level (Treasury, 2020a). Alert level impacts were estimated at the industry level based on beliefs about firms' ability to operate under corresponding restrictions and then assessed in aggregate against other independent forecasts. The Alert Level 4 estimate was later benchmarked and revised using March quarter GDP data for the six days spent at this level in this quarter. Other high frequency indicators, including consumer spending, unemployment, job vacancies, traffic volumes, electricity generation, business outlook, and manufacturing activity were used to benchmark the estimates of economic losses at lower alert levels. Following the release of June quarter GDP data, which showed a smaller than forecast 12.2% decline, cost estimates across alert levels were revised down (Treasury, 2020b). It is important to emphasise that these losses are not uniformly distributed across the economy, especially when, as happened in the Auckland August outbreak, restrictions are applied at the regional level.

Nonetheless, Treasury's estimates can be used to investigate the cost-effectiveness of control measures in eliminating the virus. Using Treasury's early estimates, the New Zealand Productivity Commission attempted a cost-benefit analysis of the Alert Level 4 extension that occurred in April 2020 (Heatley, 2020). However, their calculation did not include the principal benefit of the extension: namely the enhanced likelihood of elimination that followed from the extension. Indeed, the economic benefits of elimination were likely considerable, with New Zealand enjoying three months of relatively relaxed restriction relative to the rest of the world following elimination of the March/April outbreak. Similarly, other attempts at cost-benefit analyses for New Zealand (e.g. (Lally, 2020)) also fail to include the benefits of elimination. At best, the cost-benefit analyses carried out for New Zealand's control measures might be useful for informing a mitigation strategy, but are not useful for a decision-maker considering or following an elimination strategy.

Our analysis here assumes that an elimination strategy has been adopted and then focusses on the most cost-effective approach to delivering on such a strategy. Importantly, the approach we use here can account for the relationship between the duration of control measures and the likelihood of elimination. This relationship was not accounted for in the Productivity Commission's analysis (Heatley, 2020), but as well be shown here, is key in determining the length of a lockdown. We do not attempt to consider the benefits of an elimination strategy in comparison to other strategies.

While the disease remains highly prevalent overseas at the time of writing, the prevention of further community transmission in New Zealand relies on preventing re-incursion of the disease through the country's border. This analysis assumes that incursions leading to a high alert level are relatively infrequent, in particular that the next re-incursion happens after elimination of the previous incursion has been fully confirmed with a long run of zero case days. Elimination in this context is for the particular outbreak being considered rather than of COVID-19 in general. The benefits of an elimination strategy compared to a mitigation or suppression strategy therefore depend on the effectiveness of border controls and surveillance, which are not modelled here. Nor do we deal with any distributional effects of the costs, i.e. how different groups are affected, which may differ significantly between Level 4 and the less restrictive Level 3. Nonetheless, this work provides an illustration of how the disease dynamics plays an important role in any cost analysis of controls for COVID-19.

Method

When an outbreak is first detected, the government is faced with a choice between raising the Alert Level to 3 or 4 i.e. imposing a lockdown of moderate or high stringency, respectively. The high stringency Alert Level 4 would be expected to reduce case numbers more rapidly, presumably leading to an earlier exit from lockdown to achieve the same outcome as moderate stringency measures. Here, we assume that the level is lowered when new cases detected over a five day period drop below a particular threshold. Upon exit from the higher alert level, we assume that moderate social distancing measures are left in place at Alert Level 2.

We use the single seed branching process model of James et al (James, 2020) starting from a single seed case and moderate superspreading ($k = 0.4$, (Lloyd-Smith, Schreiber, Kopp, & Getz, 2005) under Alert Level 1, with a long symptom onset to testing time (average 6 days) and a low probability of case detection ($p_{detect} = 0.1$). Without case isolation an infected individual will cause, on average, 3 secondary cases ($R_0 = 3$). This is intended to reflect the conditions that existed in early August in New Zealand, after more than three months with no detected community cases.

