Doherty Modelling Report for National Cabinet 30 July 2021

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Executive summary

- Models of COVID-19 infection and vaccination were used to define a target level of vaccine coverage for transition to Phase B of the National Plan. The model was based on the simplifying assumption of a single national epidemic, with COVID-19 transmission, severity and vaccine effectiveness as for the Delta variant.
  - Vaccine allocation scenarios were defined towards threshold coverage targets (16+ years) of 50/60/70/80%, noting achieved coverage to date has been largely concentrated in high-risk groups and elder populations in line with existing strategy;
  - We compared relative impacts on transmission and health outcomes of continuing the current risk focused strategy, with alternatives focused on reducing infection spread across the whole population. We included a scenario assessing the additional impact of increasing age eligibility for vaccination to 12+ years;
  - Recognising that additional social measures would likely be required to constrain epidemic growth under different achieved coverage assumptions, we estimated ability of the 'test, trace, isolate, quarantine' approach and different bundles of public health and social measures to reduce transmission across the population;
  - Clinical consequences of uncontrolled outbreaks were estimated by seeding infections at the time of reaching threshold levels of vaccine coverage, for the different allocation strategies.
- Stated objectives of the immunisation program enabling the transition to Phase B are to constrain severe outcomes within clinical capacity and reduce the intensity and length of requirement for socially and economically impactful public health and social measures.
  - For 'baseline' levels of social and behavioural restrictions, rapid epidemic growth is expected at 50 and 60% coverage, with more substantial transmission reduction by 70 and 80% targets. In these scenarios reduced effectiveness of the public health 'test, trace, isolate, quarantine' (TTIQ) response is anticipated due to high caseloads;
  - Accordingly, extended and stringent social measures would likely be required to control epidemic growth if the transition to Phase B is made at 50% or 60% coverage;
  - Supporting optimal public health TTIQ capacity by applying continuous low level social restrictions makes the requirement for stringent lockdowns unlikely at 70% population vaccine coverage, under transmission reducing allocation strategies;
  - At this stage of the national COVID-19 vaccine rollout, extending eligibility to key transmitting age groups offers greatest potential to reduce transmission even at lower coverage, reducing workplace absenteeism, clinical cases and deaths across the whole population;
  - Expanding the vaccine program to the 12-15 year age group has minimal impact on transmission and clinical outcomes for any achieved level of vaccine uptake;
  - These findings are conditional on public health workforce and response capacity which varies nationally, population compliance with public health recommendations and orders, and persistence of immunity following infection or vaccination over a 6 months timeframe;
  - Emergence of 'vaccine escape' variants will require re-evaluation of targets and associated requirements for public health measures.
- *This phase of reporting defines aspirational coverage targets to minimise the consequences of community transmission. Achievement of these targets at small area level will be critical to ensure equity of program impact, as ongoing outbreaks in undervaccinated populations are reasonably anticipated from international experience.*
- *Particular attention should be paid to groups in whom socioeconomic, cultural and other determinants are anticipated to result in higher transmission and/or disease outcomes.*
- *Ongoing situational assessment of measured transmission potential and circulating SARS-CoV-2 variants in the Australian population over coming months will allow benchmarking of these hypothetical scenarios to guide real time policy decision making about the transition to Phase B of the National Plan.*

Rationale

On 2nd July 2021, National Cabinet agreed to formulate a National Plan to transition Australia's COVID response. The plan consists of four phases defined by achievement of vaccination thresholds broadly expressed as a percentage of the eligible population (aged 16+ years). Modelling is to be used to define target levels of coverage sufficient to transition between:

A. Current Phase – Vaccinate, prepare and pilot, with a continuing focus on strongly suppressing the virus, including through the use of early and stringent short lockdowns, for the purpose of minimising community transmission;
B. Post vaccination phase – focused on minimisation of serious illness, hospitalisation and fatality as a result of COVID-19 through a combination of vaccination and some ongoing degree of light social restrictions, with lockdowns deemed unlikely;
C. Consolidation phase – public health management of COVID-19 consistent with other infections, but no lockdown requirement;
D. Final phase – removal of all border restrictions.

Background

Modelling prepared for National Cabinet on the 4th June 2021 considered the likely impact of Astra Zeneca vaccines on transmission potential of the Alpha strain of SARS-CoV-2, as well as a *more transmissible variant* with properties similar to the Delta strain of the virus. That work demonstrated that even at very high levels of vaccine uptake (80% or above), suppression of epidemic growth below the critical reproduction number of one required to attain 'herd immunity' was unlikely for such a strain. However, substantive reductions in transmission potential could be achieved which, together with intermittent application of social measures, would constrain the rate and extent of epidemic growth. In addition, the decrease in disease severity in vaccinated individuals would lead to lower rates of hospitalisation, intensive care utilisation and death.

This next phase of work focuses on the Delta variant as a 'base case' strain, using updated transmission, severity (Table S1) and vaccine effectiveness assumptions (Table S2.3, S2.5) against this strain.

- Should more transmissible variants emerge in future, transmission potential will be higher than anticipated here for any given level of completed vaccine coverage.
- Sensitivity analyses explore scenarios for a hypothetical future variant against which vaccines are only half as effective. In such a case, vaccine impacts on transmission potential will be less, due to a reduction in vaccine protection against infection *and* an increase in 'breakthrough' infections in immunised individuals (Table S2.4).

Ongoing situational assessment of measured transmission potential and circulating SARS-CoV-2 variants in the Australian population over coming months will allow benchmarking of these hypothetical scenarios to guide real time policy decision making about the transition to Phase B of the National Plan.

We extend on earlier methods to consider more realistic scenarios of vaccine distribution for the Australian population, incorporating both Astra Zeneca and Pfizer vaccines. Under the evidently coarse simplifying assumption that COVID-19 would spread uniformly across the Australian continent, we use an agent-based model of the total population to represent epidemic dynamics and the combined impacts of vaccination and public health and social measures to limit transmission and reduce the outcomes of interest. Hospital and ICU admissions are benchmarked against stated national capacity, based on the additional simplifying assumption that such resources are equally accessible to every Australian.

Objectives

Objectives of the immunisation strategy to enable a transition from Phases A to B are:

1. Minimisation of moderate and severe health outcomes, defined as all identified cases leading to workforce absenteeism as well as that subset resulting in hospitalisation, intensive care requirement and death (to be constrained within national capacity for hospital ward and ICU admissions);
   and
2. Reduction of the intensity and length of application of socially and economically disruptive public health and social measures, which are currently the primary means of reducing transmission. Ongoing 'light' restrictions will likely be needed to augment vaccine impacts, but lockdowns would be deemed unlikely.

Given the time horizon, transitions to later phases (C and D) will be associated with greater uncertainty because of:

- Likely emergence of new variants within Australia or internationally exhibiting one or more of heightened transmissibility, severity or immune escape;
- Changing global epidemiology of COVID-19 affecting the risk profile of travellers from different countries and regions;
- Waning of vaccine-derived and natural immunity over time;
- Development of new vaccine products (eg multivalent or specific VOC vaccines) and schedules including administration of booster doses to high risk subgroups or whole population;
- Population fatigue and the potential for declining compliance with restrictions;
- Potential for future development of readily bioavailable therapeutics that might be used for either or all of transmission reduction, prevention of disease progression and life-saving therapies.

Acknowledging Australia's vast geographical distances and the variable size, demography, rurality/remoteness and public health/health service capacity of states and territories our next phase of work will adapt the agent-based model framework to represent the key population characteristics and public health and clinical capacities of each. Working closely with the jurisdictions, we will consider the way in which state-based differences may require tailored adaptation of the national strategy, including definition of key subpopulation coverage targets, to achieve overarching program objectives.

Exploring vaccine thresholds for transition to Phase B of the National Plan

To define a 'manageable' level of vaccine coverage for transition to Phase B of the national plan, we explore the consequences of uncontrolled outbreaks that effectively seed ongoing community transmission of COVID-19, following completion of alternative target vaccine coverage/allocation scenarios.

When defining overall target coverage thresholds for the eligible population, it is vital to consider the distribution of doses received across all age categories, which will impact on population level outcomes of the program in different ways:

- Older individuals are more likely to experience severe disease outcomes, making them an early priority group for vaccine protection in Australia's COVID-19 vaccine rollout;
- Young and working age adults are peak transmitters of COVID-19. Increasing the proportional coverage in these groups will have a greater impact to reduce transmission.

We assume that case isolation, contact tracing and quarantine will continue, while recognising that the intensity and effectiveness of these public health responses must decline as caseloads increase. Likely requirements for overlaid 'bundles' of social measures to constrain epidemic growth are considered.

Defining vaccine allocation scenarios within supply/delivery constraints

From a starting point of achieved vaccine coverage in the Australian age eligible (16+ years) population as of 12th July 2021 based on Australian Immunisation Register (AIR) data (33% one-dose completion, 11.5% two-dose completion – Table S3.1), we have devised a series of vaccine delivery scenarios towards completed (2 dose) coverage targets of 50, 60, 70 and 80% in the age eligible (16+) population.

Within the constraints of available supply and achievable delivery, vaccines are allocated according to current routine indications as follows:

- Astra Zeneca – age eligible population 60+ years, dosing interval 12 weeks, delay from second dose completion to full efficacy 2 weeks;
- Pfizer/BioNTech – age eligible population 16+ years, dosing interval 3 weeks, delay from second dose completion to full efficacy 2 weeks.

Given these assumptions, we compare alternative theoretical approaches to delivery, to explicitly indicate the importance of allocation for impacts on transmission and disease:

Table 1.1 – Vaccine allocation strategies by age, assuming current recommendations for Astra Zeneca vaccine age eligibility (60+ years) and dosing interval (12 weeks)

Strategy	Allocation sequence
Oldest first	Vaccinations are prioritised from oldest to youngest. Specifically, prioritization occurs in the following order: 80+, 70-79, 60-69, 50-59, 40-49, 30-39, 20-29, 16-19
40+ years first	Vaccinations are prioritised from 40+ upwards, then 16+. Specifically, prioritization occurs in the following order: 40-49, 50-59, 60-69, 70-79, 80+, 16-19, 20-29, 30-39
All adults	Vaccinations are not prioritised in any particular order by age

Along with age-based allocation strategies, we compare the impact of approaches intended to hasten the timing of vaccine rollout within available supply, towards threshold coverage targets. Proposed changes in indications for the Astra Zeneca vaccine are aligned with the recent ATAGI advice on recommendations for outbreak settings, developed in the context of a surge in cases in

NSW (https://www.health.gov.au/news/atagi-statement-on-use-of-covid-19-vaccines-in-an-outbreak-setting).

Table 1.2 – Strategies to accelerate rollout, by reducing the Astra Zeneca (AZ) vaccine dosing interval from 12 weeks and/or lowering the age recommendation from 60+ years

Strategy	Allocation sequence	Impact on VE against infection (E_i)	Overall reduction in transmission*
AZ 40+ years	Recommend Astra Zeneca for 40+ year olds	Nil beyond dose interval	86% (assuming 12-week interval)
AZ 8 weeks	Reduce AZ dosing interval to 8 weeks	15% reduction	83%
AZ 4 weeks	Reduce AZ dosing interval to 4 weeks	25% reduction	81%

**Calculated overall reduction in transmission = $1-(1-E_i)*(1-E_t)$*

In the absence of robust evidence for the efficacy of 4- and 8-week interval dosing schedules for AZ against the Delta strain, we estimated vaccine efficacy for these scenarios by assuming 25% (4-week) and 15% (8-week) reductions in efficacy against infection following 2 dose completion relative to the 12-week schedule. This is broadly consistent with observed reductions in efficacy against both symptomatic infection and antibody titre from 2020 strains with <6-week versus ≥12 week schedule (Voysey et al. *Lancet* 2021, relating antibody responses to efficacy according to Khoury et al. *Nature Medicine* 2021). Assuming that the reduction in onward transmission from a vaccinated infected individual (E_t) is unchanged, these estimates result in an overall efficacy against disease transmission of 81% for a 4-week interval and 83% for an 8-week interval (Table 1.2).

Timeliness of achieving coverage targets by vaccine allocation scenario

The rate of vaccine delivery is shown in Figure S1 and the indicative date of completion of the rollout for different combinations of these strategies is reported in Table 1.3. Greatest potential benefits are observed early in the rollout, with achievable gains of almost a month to reaching 50% uptake by shortening the dosing interval to 4 weeks and making a positive recommendation for administration to 40+ year olds. Lesser temporal gains are observed for higher target thresholds. Completion dates are equivalent regardless of the age-based allocation (oldest, 40+ years first or all adults). The distribution of proportional coverage by age cohort for the different allocation strategies is shown in Table S3.2.

Table 1.3 – Date of achieving a given vaccine coverage threshold by any age-based allocation strategy (oldest, 40+ years first or all adults), assuming a start date and population completed doses (AIR) as of 12th July 2021

AZ recommendation		Date by which coverage target achieved			
Age	**Interval**	**50%**	**60%**	**70%**	**80%**
60+ years	**12-weeks**	4 October	18 October	1 November	22 November
	8 weeks	27 September	11 October	1 November	22 November
	4 weeks	27 September	11 October	1 November	22 November
40+ years	**12-weeks**	4 October	11 October	25 October	15 November
	8 weeks	20 September	4 October	18 October	8 November
	4 weeks	6 September	4 October	18 October	8 November

Transmission potential (TP) by vaccine coverage and allocation strategy

The rate of epidemic growth following loss of control is related to the population level *transmission potential (TP),* a measure routinely reported in the Common Operating Picture. TP is akin to the effective reproduction number (R_{eff}). If below 1, no public health actions are required to control disease and an outbreak will be self-limiting. The higher above 1 it moves the more rapidly case numbers will escalate and the harder the disease is to control with public health measures. Vaccination reduces population level susceptibility to infection, and ongoing spread from immunised infected individuals, thereby reducing TP.

Baseline TP will be influenced by spontaneous and imposed changes in physical distancing behaviours, the number of social contacts on average between individuals and the timeliness of test, trace, isolate, quarantine (TTIQ) measures. We use a starting TP of 3.6 for the Delta variant based on averaged observations from NSW in March 2021, a period with minimal social restrictions and no major outbreaks. TTIQ assumptions are based on the performance of the Victorian public health response at the height of the 'second wave' in 2020 as our best estimate of achievable effectiveness at high caseloads. Note that the TP in WA over the same period under similar levels of restrictions was 4.5.

Tables 2.1-2.3 report the TP achieved under alternative vaccine allocation and delivery strategies. Given greater proportional coverage of peak transmitting age groups (Table S3.2, Figures S2.2-2.5) the 'all adults' allocation strategy is slightly more effective at reducing TP earlier in the rollout, across all delivery approaches and vaccine eligibility assumptions. Improved early constraint of transmission can have substantive impacts on the timing and peak of epidemics, because of the nonlinear nature of epidemic growth. The marginal gain in timeliness of reaching the 50% coverage threshold under the accelerated AZ strategies is at some short-term cost of TP reduction, given the lower efficacy of reduced interval schedules. We will therefore constrain scenarios in this report to those assuming 'standard' AZ recommendations, noting that the potential benefits of accelerated delivery in short term response merit further exploration.

Table 2.1: Scaled values of Delta variant transmission potential (TP) for 50%, 60%, 70% and 80% population coverage by the 'Oldest first' vaccine allocation strategy, and exploring age recommendations and dosing intervals for AZ. We use a starting TP of 3.6.

AZ recommendation		**Eligible population coverage (16+)**			
Age	**Interval**	**50%**	**60%**	**70%**	**80%**
60+ years	**12-weeks**	2.1	1.7	1.5	1.3
	8 weeks	2.2	1.9	1.5	1.3
	4 weeks	2.2	1.9	1.5	1.3
40+ years	**12-weeks**	1.8	1.7	1.4	1.3
	8 weeks	2.1	1.8	1.5	1.3
	4 weeks	2.5	1.8	1.5	1.3

Table 2.2: As for Table 2.1 but by the '40+ years first' allocation strategy

AZ recommendation		Eligible population coverage (16+)			
Age	**Interval**	**50%**	**60%**	**70%**	**80%**
60+ years	**12-weeks**	2.1	1.9	1.6	1.3
	8 weeks	2.2	2	1.6	1.4
	4 weeks	2.2	2	1.6	1.4
40+ years	**12-weeks**	2	1.8	1.6	1.3
	8 weeks	2.2	1.9	1.7	1.4
	4 weeks	2.4	2	1.7	1.4

Table 2.3: As for Table 2.1 but by the 'All adults' allocation strategy

AZ recommendation		Eligible population coverage (16+)			
Age	**Interval**	**50%**	**60%**	**70%**	**80%**
60+ years	**12-weeks**	2	1.7	1.5	1.3
	8 weeks	2.1	1.8	1.5	1.3
	4 weeks	2.1	1.8	1.5	1.3
40+ years	**12-weeks**	1.8	1.7	1.5	1.3
	8 weeks	2	1.8	1.5	1.3
	4 weeks	2.3	1.8	1.5	1.3

Implications of 'vaccine escape' variants for impacts on transmission potential

The three age-based vaccine allocation scenarios were explored, assuming a future variant against which vaccines are less protective (Table 3.1). We model the impact of this 'vaccine escape' variant by assuming a reduction of 50% in vaccine efficacy for both infection (E_i) and onward transmission (E_t). This would result in reductions of 36% (Pfizer) and 39% (Astra Zeneca) in the efficacy of two vaccine doses against overall transmission, relative to Delta (Table S2.4). The 'all adults' allocation strategy remains marginally better than the other two scenarios, but even at 80% eligible population coverage, TP remains high at 2.0.

Table 3.1 Scaled values of transmission potential (TP) for a variant against which vaccines are only half as effective, for 50%, 60%, 70% and 80% population coverage achieved under the three age-based allocation strategies. Standard age (60+) and dosing interval (12 weeks) recommendations are assumed for the AZ vaccine. Comparators for each strategy are the top rows of each of Tables 2.1, 2.2 and 2.3.

Strategy	Eligible population coverage (16+)			
	50%	**60%**	**70%**	**80%**
Oldest first	2.7	2.4	2.2	2.0
40+ years first	2.6	2.4	2.2	2.0
All adults	2.5	2.3	2.1	2.0

Implications of extending vaccine eligibility to the population aged 12+ years

The potential benefit of immunising school children aged 12-15 years was also explored. The primary purpose of this 'thought experiment' was to assess the impact of extending the age of vaccine eligibility down to age 12 years.

To implement this hypothetical scenario, we assumed the rate of delivery to this group approximated that of the overall national program. For each date at which whole population two dose coverage targets were achieved, we assumed that the same proportion of this school aged cohort would have received at least one vaccine dose.

In reality, the achievable pace of rollout to this age cohort will depend on supply considerations determining whether and when additional doses might be allocated to this group. There will also be jurisdictional differences in the workforce available to deliver immunisation through school-based programs, which would be assumed the most efficient way to achieve high uptake. These supply, allocation and delivery issues need to be resolved before more realistic scenarios can be implemented in the model.

The impact achieved by expanding age eligibility was a reduction in TP of 0 or 0.1 across all allocation strategies and coverage thresholds. **Based on these minimal impacts, it is anticipated that inclusion of 12-15 year olds in the vaccine roll out as an early priority group would not materially change the expected overall health outcomes at each key vaccination threshold**. For a given level of vaccination, the total number of Australians who experience severe illness from COVID-19 will be similar regardless of whether the vaccination rate has been achieved across the 12+ or 16+ population.

Table 3.2: Scaled values of Delta variant transmission potential (TP) showing the *overall impact (difference in brackets)* on TP of additionally immunising school children aged 12-15 years, for 50%, 60%, 70% and 80% population coverage achieved under the three age-based allocation strategies. Standard age (60+) and dosing interval (12 weeks) recommendations are assumed for the AZ vaccine. Comparators for each strategy are the top rows of each of Tables 2.1, 2.2 and 2.3.

Strategy	Eligible population coverage (16+)			
	50%	60%	70%	80%
Oldest first	2 (-0.1)	1.7 (0)	1.4 (-0.1)	1.2 (-0.1)
40+ years first	2.1 (0)	1.9 (0)	1.6 (0)	1.3 (0)
All adults	1.9 (-0.1)	1.7 (0)	1.4 (-0.1)	1.2 (-0.1)

Impact of public health response and bundled social measures on TP

The ability to reduce TP to less than 1 is needed both to contain community transmission in the current suppression phase (A) and to prevent cases from exceeding health sector capacity in phase B. Personal risk reduction behaviours and constraints on social mixing known as Public Health and Social Measures (PHSM) are the levers currently employed to manage TP in response to incursions and outbreaks. Over time, behaviours change, either spontaneously because of heightened concern or complacency, or in response to public health orders invoking various elements of PHSMs.

We therefore investigated what level of PHSM would be required to bring TP below 1 under different scenarios of vaccination coverage. We considered four 'bundles' of PHSM restrictions: baseline, low, medium and high. Each bundle relates to a specific time and place in Australia's pandemic experience, thereby capturing both real-world behavioural responses and the proportional reduction in TP achievable by PHSMs in our context:

- Baseline PHSM - only minimal density/capacity restrictions, as in NSW March 2021 (baseline TP as used above)
- Low PHSM - more stringent capacity restrictions, as in NSW 23 August 2020
- Medium PHSM - stringent capacity restrictions, group size limits, stay-at-home orders (except work, study, essential purposes), as in NSW 1 July 2021
- High PHSM - no household visitors, curfew, stay-at-home orders (except essential purposes & permitted work), as in VIC 23 August 2020

As in the TP estimates above, each of these PHSM bundles includes a Test, Trace, Isolate, and Quarantine (TTIQ) capability. We assume that once community transmission becomes established leading to high caseloads, TTIQ is less efficacious than the optimal levels observed in Australia because public health response capacity is finite. We calibrate this partial TTIQ effect to its impact on TP as at Australia's daily peak of local cases in VIC 4 August 2020. By comparing optimally and partially effective responses, we assess the contribution of TTIQ to the overall level of achievable constraint on transmission.

Figures 1.1 and 1.2 illustrate that as vaccination coverage increases, less stringent PHSM will be required to bring TP below 1. Maintaining a rapid and highly effective TTIQ response capacity is critical for ongoing epidemic control. Should TTIQ responses become only partially effective due to high caseloads, high PHSM would be needed to curb transmission at the 50% and 60% coverage thresholds, whilst low PHSM *may* be sufficient for control at 80% coverage (Figure 1.1). More optimistically, the combination of 70% vaccine coverage and ongoing low PHSMs would likely be sufficient for control, *if optimal TTIQ can be maintained* (Figure 1.2). Note that compliance with imposed measures will vary their effectiveness between populations and timepoints. This uncertainty is conceptually represented by the upper and lower bounds of each 'box' for each set of restrictions in the Figures.

When interpreting the combined impacts of these measures it is important to reflect that:

- Weekly situational assessments provided to AHPPC reveal substantial variation in TP over time by jurisdiction in the absence of active cases affecting the 'starting TP' upon which measures act;
- The proportional reduction in TP achieved by imposition of public health orders differs nationally and within a given jurisdiction over time and at small area level, reflecting variable population co-operation with PHSMs that affect the degree of achievable ongoing or reactive suppression;
- TTIQ response capacity varies markedly by jurisdiction, based on the size of the public health workforce and related laboratory capacity, both of which are critical to rapid case identification for the purposes of case isolation and contact tracing.

Because of these differences, a precautionary approach is advised when defining a 'national' vaccine coverage threshold that would be applicable across small and large jurisdictions.

Figure 1.1: Combined effects of vaccination and PHSM scenarios on COVID-19 transmission potential under the 'All adults' vaccination scenario assuming only *partial TTIQ effectiveness*, due to high caseloads. Standard age (60+) and dosing interval (12 weeks) recommendations are assumed for the AZ vaccine.

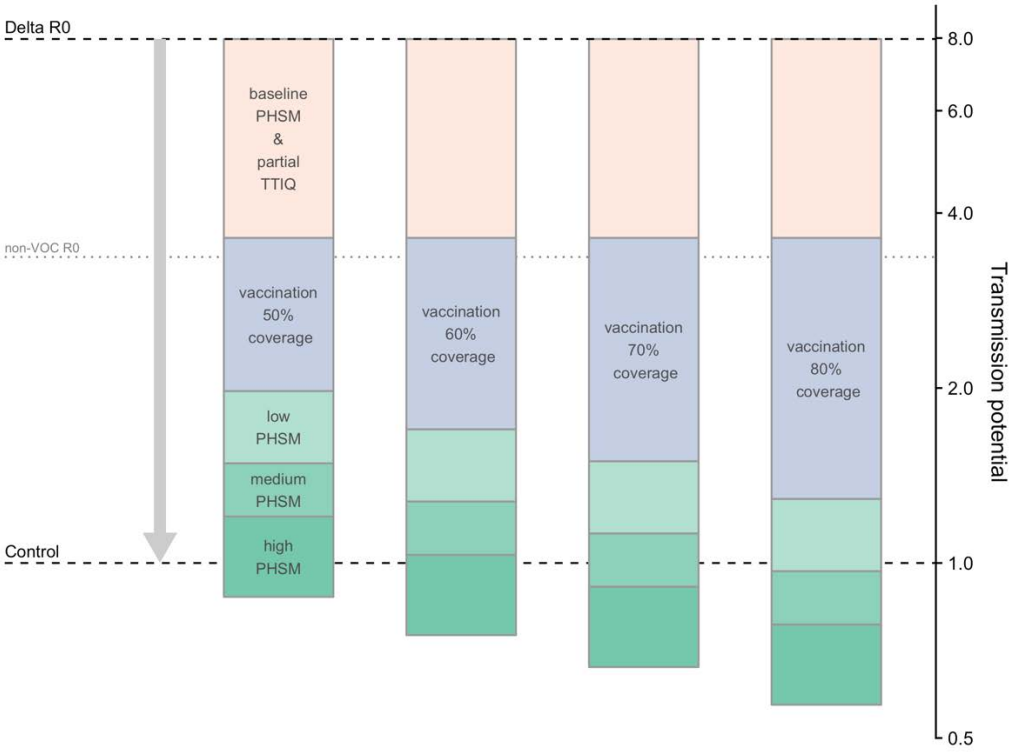
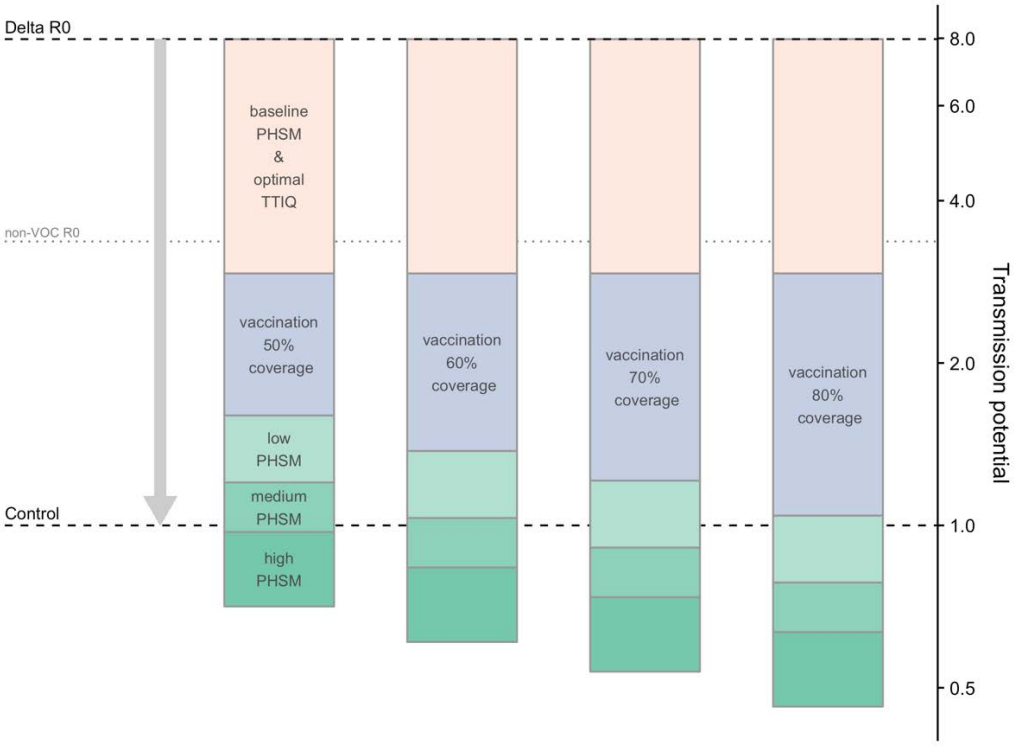