When the first case is detected, a higher alert level (either 3 or 4) is immediately imposed. Resulting transmission rates drop, the increased awareness of the disease combined with contact tracing measures both reduce the expected symptom onset to testing time to 3 days and increase the case detection rate ($p_{detect} = 0.9$), while gathering size restrictions make superspreading events less frequent ($k = 0.7$). The higher alert level runs for at least 5 days. The criterion for a drop to Alert Level 2 is set by the total number of cases reported in the last 5 days, N_5. When this threshold is met, the subsequent return to Alert Level 2 leads to increased transmission rates ($R_0 = 1.33$) but superspreading events remain rare ($k = 0.7$) reflecting retained limits on gathering sizes. Alert Level 2 continues until there are 14 days with no reported cases.

During the August outbreak, transmission rates under Level 3 were estimated using this single seed model to be approximately $R_0 = 0.75$, i.e. on average 0.75 secondary cases were caused, assuming no contact tracing or case isolation measures. Due to the multiple seed cases involved in the March-April outbreak, estimation of transmission reduction for Alert Level 4 is less certain, so we use $R_0 = 0.33$ as an optimistic estimate of the effects of Alert Level 4 and $R_0 = 0.5$ as a more pessimistic estimate. The optimistic estimate reflects what was seen in the March-April outbreak, albeit with multiple seeds and with restrictions imposed nationally. The pessimistic estimate reflects the higher transmission rates that were observed early in the August outbreak compared to those in March-April (James, 2020). A range of other values for R_0 under level 4 conditions were also tested from 0.2 to 0.7. The model behaves as expected, lower values of R_0 reach the case threshold more quickly and result in costs whereas higher values take longer.

Using 5000 simulation runs at each parameter combination the model generates i) the length of time spent at the high alert level before the case threshold is reached, ii) the probability the outbreak was eliminated, i.e. there were no more active cases exposed in the following two months, iii) the length of time spent at Level 2 given the outbreak was eliminated and iv) the expected size of the outbreak given it was eliminated. We use Treasury's estimates (Treasury, 2020b) for the associated relative loss of earnings in the Greater Auckland region at Alert Levels 2-4 to calculate the cost of lockdown for an associated probability of elimination: Alert Level 4: 30% of GDP, Alert Level 3: 18% of GDP, Alert Level 2: 9% of GDP (Table 1).

Restrictions	Cost (% GDP)	Cost/day (NZ$million)
AL 2	9%	29
AL 3	18%	57
AL 4	30%	94

Table 1: Lost economic activity in Auckland by Alert Level. This is measured in percent GDP and daily by dollar amount. For this calculation Auckland annual GDP is assumed to be $115 billion (Treasury, 2020b).