Figure 1.2: As for Figure 1.1 but assuming *optimal TTIQ effectiveness*



Anticipated requirements for social measures, by coverage scenario

During outbreak suppression (phase A) early stringent lockdowns are temporarily used to bring TP below 1 for the purposes of driving local cases from an outbreak to zero, in the context of an optimal TTIQ response. During phase B, stringent PHSM might need to be used *intermittently* to reduce caseloads to prevent overwhelming the health sector. Ongoing application of some degree of social measures through this phase reduces the likelihood for high restrictions and preserves TTIQ effectiveness by keeping case numbers low.

TP estimates with and without stringent PHSM can be used to calculate the approximate proportion of time those stringent measures would need to be in place to prevent exceedance of health sector capacity over a hypothetical long-term. This static analysis can indicate the plausible societal and economic impacts of the PHSM required to constrain transmission under each scenario and coverage over the long-term. The next section considers epidemic dynamics and clinical consequences of infections for 'baseline' social measures and partially effective TTIQ (assumed if caseloads escalate).

Tables 4.1 and 4.2 compare the proportion of time that would need to be spent with high PHSM on top of ongoing light restrictions to maintain case counts at some level, by vaccine coverage and allocation strategy. We assume periodic switching between low PHSM and high PHSM over a long period with the same vaccination coverage. With long-term coverage held at 50%, 60%, or 70%, high PHSM would be needed for significant fractions of time (18-89%) if caseloads escalate, leading to 'partial' TTIQ effectiveness. For the 'optimal' TTIQ scenario and an achieved adult population coverage of 70%, high PHSM would be needed rarely if at all.

Table 4.1: Percentage of time high PHSM would need to be in place for long-term control, with reversion to low PHSM at other times, for 50%, 60%, 70% and 80% population coverage achieved under the three age-based allocation strategies. These scenarios assume *partial* TTIQ effectiveness, under high caseloads. Standard age (60+) and dosing interval (12 weeks) recommendations are assumed for AZ vaccine.

Strategy	Eligible population coverage (16+)			
	50%	**60%**	**70%**	**80%**
Oldest first	82%	49%	18%	0%
Middle years first	89%	67%	39%	2%
All adults	75%	46%	22%	0%

Table 4.2: As for Table 4.1 but assuming *optimal* TTIQ effectiveness, given low caseloads

Strategy	Eligible population coverage (16+)			
	50%	**60%**	**70%**	**80%**
Oldest first	42%	9%	0%	0%
Middle years first	49%	27%	0%	0%
All adults	35%	6%	0%	0%

More detailed breakdowns of the level of time likely required under differing degrees of social restrictions for the various coverage thresholds and allocation strategies are shown in Tables S4.2 and 4.3 (assuming partial/optimal TTIQ), and S4.4 and 4.5 (in context of ongoing 'light' restrictions).

Dynamics and consequences given timing of transition to Phase B

Epidemic simulations assume a population size of 24 million. Infection outputs reflect the range of results observed across 20-30 separate model runs for each scenario. We assume that a single outbreak involving 30 individuals initiates community transmission at the time of transition to Phase B, once target vaccine coverage is achieved. Each simulation is run for 180 days after this initiating date. As immunisation rollout is ongoing, achievement of future vaccine targets is indicated as relevant, in relation to evolving epidemics.

Early epidemic growth given established transmission, for key scenarios

Exemplar epidemic curves are shown for the different coverage levels and allocation assumptions in Figures 2.1-2.3 below to demonstrate the relative rate and extent of epidemic growth for each. Given rapidly escalating caseloads in such scenarios, we assume only 'partial' TTIQ effectiveness. In the first instance we report the total number of incident infections, agnostic to their severity and including asymptomatic individuals. Note that these exemplar scenarios assume a starting transmission potential of 3.6, consistent with estimated levels of distancing behaviour in NSW during March 2021 (see Table 1.1). The speed and extent of epidemic growth would be greater for jurisdictions with higher transmission potential and/or if further relaxation of distancing behaviour occurred.

Figure 2.1: Epidemic growth to 180 days given transition to Phase B leading to established community transmission for the threshold coverage targets of 50, 60, 70 and 80%, with vaccine allocation according to the 'Oldest first' strategy (*note different y axes)

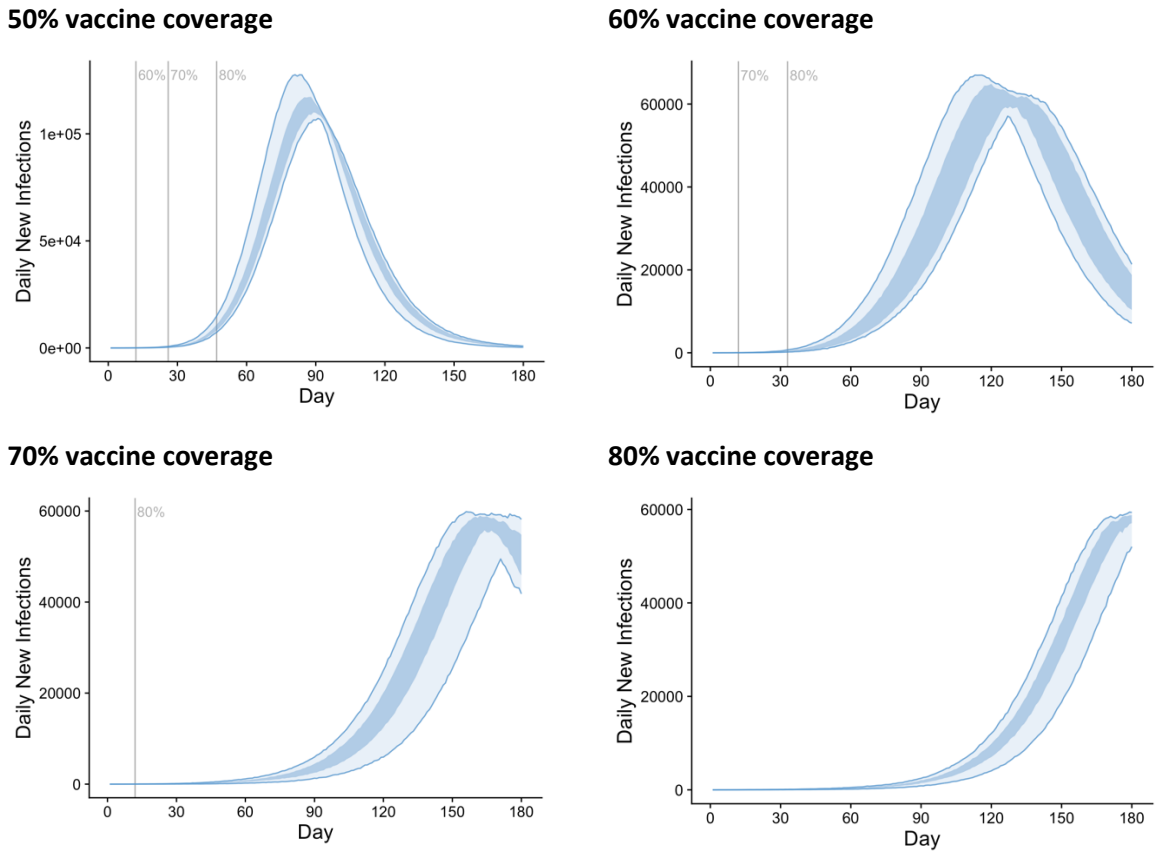
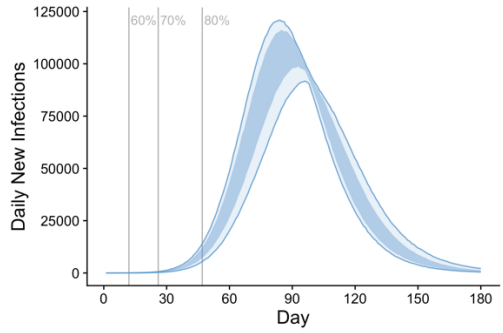
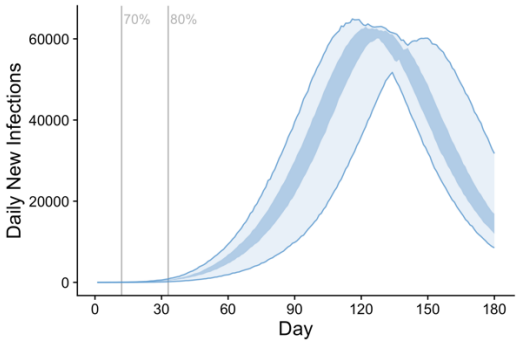


Figure 2.2: As for Figure 2.1 but for the '40+ years first' strategy (*note different y axes)

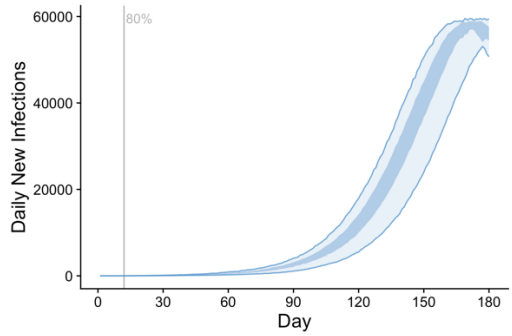
50% vaccine coverage



60% vaccine coverage



70% vaccine coverage



80% vaccine coverage

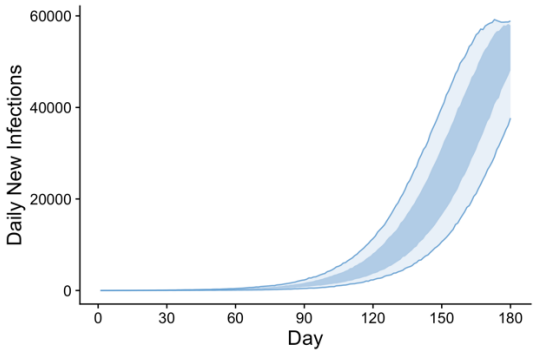
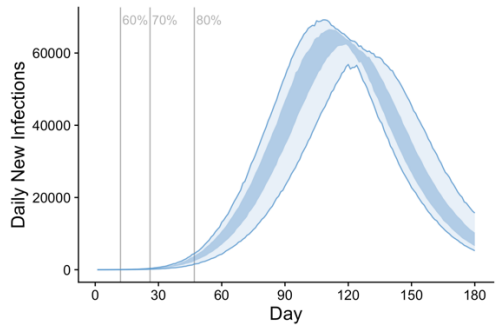
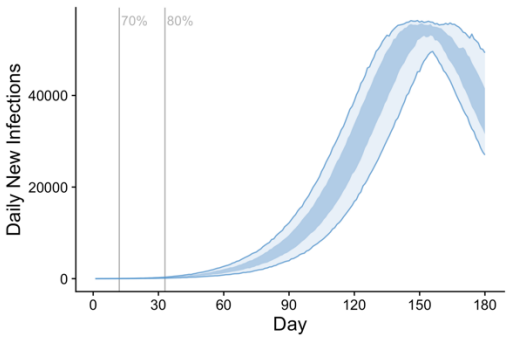


Figure 2.3: As for Figure 2.1 but for the 'All adults' strategy (*note different y axes)

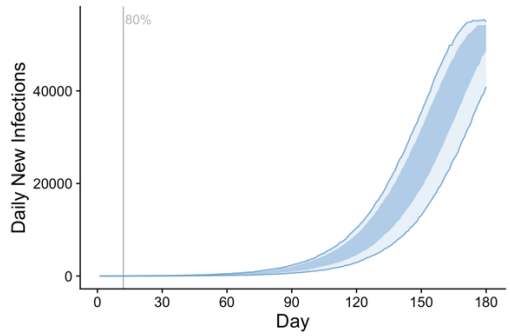
50% vaccine coverage



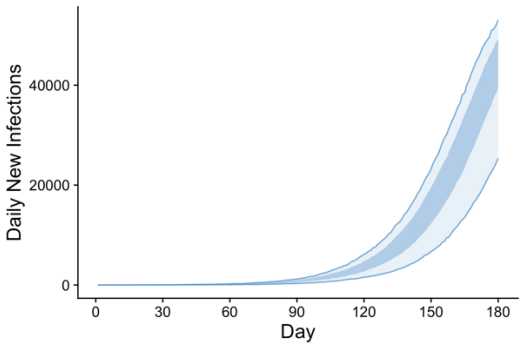
60% vaccine coverage



70% vaccine coverage

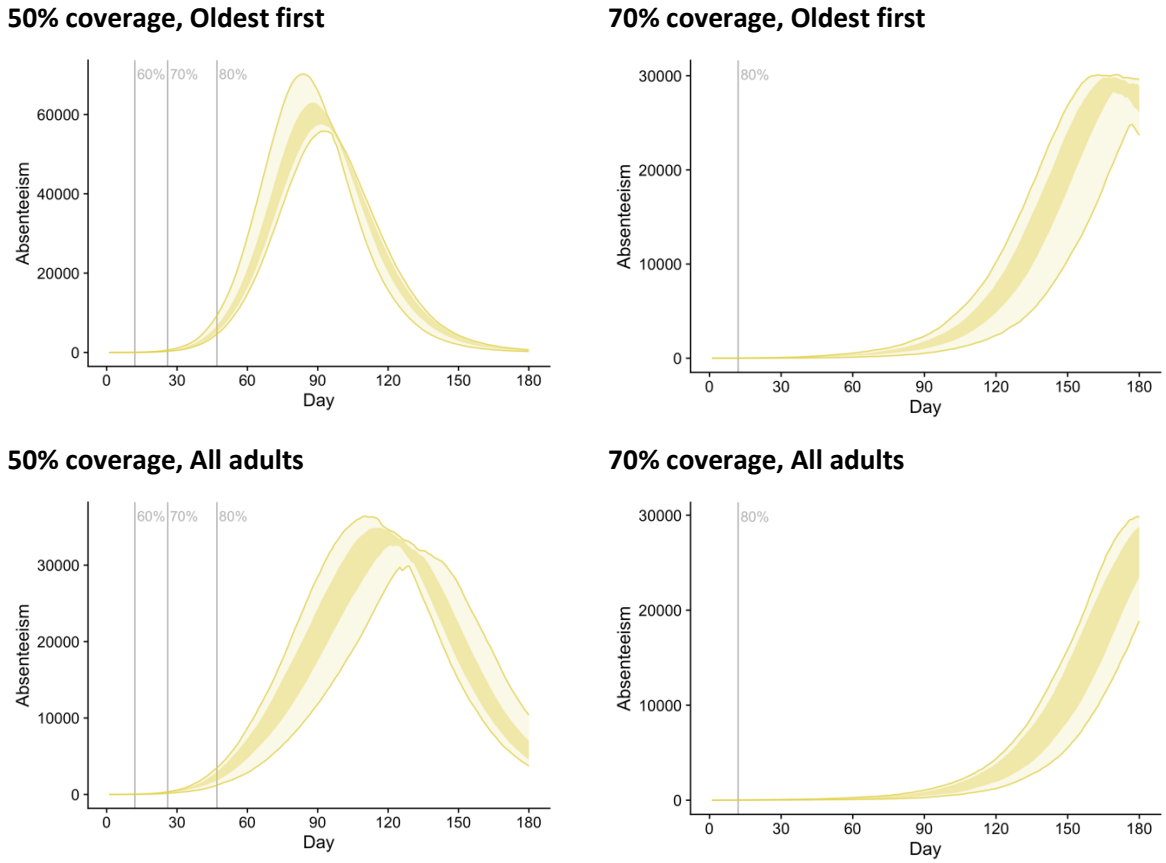


80% vaccine coverage



Figures 2.1-2.3 demonstrate marked differences in early epidemic dynamics with increasing vaccine coverage. Comparison of the y axis for the 50% coverage scenarios in Figures 2.1 and 2.3 shows the marked reduction in incident infections achieved by preferentially immunising younger age groups, for the same level of achieved population vaccine coverage. Figure 2.4 relates these infections to anticipated workforce absenteeism of symptomatic individuals identified as cases and isolated for the minimum period of 10 days, assuming that they would be fit to return to work thereafter (workforce participation rates based on Treasury statistics, by age – Table S5).

Figure 2.4: Prevalence of individuals absent from the workforce due to symptomatic infection and mandatory isolation (10 days) for the 50 and 70% coverage scenarios, assuming 'Oldest first' and 'All ages' allocation strategies (*note y axes differ)



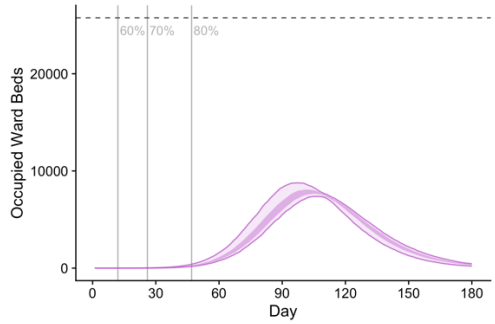
Associated health impacts of transmission, relative to health sector capacity

Outputs from the infection model provided inputs to the clinical pathways model. Each input is iterated over multiple runs so that the clinical pathways model is run 200 times for each scenario. Figures 3.1-3.3 report the range of corresponding health impacts across simulations for the epidemic growth scenarios shown above.Workforce absenteeism, occupied hospital beds, occupied ICU beds and deaths lag incident cases given time for progression of the clinical course towards more severe outcomes. Where relevant, these are related to estimated national clinical capacities (Table S6).

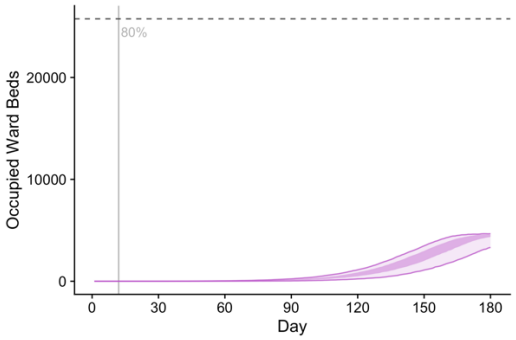
Note that even for high coverage, late epidemics are observed, with associated severe outcomes, reflecting the ability for circulation in unvaccinated population subgroups, which are likely to be concentrated within communities and geographical areas. Further improvements in vaccine uptake would be needed to prevent these outcomes.

Figure 3.1: Occupied hospital ward beds over the course of the epidemic, in relation to stated national capacity, which represents 50% of the total. Scenarios shown are for 50% achieved coverage at epidemic onset, with vaccines allocated to 'oldest first' or 'all adults'

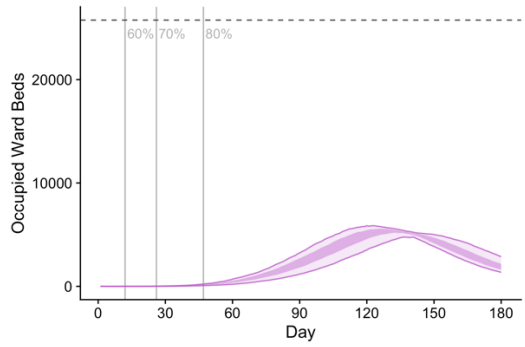
50% coverage, Oldest first



70% coverage, Oldest first



50% coverage, All adults



70% coverage, All adults

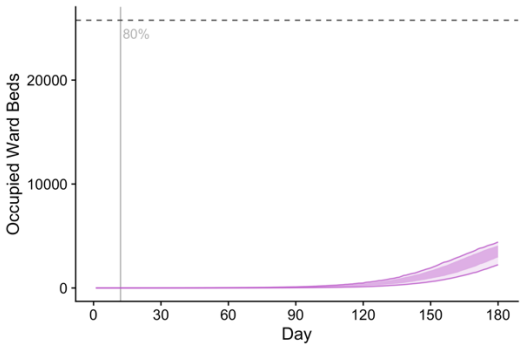
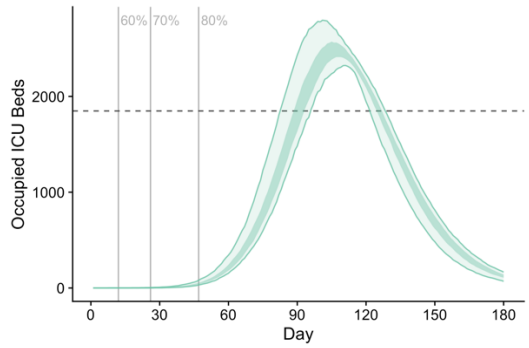
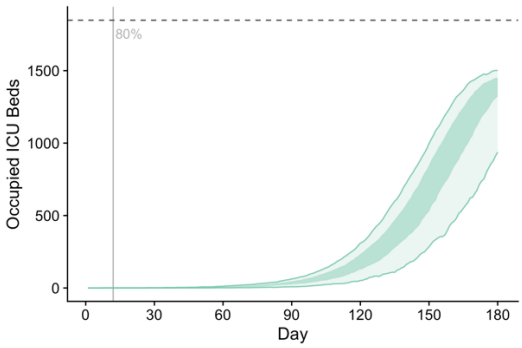


Figure 3.2: As for Figure 3.1 but for occupied ICU beds in relation to national capacity

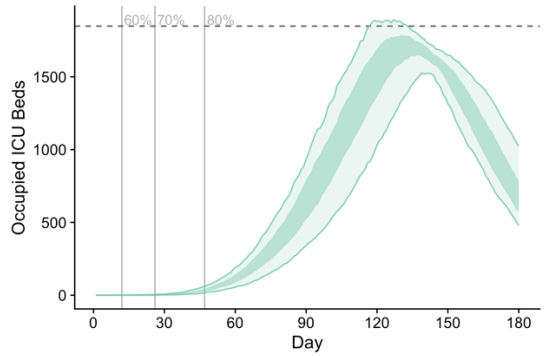
50% coverage, Oldest first



70% coverage, Oldest first



50% coverage, All adults



70% coverage, All adults

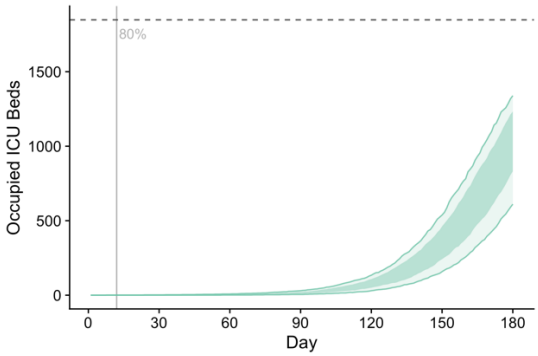
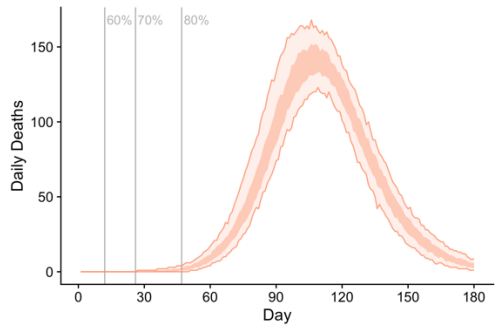
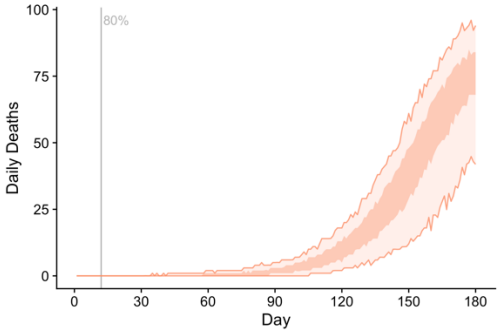


Figure 3.3: As for Figure 3.1 but reporting daily deaths (*note y axes differ)

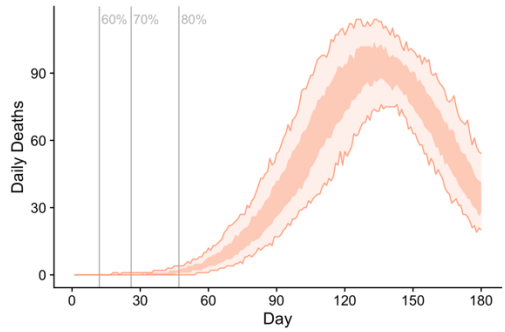
50% coverage, Oldest first



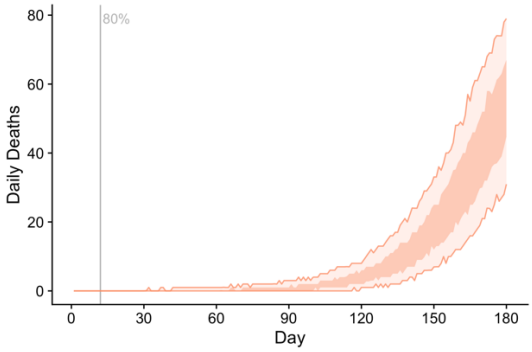
70% coverage, Oldest first



50% coverage, All adults



70% coverage, All adults



Health impacts by age group and vaccine status

Central estimates of these health impacts over the first 180 days following established community transmission are provided in the tables below, for ease of comparison across coverage thresholds, allocation strategies, vaccination status and age group. Note that given epidemic stochasticity and uncertainty, these estimates are drawn from a broader range of possible values as demonstrated by the Figures above. **All scenarios assume only baseline restrictions and 'partial' TTIQ effectiveness.**