Results

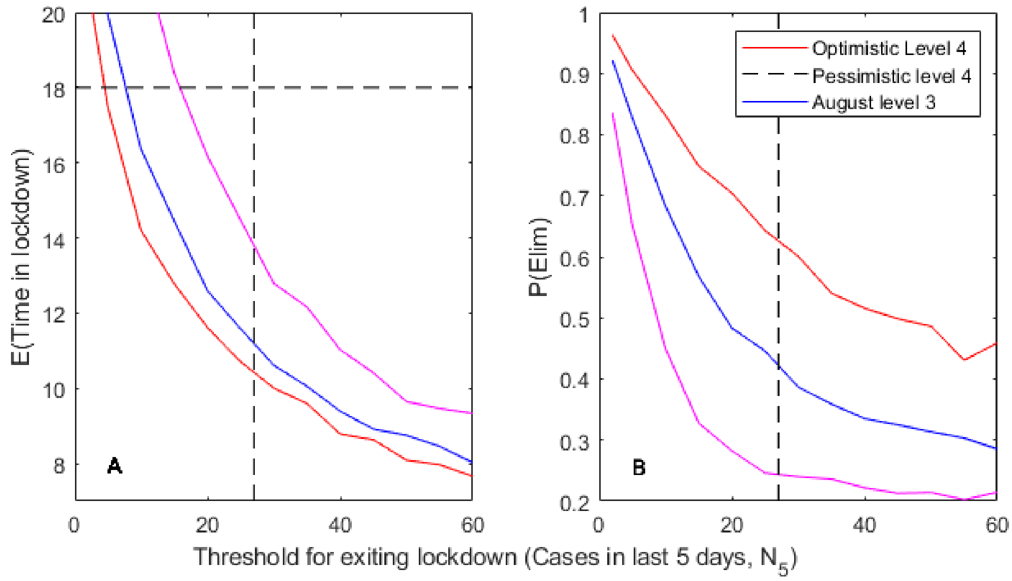

Figure 1: A stricter criterion for exiting lockdown results in a longer lockdown period, but a higher probability of elimination. The expected time spent in lockdown (A, left) and the probability of elimination (B, right) are shown as a function of the exit criteria, N_5. Three scenarios are considered: an optimistic Level 4 lockdown ($R_0 = 0.33$); a pessimistic Level 4 lockdown ($R_0 = 0.5$); and the Level 3 lockdown as observed in the August outbreak ($R_0 = 0.75$). Dashed lines show data from the August Auckland cluster (19 days in lockdown, 27 reported cases in the previous 5 days).

Figure 1A shows the effect of different criteria for lowering the alert level on the time spent in lockdown. During the August outbreak, Auckland moved out of Alert Level 3 after 19 days when there had been 27 new reported cases over the previous 5 days. The model predicts this would occur, on average, after 13 days with an interquartile range of 6 to 22 days. The probability of elimination is calculated as – given there is a move to alert level 2 when this criteria is reached what proportion of trajectories have no new exposed after two months. There may still be active cases but there is no further transmission from this point. Using the Auckland August data we see that in approximately 25% of simulations that move from level 3 to level 2 with 27 cases in the preceding 5 days the outbreak will be eliminated (Fig 1B). As the model uses an effective transmission rate above 1 for level 2 the remaining 75% of simulations would likely result in an exponentially growing number of cases that would need additional time at a higher alert level to control.