Table 5.1 Cumulative outcomes of interest over the first 180 days by achieved coverage threshold prior to transmission, for the 'Oldest first' vaccine allocation strategy

	Vaccine Coverage			
	50%	**60%**	**70%**	**80%**
Symptomatic infections	1,174,450	900,431	617,291	471,107
Ward admissions	48,002	36,113	22,379	16,130
ICU admissions*	11,465	8,523	5,002	3,494
Deaths	10,311	7,276	3,563	2,309

**ICU admissions are reported here and below assuming unconstrained capacity, even when national thresholds are anticipated to be reached or exceeded, so reflect 'true' requirements*

Table 5.2 As for Table 5.1, for the 'All adults' allocation strategy

	Vaccine Coverage			
	50%	**60%**	**70%**	**80%**
Symptomatic infections	964,153	737,971	393,515	279,001
Ward admissions	42,567	29,960	14,130	9,669
ICU admissions	10,302	6,947	3,084	2,075
Deaths	8,894	5,294	1,984	1,281

Table 5.3: Cumulative symptomatic infections, ward admissions, ICU admissions and deaths over the first 180 days for coverage thresholds of 50%, 60%, 70% and 80% achieved by the 'Oldest first' and 'All adults' strategies, broken down by vaccination status[#]

	Oldest First		All Adults	
Achieved eligible population coverage	**Vaccinated**	**Unvaccinated**	**Vaccinated**	**Unvaccinated**
50%				
Symptomatic infections	222,193	952,257	171,467	792,686
Ward admissions	15,575	32,427	13,092	29,475
ICU admissions	4,082	7,384	3,446	6,856
Deaths	3,765	6,546	3,089	5,805
60%				
Symptomatic infections	148,992	751,440	120,173	617,798
Ward admissions	11,449	24,665	9,115	20,845
ICU admissions	2,978	5,545	2,313	4,634
Deaths	2,633	4,643	1,851	3,443

Table 5.3 (cont)

	Oldest First		All Adults	
Achieved eligible population coverage	**Vaccinated**	**Unvaccinated**	**Vaccinated**	**Unvaccinated**
70%				
Symptomatic infections	93,398	523,893	58,165	335,350
Ward admissions	6,870	15,509	4,144	9,986
ICU admissions	1,693	3,309	993	2,091
Deaths	1,278	2,285	685	1,298
80%				
Symptomatic infections	67,946	403,162	40,010	238,991
Ward admissions	4,860	11,270	2,817	6,852
ICU admissions	1,163	2,331	666	1,409
Deaths	819	1,490	439	842

 # Note that in the case of emergence of a 'vaccine escape' variant, both the total number of infections and the proportion of severe cases occurring in fully immunised individuals would increase dramatically.

As can be seen from Tables 5.4 and 5.5, the enhanced indirect protection achieved by the 'All adults' strategy results in a substantial reduction in symptomatic infections and severe outcomes across all age groups, including unvaccinated children.

Table 5.4: Cumulative symptomatic infections, ward admissions, ICU admissions and deaths over the first 180 days for the coverage threshold of 70% achieved by the 'Oldest first' strategy, broken down by vaccination status and age

	<16 yrs		16-39 yrs		40-59 yrs		60+ yrs		70+ yrs	
	Vacc'd	**Unvac**	**Vacc'd**	**Unvac**	**Vacc'd**	**Unvac**	**Vacc'd**	**Unvac**	**Vacc'd**	**Unvac**
Denominator population*	0	5,075,816	3,539,772	4,989,859	5,859,393	3,196,468	5,199,031	468,491	2,835,618	125,031
Symptomatic infections	0	355,505	34,390	103,350	33,166	54,710	20,283	8,626	5,559	1,703
Ward admissions	0	3,305	738	3,167	1,933	4,956	2,919	3,039	1,280	1,043
ICU admissions	0	286	133	563	581	1,474	748	808	231	178
Deaths	0	86	21	141	160	608	703	992	394	459

**Note that 'denominator population' refers to numbers of persons at the time the 70% threshold coverage is achieved – vaccination continues during the simulations to the 80% coverage threshold values*

Table 5.5: As for table 5.4, for the 'All adults' allocation strategy

	<16 yrs		16-39 yrs		40-59 yrs		60+ yrs		70+ yrs	
	Vacc'd	Unvac	Vacc'd	Unvac	Vacc'd	Unvac	Vacc'd	Unvac	Vacc'd	Unvac
Denominator population*	0	5,075,816	5,062,890	3,466,741	4,606,867	3,354,501	4,887,948	779,933	2,613,873	346,776
Symptomatic infections	0	227,251	19,890	62,845	22,440	38,565	12,462	5,586	3,374	1,103
Ward admissions	0	1,993	468	2,099	1,202	3,343	1,726	1,897	748	654
ICU admissions	0	168	82	367	349	961	431	487	131	108
Deaths	0	45	13	84	92	361	373	552	207	257

**Note that 'denominator population' refers to numbers of persons at the time the 70% threshold coverage is achieved – vaccination continues during the simulations to the 80% coverage threshold values*

Table 5.6 Cumulative symptomatic infections, ward admissions, ICU admissions and deaths over the first 180 days for the coverage threshold of 80% achieved by the 'Oldest first' strategy, broken down by vaccination status and age

	<16 yrs		16-39 yrs		40-59 yrs		60+ yrs		70+ yrs	
	Vacc'd	Unvac	Vacc'd	Unvac	Vacc'd	Unvac	Vacc'd	Unvac	Vacc'd	Unvac
Denominator population	0	5,075,816	5,709,467	2,820,164	5,862,689	3,193,172	5,320,048	347,833	2,837,516	123,133
Symptomatic infections	0	276,576	25,005	77,813	24,135	41,190	14,705	6,324	4,051	1,260
Ward admissions	0	2,420	523	2,327	1,362	3,601	2,066	2,170	910	752
ICU admissions	0	206	92	404	399	1,036	513	561	160	124
Deaths	0	57	13	92	101	396	451	644	254	302

Table 5.7: As for table 5.6, for the 'All adults' allocation strategy

	<16 yrs		16-39 yrs		40-59 yrs		60+ yrs		70+ yrs	
	Vacc'd	Unvac	Vacc'd	Unvac	Vacc'd	Unvac	Vacc'd	Unvac	Vacc'd	Unvac
Denominator population	0	5,075,816	6,387,623	2,142,008	5,295,963	3,265,813	5,180,499	487,382	2,743,990	216,659
Symptomatic infections	0	163,282	13,695	44,046	15,467	27,074	8,523	3,833	2,326	757
Ward admissions	0	1,379	318	1,453	819	2,295	1,171	1,285	509	440
ICU admissions	0	113	55	252	235	648	288	325	88	71
Deaths	0	29	8	54	59	232	239	357	133	168

Ongoing work and next steps

Next steps are still under discussion but may include some or all of the following:

- Further exploration of dynamic scenarios showing the interplay between epidemic growth for different levels of achieved vaccine coverage, overlaid with social measures to limit transmission;
- Further reporting of outcomes for 'vaccine escape' variants;
- Extension of this work to state and territory level, focusing on key subpopulations including First Nations Australians and also more realistic delivery allocations given workforce constraints;
- Potential to consider reactive outbreak immunisation approaches, including in closed and special population settings;
- Potential to consider future allocation strategies including booster doses.

TECHNICAL APPENDIX

Virus assumptions

Given recent emergence of Delta variants, there is presently very limited evidence of their severity relevant to antecedent strains. While early reports from Scotland and Canada suggest clinical outcomes might be worse than for Alpha variants, it is important to note that infections in these settings are skewed towards unvaccinated population groups in whom other risk determinants may also differ, potentially confounding and inflating early estimates of severity.

On this basis we will assume that the severity of Delta strains approximates Alpha strains. Again, given the limited evidence of clinical outcomes for Alpha relative to the much more extensive literature on original 'wild-type' strains we draw our starting assumptions regarding disease progression from wild-type. We then apply age-based risk multipliers as indicated based on observations of the Alpha variant.

Table S1. Disease severity assumptions

Parameter	Description	Source		Value(s)
Wildtype severity parameters				
Pr(symptoms|wt)	Probability of symptomatic disease given wildtype infection	Davies et al. Nature Medicine (2020) [1] Clinical fractions estimated for 10-year age groups.	Age group	Symptomatic fraction
			0-9	0.28
			10-19	0.20
			20-29	0.26
			30-39	0.33
			40-49	0.40
			50-59	0.49
			60-69	0.63
			70+	0.69
Pr(hosp| symptoms)	Probability of hospital admission given symptomatic wildtype infection	Knock et al. Pre-print [2]. Prepared for UK roadmap modelling by Imperial group. UK data first wave.		Age-specific. See Tables S6 and S8 of Knock et al.
Pr(ICU|hosp)	Probability of ICU admission given hospital admission	Same as above.		Same as above.
Pr(death|ward)	Probability of death for ward patients (no ICU stay)	Same as above.		Same as above.

Pr(death|ICU)	Probability of death for ICU patients	Same as above.	Same as above.
Pr(death|post-ICU ward)	Probability of death for post-ICU patients	Same as above.	Same as above.
Alpha severity parameters			
Pr(symptoms|alpha)	Probability of symptomatic disease given Alpha infection	A number of studies using UK data suggest that the probability of reporting symptoms is consistent for wildtype and Alpha Walker et al. Pre-print [3]. Graham et al. Lancet Public Health (2021) [4].	RR=1
Pr(hosp|alpha)	Probability of hospitalisation given Alpha infection	Bager et al. Lancet Infect Dis (2021) [5]. Denmark data.	OR=1.42
Pr(ICU|alpha)	Probability of ICU admission given Alpha infection	Patone et al. Pre-print [6]. UK data.	HR=1.99
Pr(death|alpha)	Probability of death given Alpha infection	Davies et al. Nature (2021) [7]. UK data.	HR=1.61

Vaccine effectiveness assumptions

1. ATAGI advice on parameters to be used in the modelling

Table S2.1. Vaccine effectiveness estimates (%) against overall (asymptomatic and symptomatic) infection of SARS-CoV-2 Delta variant (based on Shiek et al 2021 [8])

Vaccine	Dose 1*			Dose 2†		
	Lower limit	**Point estimate**	Upper limit	Lower limit	**Point estimate**	Upper limit
AstraZeneca	9	**18**	25	53	**60**	66
Pfizer BNT	17	**30**	41	75	**79**	82

*estimates in study for ≥28days post dose 1 and pre dose 2
†estimates in study for ≥14days post dose 2

Table S2.2. Vaccine effectiveness estimates (%) reasonable to use as against onward transmission to household members in case of breakthrough infections in vaccine recipients for the Delta variant (Based on Harris et al 2021 [9])

Vaccine	Dose 1			Dose 2
	Lower limit	**Point estimate**	Upper limit	**Point estimate**
AstraZeneca	38	**48**	57	**65**
Pfizer BNT	38	**46**	53	**65**

Note: these estimates obtained from the published version of Harris et al study are marginally different to those in the May 2021 advice which were from the pre-print that was available at the time

Table S2.3. Combined vaccine effectiveness assumptions on transmission for the Delta variant

Vaccine	Reduction in infection *(E_i)*	Reduction in onward transmission *(E_t)*	Calculated overall reduction in transmission*
AstraZeneca Dose 1	18%	48%	57%
AstraZeneca Dose 2	60%	65%	86%
Pfizer BNT Dose 1	30%	46%	62%
Pfizer BNT Dose 2	79%	65%	93%

**Calculated overall reduction in transmission = $1-(1-E_i)*(1-E_t)$*

Table S2.4. Combined vaccine effectiveness assumptions on transmission for a hypothetical vaccine escape variant with 50% reduction in both E_i and E_t

Vaccine	Reduction in infection *(E_i)*	Reduction in onward transmission *(E_t)*	Calculated overall reduction in transmission*
AstraZeneca Dose 1	9%	24%	31%
AstraZeneca Dose 2	30%	33%	53%
Pfizer BNT Dose 1	15%	23%	35%
Pfizer BNT Dose 2	40%	33%	59%

Table S2.5. Vaccine effectiveness estimates (% reduction) against symptomatic disease, hospitalisation, ICU admission and death for the Delta variant.

Outcome	Vaccine effectiveness			
	Pfizer BNT		AstraZeneca	
	1 dose	2 doses	1 dose	2 doses
Symptomatic infection[a]	33%	83%	33%	61%
Hospitalisation[b]	71%	87%	69%	86%
ICU admission[c]	71%	87%	69%	86%
Mortality[b]	71%	92%	69%	90%

[a] Sheik et al [8]. Study cited in ATAGI advice informing VE against any infection. Estimates of VE against symptomatic infection from the Appendix table.

[b] LSHTM central estimates used for UK roadmap modelling on 9 June 2021 for Alpha [10]. Estimates are based on a range of studies and in line with Public Health England's COVID-19 vaccine surveillance report for pre-Alpha and Alpha (week 22) [11] except for mortality (informed by Dagan et al [12] and Lopez Bernal et al [13]). For Delta, VE for hospitalisation and mortality is reduced by half of the relative reductions by dose and product as estimated by Lopez Bernal et al. See LSHTM roadmap report from 9 June for details.

[c] Few studies report VE against ICU admission. ATAGI Appendix table refers to single study conducted in India (Victor et al [14]) which reports 95% and 94% reductions in ICU admission after dose 1 and dose 2 of AstraZeneca, respectively. The findings from this study are unlikely to be directly transferable to the Australian setting due to health system differences. As per previous work, we assume the same reductions in ICU admission given vaccination as for hospitalisation.

2. Model parameters incorporated in UK roadmap modelling

Table S2.6. Central scenarios used by UK SPI-M-O modelling groups on 9 June for Delta [10]. Imperial/LSHTM/Warwick.

Vaccine	**% Reduction in infection**	**% Reduction in onward transmission**
1 dose		
AstraZeneca	33/43/34	33/24/45
Comirnaty	33/47/34	33/33/45
2 doses		
AstraZeneca	55/62/71	33/45/45
Comirnaty	85/80/73	33/56/45

Table S2.7. Central vaccine effectiveness scenarios used for UK SPI-M-O modelling groups on 9 June 2021 [10], incorporating evidence from Public Health England and Public Health Scotland on vaccine effectiveness against Delta. Imperial/LSHTM/Warwick.

Outcome	Vaccine effectiveness (% reduction)			
	Pfizer BNT		AstraZeneca	
	1 dose	2 doses	1 dose	2 doses
Symptomatic disease	33/47/34	85/84/83	33/43/34	55/71/82
Hospitalisation	73/71/64	89/87/91	73/69/64	85/86/90
Mortality	73/71/60	89/92/96	73/69/60	85/90/96

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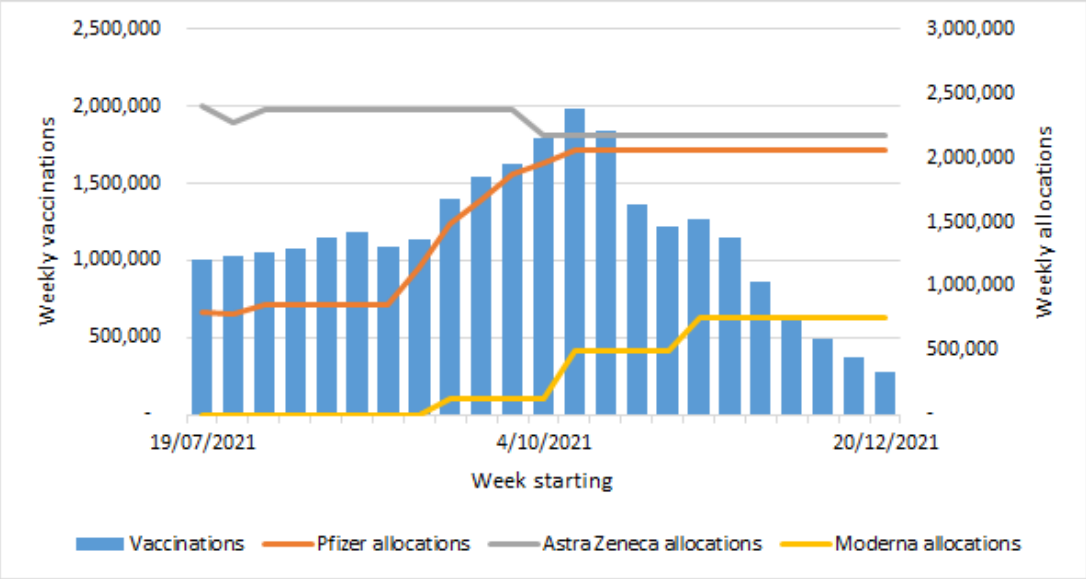
Vaccine allocation scenarios

Scenario vaccination rates are determined using an agent-based simulation model utilising location and allocation data on vaccination sites and location data for the Australian population. Each week, a subset of the population seeks vaccination at available sites within their respective area. Sites receive deliveries of vaccines and administer vaccinations to the seeking population up to their level of stock.

Site allocations to Primary Care channels and State and Territory channels are based on planned allocations approved by the Health Minister as of 15 July 2021, weighted by assumptions about maximum capacities and geographical coverage provided by the National COVID Vaccine Taskforce Planning Team. Figure S1 shows total weekly allocations by vaccine.

Figure S1: Weekly allocations and modelled vaccinations for oldest first, AZ 12 weeks dose interval and AZ 60+ years strategy.



Note: Weekly vaccination rates taper towards the end of the rollout due to potential allocation constraints by geography, which means some areas reach completion before others. Further, modelled vaccination rates in an area may taper before completion because not all individuals seek a vaccination every week.

Locations for known existing and known planned Primary Care sites are provided by the Department of Health Primary Care Response Team. Sites are assumed to order and have the capacity to fulfil 78% of their planned allocations based on recent calculated vaccine utilisation rates by vaccination sites, as of 15 July 2021. Sites are also assumed to prioritise second doses over first doses, and any unused doses are assumed to be able to be used for future weeks.

Australian population is based on 2016 ABS Census data, scaled to 2021 Estimated Resident Populations (ERPs). Individuals are assumed to be willing to drive up to 30, 60 or 120 minutes to sites depending on their remoteness. Individuals are also assumed to seek vaccination once every 4 weeks on average, with each seeking individual assumed to be willing to try up to 5 sites to receive vaccination. The vaccinations are modelled from a starting point of existing administrations up to and including 11 July 2021, with coverage of at least 1 or 2 vaccine doses at 33.2% and 11.4% respectively based on AIR data as of 15 July 2021 (Table S3). Note that dose 1 coverage includes individuals who go on to receive dose 2.

Table S3.1: Distribution of vaccination coverage within each age band up to and including 11 July 2021 based on Australian Immunisation Register (AIR) data as of 15 July 2021.

Age band	Pfizer dose 1	Pfizer dose 2	Astra Zeneca dose 1	Astra Zeneca dose 2	Total dose 1	Total dose 2
16-19	2.9%	1.6%	0.9%	0.5%	3.8%	2.1%
20-29	8.5%	6.0%	2.1%	1.5%	10.6%	7.5%
30-39	11.4%	8.1%	2.6%	1.8%	13.9%	9.9%
40-49	26.4%	20.2%	3.5%	2.4%	29.9%	22.6%
50-59	12.2%	7.3%	29.5%	5.0%	41.8%	12.3%
60-69	5.2%	4.2%	53.0%	8.0%	58.2%	12.2%
70-79	4.5%	3.0%	72.5%	27.2%	77.0%	30.2%
80+	16.2%	11.8%	65.3%	22.0%	81.5%	33.8%
Total	**11.4%**	**6.7%**	**21.8%**	**4.8%**	**33.2%**	**11.4%**

Figures represent vaccinations as a percentage of total eligible population (age 16+).

Scenario parameters are implemented in the model as follows:

- Vaccine age prioritisation: Age prioritisation occurs independently within each local region (mixture of non-overlapping ABS Mesh Blocks, Statistical Area Level 1 and Statistical Area Level 2). Individuals within the same region are vaccinated in the order of the respective prioritisation strategy. For example, under the 'oldest first' strategy, each region will vaccinate their 80+ age band first and can move on to their 70-79 age band as soon as they've completed their 80+ age band. This means vaccination timing for each age band differs for each region and is dependent on the region's age distribution. Note that timing is also dependent on the vaccination rate of each region (determined by nearby site allocations).
- Astra Zeneca dosing interval: Under the current dose interval of 12-weeks, individuals are only able to begin seeking their second dose 12-weeks after their first dose. Reducing the dosing interval to 8-weeks or 4-weeks allows individuals to seek their second dose earlier.
- Astra Zeneca age recommendation: Under the current age recommendation of 60+, we assume for simplicity half of the remaining 60+ population to be vaccinated will seek Astra Zeneca while the other half will seek Pfizer. Similar logic follows under a recommendation of 40+, resulting in an increased number of individuals seeking Astra Zeneca.

Under these implementation assumptions, the age distribution of achieved vaccine coverage varies by age cohort by achievement of the 80% coverage target (Table S3.2). Of particular note, the uptake for the 16-39 age bands is highest in the 'random' strategy (6.4m people) out of the three scenarios explored (5.7m people for either of the other two strategies).

**Note that these allocation scenarios are artificial by design, to demonstrate the impacts of alternative immunisation approaches. Further modelling is required to map observed benefits to deliverable allocation strategies given the current stage of the national COVID-19 vaccine rollout.*

Table S3.2: Distribution of vaccination coverage by age band by achievement of the 70% vaccination coverage threshold (1st November) for standard AZ dosing indications (60+, 12 week interval between doses) and the three age-based allocation strategies.

		Proportion of age band eligible pop fully vaccinated		
Age band	Eligible pop	Oldest first	40+ years first	All adults
16-19	1190616	4.2%	86.1%	57.1%
20-29	3577491	18.9%	52.6%	58.8%
30-39	3761524	74.8%	16.6%	60.6%
40-49	3295699	90.4%	90.6%	69.0%
50-59	3127124	92.1%	92.0%	74.6%
60-69	2707232	87.3%	93.8%	84.0%
70-79	1897838	96.1%	93.3%	89.4%
80+	1062811	95.2%	83.0%	86.3%

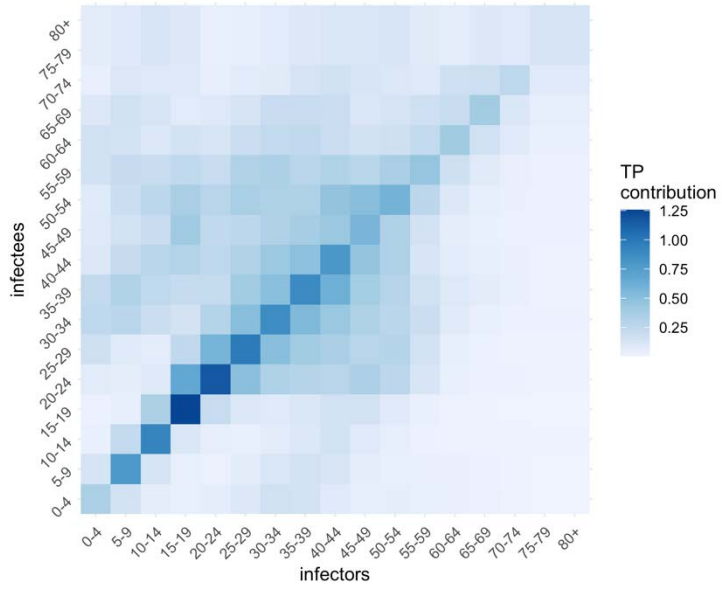
Table S3.3: Distribution of vaccination coverage by age band by achievement of the 80% vaccination coverage threshold (22nd November) for standard AZ dosing indications (60+, 12 week interval between doses) and the three age-based allocation strategies.

		Proportion of age band eligible pop fully vaccinated		
Age band	Eligible pop	Oldest first	40+ years first	All adults
16-19	1190616	8.6%	86.9%	73.5%
20-29	3577491	64.1%	87.1%	74.6%
30-39	3761524	88.1%	41.4%	75.6%
40-49	3295699	90.5%	90.6%	80.8%
50-59	3127124	92.1%	92.0%	84.2%
60-69	2707232	91.7%	94.2%	90.0%
70-79	1897838	96.2%	95.9%	93.4%
80+	1062811	95.2%	89.2%	91.4%

Population mixing assumptions

Population mixing within and between age groups is configured based on widely accepted social contact matrices published by Prem et al (PLoS Computational Biology 2017)(Figure S2.1). It has been expanded to include an 80+ age class (assumed to have the same mixing rates as 75-79 years). Age-specific susceptibility and transmissibility estimates from Davies et al. (Nature Medicine 2020) are used and transmission rates have been calibrated to our baseline population-wide TP (here denoted R) of 3.6. Of note, the greatest mixing intensities are anticipated between individuals aged from 15-24 years, remaining high through adults of working age. While intense school-based mixing is anticipated between children aged 5-14, the transmission matrix accounts for the relatively low observed infectiousness of this age group, associated with a high proportion of asymptomatic infections.

Figure S2.1: Age-based transmission matrix derived from Prem et al (2017)



The key message of Figure S2.1 is that in the absence of vaccination, individuals of different ages do not contribute equally to the spread of infection in the population.

The impact of vaccination on overall transmission will therefore be substantially influenced by the rate of vaccine uptake achieved **within distinct population age cohorts.** Table S3.2 shows the range of values for achieved coverage by age group underpinning 80% 'age eligible coverage' for our three hypothetical vaccine allocation strategies.

Figures S2.2-S2.5 provide a visual demonstration of the reduction in transmission achieved for each age band depending on the rollout scenario. Light grey bars show the contribution of each age group to transmission potential given different numbers of contacts and age differences in both susceptibility and infectiousness, in the absence of vaccination. Dark grey bars show the contribution of each age group to transmission potential for that vaccine allocation strategy and coverage. The 'all ages' strategy consistently produces the greatest proportional reductions in infectiousness across peak transmitting age groups.