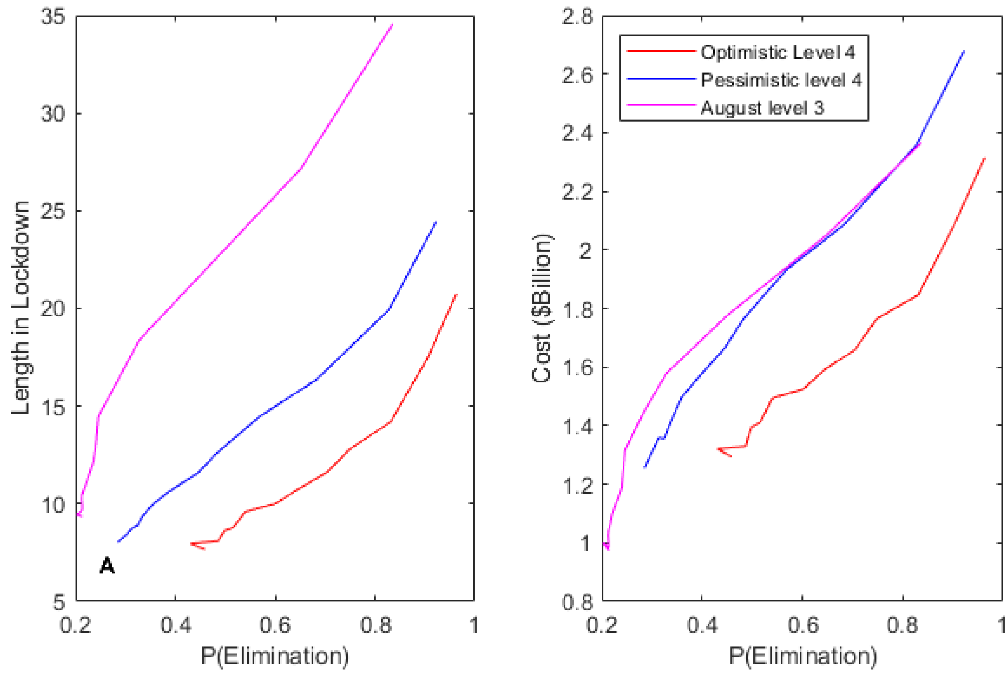

Figure 2: A higher alert level can achieve a higher probability of elimination with a shorter lockdown but may have a similar economic cost. The length of time spent in lockdown (A, left) and the cost of lockdown in lost economic activity in Auckland (B, right) to achieve a given probability of elimination for the optimistic Level 4 lockdown ($R_0 = 0.33$); the pessimistic Level 4 lockdown ($R_0 = 0.5$); and the Level 3 lockdown as observed in the August outbreak ($R_0 = 0.75$).

We compare the length of time needed in lockdown to achieve a given probability of elimination (Fig 2A). For example, to achieve a 50% probability of elimination the August Level 3 lockdown would have needed to last approximately 23 days (interquartile range 10-35 days), whereas an optimistic Level 4 lockdown could have achieved the same elimination probability after only 10 days and the pessimistic Level 4 lockdown only 15 days. Figure 2B shows the economic cost of the outbreak for a particular probability of elimination in the cases where the elimination was successful. For example if the higher Alert Level was continued until case numbers indicated a 50% chance of elimination was reached, the expected cost under an optimistic Alert Level 4 would be approximately $1.4 billion. If Alert Level 4 only achieved the pessimistic reduction in transmission rates it would have cost approximately $1.8 billion to achieve a similar result. This is almost identical to the cost if Alert Level 3 had been used. However, Alert Level 4 would have achieved this outcome with fewer people infected (Table 2).

Restrictions	Transmission rate (R_0)	Cases in 5 days before lowering alert level	E(days under high restrictions) (IQR)	Cost ($billions)	Median Outbreak size (IQR)
AL 3	0.75	9	23 (7, 34)	1.84	144 (60,203)
AL 4 (pessimistic)	0.5	19	13 (6,19)	1.79	101 (42, 149)
AL 4 (optimistic)	0.33	44	9 (6,12)	1.39	81 (21, 123)

Table 2: Comparison of model outputs to achieve a 50% probability of elimination under the three scenarios. Costs shown do not include health costs which would increase with the epidemic size. The observed outbreak in Auckland had 179 cases in total, 19 days at Level 3 restrictions and there were 27 cases in the 5 days before restrictions were lifted. These data lie within the interquartile ranges predicted by the model.

Model Limitations

In the simple decision-making model used here we do not take into account the fact that, as happened in April 2020, the government would likely have chosen to step down 1 Alert Level at a time. That is, rather than moving straight from Level 4 to Level 2 as assumed here, the transition would have been made with an intermediary period of time at Level 3. This is a more complicated scenario, with many variants, but may be worth investigating in future work. In particular, this would be a useful addition to the analysis performed by the Productivity Commission on whether the extension of Level 4 during the April/May outbreak was favoured by a cost-benefit analysis (Heatley, 2020).

Similarly, the relatively short duration of the periods spent at Level 4 in some of the simulations may also be unrealistic from a decision-making point of view: in reality, the decision to de-escalate Alert Levels relies on many inputs, not case numbers alone as are considered here. Other decision-making factors, including achieving the levels of testing needed to rule out the possibility of other clusters seeded from the same source, may not be ascertained as rapidly, making it much less likely that a decision to de-escalate would have been taken as quickly. A six day period at Level 4 (Table 1, lower interquartile range) would have seemed very short to decision-makers given the many other uncertainties that remained by mid-to-late August. Indeed, this may have been judged prudent given the highly stochastic nature of COVID-19 spread.