Figure S2.2: Impact of the three different allocation strategies on TP by age category, resulting in the overall TP achieved by 50% age eligible population coverage

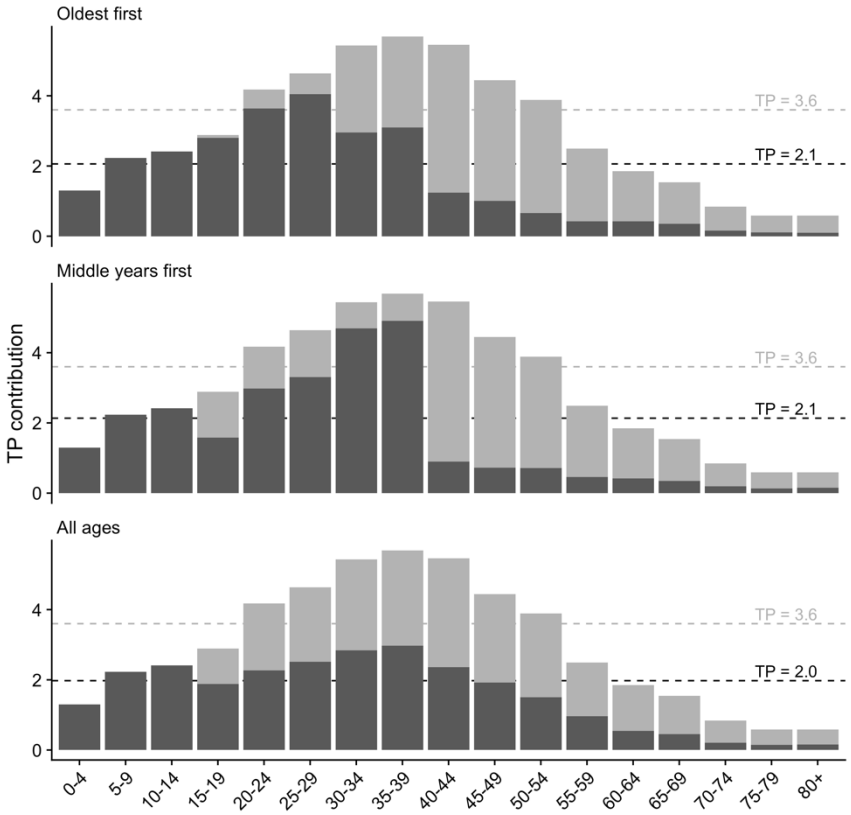


Figure S2.3: As for Figure S2.2, but for 60% age eligible population coverage

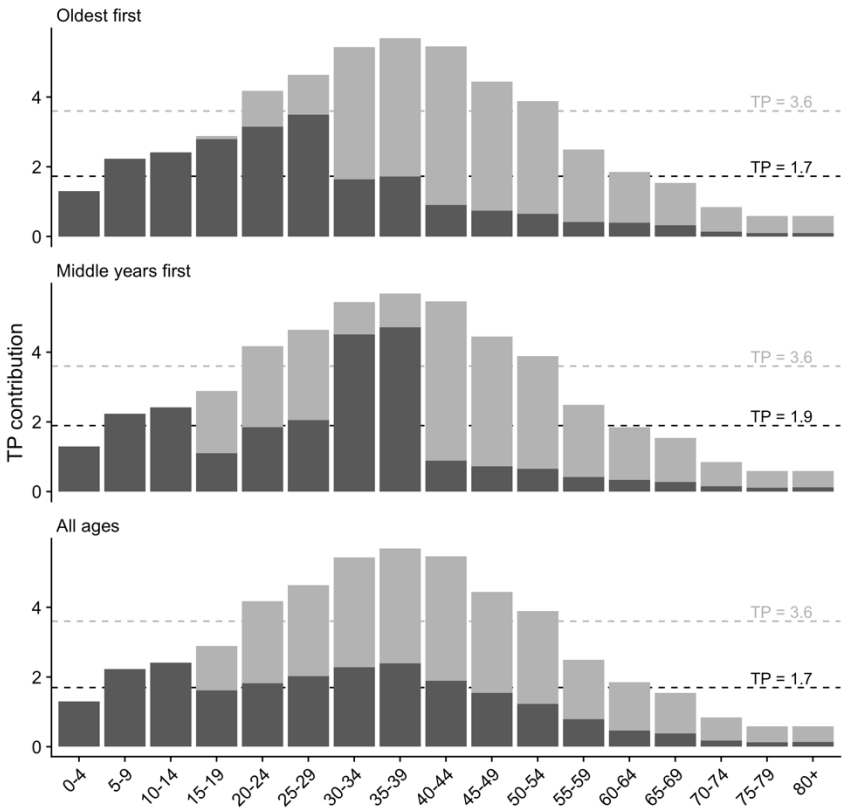


Figure S2.4: As for Figure S2.2, but for 70% age eligible population coverage

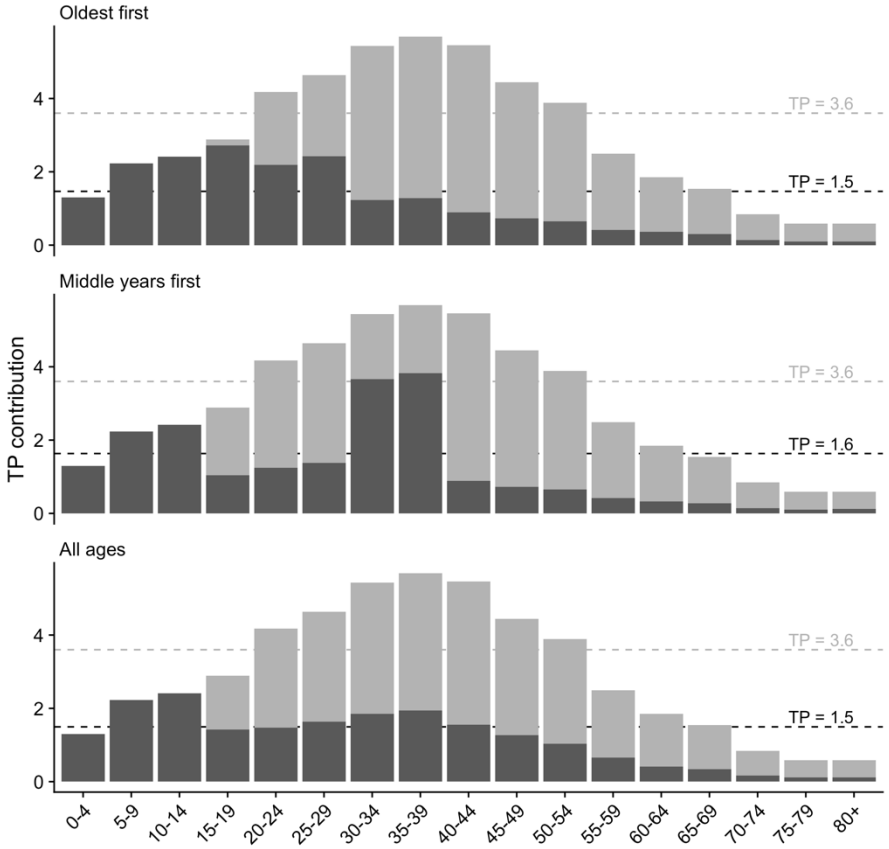
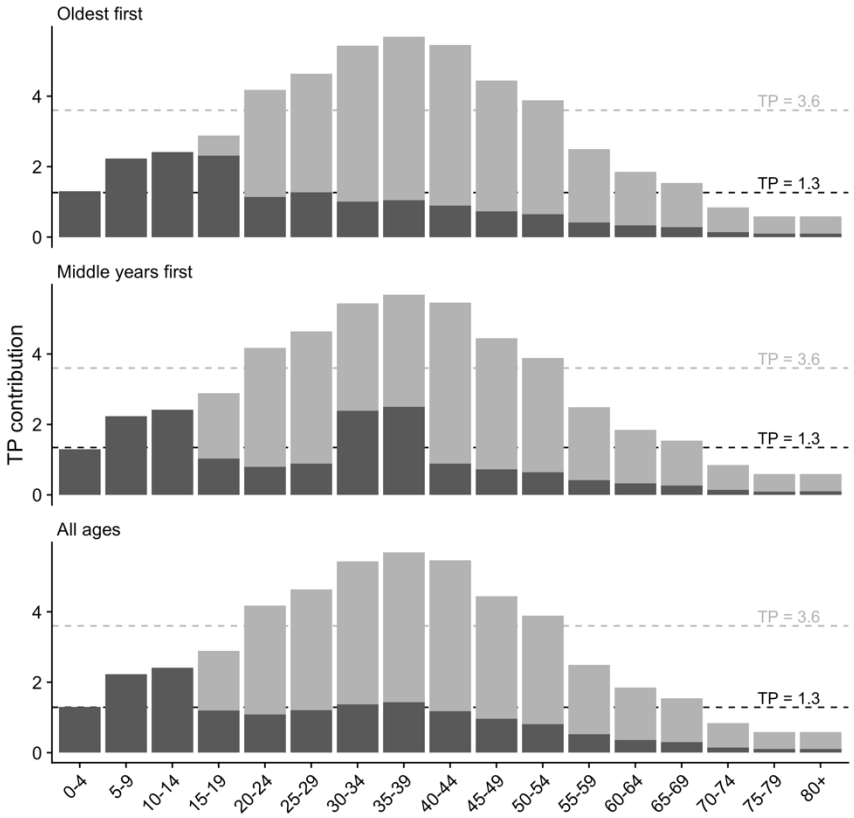


Figure S2.5: As for Figure S2.2, but for 80% age eligible population coverage



Impact of public health response and bundled social measures on TP

We estimated TP over time in each Australian state and territory using the same Bayesian semi-mechanistic model that has been used for situational awareness throughout the pandemic. This model incorporates data on case counts, mobility metrics, behavioural survey data, and delays between symptom onset and case detection to quantify the statewide averaged reproduction number that could be expected during widespread transmission. This model is described in technical detail elsewhere (https://www.doherty.edu.au/uploads/content_doc/Technical_Report_15_March_2021_RELEASED_VERSION.pdf). Subsequent to this description, the model has been updated to account for increased transmission probabilities associated with Delta (calculated via the same method as for previous variants of concern).

Impact of vaccination on TP

We estimated the percentage reduction in TP that could be expected under different vaccination coverages and distributions by age, vaccine type, and number of doses received via static analysis of the age-based transmission matrix shown in figure S2.1. For each vaccination scenario, the reduction in transmission by age group was calculated from the average vaccination efficacy against transmission (accounting for the fractions of each vaccine type and number of doses in that age group) and the age group coverage. The reductions in transmission were then applied to the columns of the transmission matrix, and the dominant eigenvalue (population-wide reproduction number) was compared between the vaccinated transmission matrix and the baseline matrix top compute a percentage reduction in TP.

PHSM bundles

PHSM bundles described in the main text represent periods when a variety of different restrictions were in place. Table S4.1 (provided by Treasury) lists restrictions corresponding to these periods. We emphasise that the TPs associated with these PHSM bundles reflect state wide population behaviours (numbers of household contacts and adherence to hygiene advice) estimated at these times, which differs substantially over time and between states, even within similar restrictions. These periods are therefore intended to reflect achievable levels of reduction in TP via PHSMs, rather than inference about the particular impacts of these sets of restrictions.

TTIQ assumptions

Recognising that the TTIQ public health response will be less effective at high caseloads, we adapted this model to include an explicit effect of reducing the time to case isolation that can be achieved through intensive contact tracing. This is in addition to the time to case detection effect already included. The empirical distribution of times to case isolation under recent, 'optimal' TTIQ capacity was estimated using a limited timeseries of case data from NSW between July 2020 and January 2021. This distribution was then calibrated to estimate the distribution of times to isolation in other times and states by assuming improvements in TTIQ are proportional to improvements in times to detection. This provided a distribution of times to case isolation under partially efficacious TTIQ (calibrated against VIC 4 August 2020 – the peak of daily locally-acquired COVID-19 cases in Australia) for use in the dynamic simulation model and estimates of the effect of partial TTIQ on transmission potential to estimate a baseline TP under community transmission.