The model also assumes that shifts between alert levels can happen instantaneously. Moving a region into or out of Alert Level 4 is logistically challenging, with a need to coordinate school and workplace closures or openings. In practice, decisions to prolong alert level durations would involve extensions of several days at least, while decisions to move down would be announced at least two days in advance. Realistic decision-making constraints such as these are likely to narrow the gap in economic cost between the Level 4 and the Level 3 scenarios even further, as additional unneeded days at Level 4 have a high cost. Because of these issues, we caution that the simple decision-making model applied here will underestimate the true economic losses associated with Level 4 restrictions.

A key parameter in this analysis is the estimate of R_0 under Alert Level 4. Here we presented the results for two values: one optimistic, the second pessimistic. The optimistic value is based on modelling from the March/April outbreak, when Alert Level 4 was in force nationally (James, 2020). The pessimistic value was chosen to illustrate the threshold where the economic costs of Level 4 are most similar to those from Level 3. For transmission rates below this Level 4 may be a better economic choice than Level 3, while for those above this, Level 3 is the better choice. All other parameters are taken from New Zealand case data or clinical studies. As long as these other parameters are similar in both the Level 3 and Level 4 model they will have little bearing on the overall results.

Finally, the model assumes that under Alert Level 2, $R_0 > 1$. In the August outbreak the observed R_{Eff} under Level 2 was very low, as the outbreak was very much under control and contact tracing on the existing cases was rapid as the edges of the cluster were reached (James, 2020). The higher R_0 used here assumes that that this is not necessarily the case, allowing case numbers to grow exponentially if elimination is not achieved.

Discussion

To achieve the same likelihood of elimination, we find that, as would be expected, both the effective and less effective Alert Level 4 measures are needed for a shorter duration than the Level 3 restrictions. The stronger restrictions at Level 4 also result in fewer people being infected, which would lead to correspondingly lower hospitalisation and death rates. Taking into account the short-term economic impacts, we find that the effective Level 4 restrictions could have produced the same elimination outcome as the Level 3 scenario for less cost. Further, we find that a less effective Level 4 would have produced the same outcome as the Level 3 scenario for a similar cost. On this basis, Level 4 restrictions may have been the least costly response to eliminating the Auckland August outbreak. As noted above, however, our decision-making model does not take into account the logistical frictions in moving between alert levels. Level 4 restrictions may also have been difficult to enforce regionally, requiring stronger disparities to be held in place across territorially boundaries. Furthermore, the imposition of a second period at Level 4 may have seen lower compliance with restrictions in the community.

Our analysis does not take into account the longer term economic costs of these measures, nor does it consider any social effects or how costs are distributed across society that might differ between scenarios. For instance, the extra restrictions at Level 4 are felt more harshly by some segments of the economy, which may cause longer-term costs not accounted for here. For example, ceasing elective surgery has large cost implications in both the short term (idle staff) and the long term (poorer health outcomes and more associated sick leave). Incorporating compliance effects and longer-term costs into our analysis here would be difficult, but it is nonetheless important to acknowledge that these factors may take the analysis to a different conclusion. Conversely the longer amount of time needed to eliminate in Level 3 has different associated costs including increased mental health issues, family violence and disrupted educational opportunities. Finally there are a range of difficult-to-predict benefits of different levels of lockdown, e.g. the reduction in seasonal influenza transmission that occurred in New Zealand during 2020.

Previous economic analyses conducted for New Zealand's elimination strategy have typically compared the benefits, measured in terms of lives saved, whether through the use of QALYs or otherwise, to the economic costs of the control measures (Heatley, 2020). Combining our approach based on disease dynamics and the probability of elimination under different scenarios with these more in-depth economic analyses may be useful in informing future responses.

The model used here has many limitations, particularly around the decision-making criteria for moving between alert levels and the effectiveness of transmission reductions at Level 4. However, given the similarities in costs, even when modelled at this simple level, we find that from the gross economic view point used here Alert Level 3 may well be the best choice in future outbreaks. This is a conclusion that can only be reached with the benefit of hindsight now that we have clear evidence that transmission rates can be effectively controlled at Level 3. That evidence, along with convincing estimates of corresponding economic losses, was not available in March 2020 when New Zealand first made use of Alert Level 4.

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