Table S4.1: Description of measures implemented under PHSM 'bundles'

	High PHSM	Medium PHSM	Low PHSM	Baseline PHSM
Reference period	VIC 23 August 2020	NSW 1 July 2021	NSW 23 August 2020	NSW March 2021
Stay at home orders	• Stay-at-home except essential purposes	• Stay-at-home except for work, study and essential purposes	• No stay-at-home orders	• No stay-at-home orders
Density restrictions	• 4 sqm rule	• 2 sqm rule	• 2 sqm rule	• 2 sqm rule
Retail trade	• Non-essential retailers and venues closed to public. • Take away and home delivery only.	• Increased retail activity, subject to density restrictions • Seated dining for small groups at cafes/restaurants	• Social distancing rules apply • Larger groups allowed	• Social distancing rules apply •
Work	• Only workplaces categorised as permitted work allowed to operate on-site and subject to restrictions	• Work from home if possible, capacity limits and restrictions on office space apply	• Return to work, but social distancing and capacity restrictions on office space apply	• 1.5 sqm rule
Schools and childcare	• Closed – remote learning only	• Closed or graduated return	• Open	• Open
Capacity restrictions	• No gatherings - Non-essential venues etc closed.	• Indoor venues closed. • Capacity limits restricted to small groups outdoors	• Recreational activities allowed and venues open but social distancing and capacity limits apply	• Large sporting venues to operate at 70 per cent capacity
Travel restrictions	• Essential movements only within 5 or 10 km radius • No intra- or inter-state travel	• Non-essential travel limited – no intra or inter-state travel •	• No travel restrictions • Interstate travel allowed	• No travel restrictions • Interstate travel allowed
Other	• Curfew • No household visitors and 2-person limit on exercise	• 5 visitors to household and limited outdoor gatherings e.g., 10 people	• Requirements for record keeping, COVID-safe plans etc	•

Fraction of time under restrictions

Where a vaccination scenario leads to either a $TP_1 > 1$ with one PHSM bundle, or $TP_2 < 1$ with a more stringent bundle, the long-term average TP can be maintained at 1 (and therefore daily case counts neither growing nor shrinking over the long term) by alternating between the two PHSM bundle states. Whilst the first PHSM bundle is in place cases will grow, and whilst the more stringent bundle is in place cases will shrink, leading to an oscillation of case counts around some average level. This reflects a strategy that might be used to keep cases below a health sector capacity limit in the event that there is long-term community transmission and under the necessary simplifying assumption that vaccination coverage is static. The fraction can be computed as:

$$\text{fraction} = -\log(TP_1) / (\log(TP_2) - \log(TP_1))$$

where $TP_1 < 1$ the fraction is zero (TP_2 is not needed) and when $TP_2 > 1$ no fraction exists, because even the more stringent PHSM bundle could not control transmission.

Tables 4.2 and 4.3 demonstrate the importance of the TTIQ response to constrain transmission, by comparing requirements for PHSMs for the same vaccine coverage thresholds, under the alternative allocation scenarios and in the context of:

- 'Optimal' TTIQ response, deemed achievable when active case numbers can be contained in the order of 10s or 100s;
- 'Partial' TTIQ response, deemed more likely when established community transmission leads to rapid escalation of caseloads in the 1,000s or beyond.

Table 4.2 shows that light or moderate restrictions will likely be insufficient to regain control of epidemics even at 70% coverage for only a partially effective TTIQ response. Prolonged lockdowns would likely be needed to limit infection numbers and caseloads. The proportion of time during which the community would experience imposition of these stringent measures logically declines as vaccine coverage increases.

In contrast, Table S4.3 shows that if optimal TTIQ can be maintained the requirement for strict lockdowns as part of the incursion response diminishes with increasing vaccine coverage. In many instances, moderate or even light restrictions may be sufficient to curb epidemic growth. Note that the share of time under restrictions will be overestimated if there are sustained periods with no new outbreaks, due to effective border control.

As shown in Figure 1.2 in the main text, ongoing application of light social restrictions is anticipated to constrain epidemic growth over and above vaccination. Assuming population co-operation these restrictions will support maintenance of optimal TTIQ response capacity, which is critical to avoidance of stringent social measures.

Table S4.2: Proportion of time lockdowns are needed to constrain transmission when the TTIQ public health response is only *partially effective,* due to high caseloads

Vaccine coverage	Allocation scenario	Light restrictions only	Moderate lockdowns only	Strict lockdowns only
50%	Oldest first	Not possible to constrain outbreak with light restrictions	Not possible to constrain outbreak with moderate lockdown	89%
	40+ years first	Not possible to constrain outbreak with light restrictions	Not possible to constrain outbreak with moderate lockdown	93%
	All adults	Not possible to constrain outbreak with light restrictions	Not possible to constrain outbreak with moderate lockdown	84%
60%	Oldest first	Not possible to constrain outbreak with light restrictions	Not possible to constrain outbreak with moderate lockdown	67%
	40+ years first	Not possible to constrain outbreak with light restrictions	Not possible to constrain outbreak with moderate lockdown	78%
	All adults	Not possible to constrain outbreak with light restrictions	Not possible to constrain outbreak with moderate lockdown	65%
70%	Oldest first	Not possible to constrain outbreak with light restrictions	77%	47%
	40+ years first	Not possible to constrain outbreak with light restrictions	99%	60%
	All adults	Not possible to constrain outbreak with light restrictions	81%	49%
80%	Oldest first	82%	47%	29%
	40+ years first	Not possible to constrain outbreak with light restrictions	59%	36%
	All adults	89%	51%	31%

Table S4.3: As for Table S4.2, but for an *optimally effective* TTIQ response

Vaccine coverage	Allocation scenario	Light restrictions only	Moderate lockdowns only	Strict lockdowns only
50%	Oldest first	Not possible to constrain outbreak with light restrictions	Not possible to constrain outbreak with moderate lockdown	63%
	40+ years first	Not possible to constrain outbreak with light restrictions	Not possible to constrain outbreak with moderate lockdown	67%
	All adults	Not possible to constrain outbreak with light restrictions	94%	58%
60%	Oldest first	Not possible to constrain outbreak with light restrictions	67%	41%
	40+ years first	Not possible to constrain outbreak with light restrictions	86%	52%
	All adults	Not possible to constrain outbreak with light restrictions	64%	39%
70%	Oldest first	60%	34%	21%
	40+ years first	97%	56%	34%
	All adults	67%	38%	23%
80%	Oldest first	7%	4%	3%
	40+ years first	29%	17%	10%
	All adults	15%	8%	5%

Table S4.4: Proportion of time lockdowns are needed to constrain transmission when the TTIQ public health response is only *partially effective,* due to high caseloads, and where light restrictions are always in place.

Vaccine coverage	Allocation scenario	Moderate lockdowns only	Strict lockdowns only
50%	Oldest first	Not possible to constrain outbreak with moderate lockdown	82%
	40+ years first	Not possible to constrain outbreak with moderate lockdown	89%
	All adults	Not possible to constrain outbreak with moderate lockdown	75%
60%	Oldest first	Not possible to constrain outbreak with moderate lockdown	49%
	40+ years first	Not possible to constrain outbreak with moderate lockdown	67%
	All adults	Not possible to constrain outbreak with moderate lockdown	46%
70%	Oldest first	46%	18%
	40+ years first	97%	39%
	All adults	55%	22%
80%	Oldest first	0%	0%
	40+ years first	4%	2%
	All adults	0%	0%

Table S4.5: As for Table S4.4, but for an *optimally effective* TTIQ response

Vaccine coverage	Allocation scenario	Moderate lockdowns only	Strict lockdowns only
50%	Oldest first	Not possible to constrain outbreak with moderate lockdown	42%
	40+ years first	Not possible to constrain outbreak with moderate lockdown	49%
	All adults	87%	35%
60%	Oldest first	23%	9%
	40+ years first	66%	27%
	All adults	15%	6%
70%	Oldest first	0%	0%
	40+ years first	0%	0%
	All adults	0%	**0**%
80%	Oldest first	0%	0%
	40+ years first	0%	0%
	All adults	0%	0%

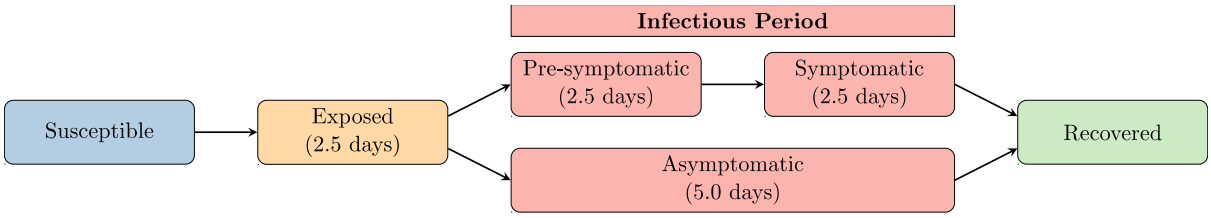
Transmission model description

We implement an individual-based model to estimate COVID-19 spread under various vaccination allocation and coverage scenarios. We use an individual-based framework because it allows us to specify arbitrary vaccine schedules and to efficiently implement case-finding, case isolation and contact quarantine in the model.

The model defines a population, where every individual has an age, corresponding to an input age-structure. Infected individuals contact others in the population at random, modified by an input age-structured contact matrix. based on 2016 ABS Census data, scaled to 2021 Estimated Resident Populations (ERPs) and we assume mixing between age groups as estimated by Prem et al. (PLoS Computational Biology 2017). When a susceptible individual contacts an infectious individual, there is a probability that they will contract the virus.

When infected, an individual transitions into an exposed class, before moving into an infectious class, where they can be either asymptomatic or symptomatic, and finally they move into a recovered class (Figure S3).

Figure S3: Transitions between states in the individual based model



The model incorporates age-specific susceptibilities to infection and probabilities of developing symptoms given infection (according to Davies et al Nature Medicine 2020).

Vaccine assumptions

COVID-19 vaccines act on multiple elements of transmission and disease. We assume that vaccination reduces susceptibility to infection (according to Table S2.1) and the probability of developing symptomatic disease given infection (according to Table S2.5). The latter impacts transmission since we assume that asymptomatic individuals are 50% less infectious. We further assume that infected vaccinated individuals are less infectious by a factor calculated to match combined vaccine effectiveness assumptions on transmission (Table S2.3).

Model initialisation and simulations

For the scenarios presented in the main report, we use a population of approximately 24 million individuals and an initial basic reproduction number (R_0) of 6.32 which corresponds to our baseline population-wide TP minus the effects of TTIQ or surveillance. We note that the effective reproduction number is below 6.32 due to the incorporation of TTIQ and vaccination in the simulation.

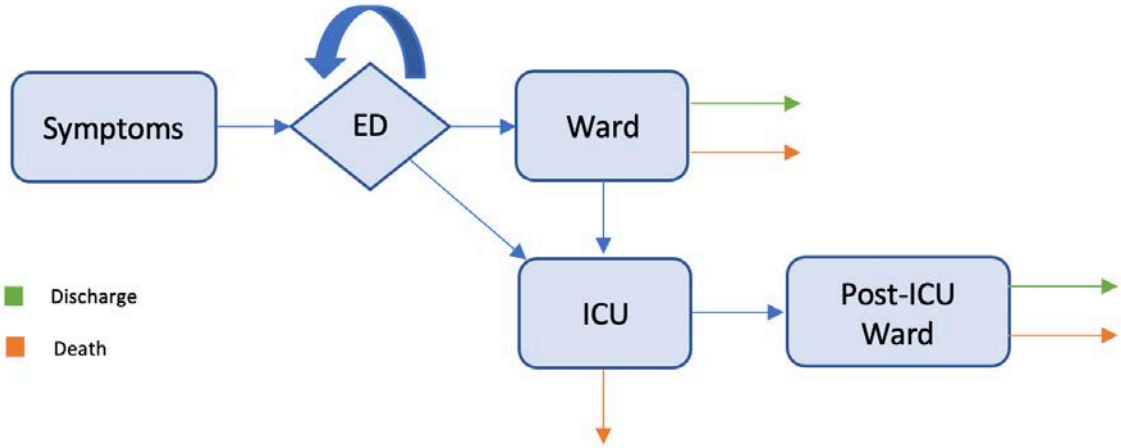
Individuals are vaccinated dynamically in the model, according to an age-specific schedule of doses per day (Figure S1). Second doses are given at a set time from the first dose, which is 3 weeks for mRNA Pfizer/Moderna and 12 weeks for AstraZeneca.

Once the predefined vaccination threshold is reached (50%, 60%, 70% or 80%), we expose 30 unvaccinated individuals, triggering the start of disease transmission. For all scenarios, we assume partial TTIQ effectiveness which isolates each individual according to a known distribution estimated from Victorian data at the height of the 'second wave' in 2020 as our best estimate of public health response performance under high caseloads. As the virus is spreading through the community, we continue the dynamic vaccination of individuals.

Each simulation outputs a line list of infections by age, vaccination status (dose number and product), and symptom status (symptomatic or asymptomatic), from which we can generate our daily case numbers.

Clinical pathways model

Figure S4: Schematic representation of states captured in the clinical pathways model



The clinical pathways model takes inputs of daily symptomatic individuals, stratified by age and vaccination status, from the epidemic model. There is a delay between the onset of symptoms and presentation to ED. Upon arrival to ED individuals are either admitted to ward immediately, admitted to ICU immediately, or if ED is at capacity, individuals are not admitted and may re-present the next day. For this phase of the work, we assume the only symptomatic cases requiring hospitalisation present to ED. Individuals who are admitted to ward will either die, be discharged from ward or eventually require ICU care. Individuals in ICU will either die in ICU or return to ward, from here they will either die or be discharged.

The lengths of stay in each compartment/clinical setting depends on the eventual clinical pathway of individuals. For example, lengths of stay in ward will typically be shorter for individuals who later require ICU care. The pathways of individuals through the health system are dependent on both their age and vaccination status. All length of stay distributions and age stratified probabilities of transitions between compartments are taken from [2], which are scaled for the Delta variant according to Table S1 and vaccination status according to Table S2.5. The model accounts for uncertainty by using stochastic inputs from the epidemic model, generating stochastic trajectories/pathways through the hospital system and sampling from the posterior length of stay distributions from [2].

Workforce participation assumptions

Table S5: Workforce participation proportions, by age. Source: Treasury

10-19	20-29	30-39	40-49	50-59	60-69	70-79	80+
0.27006	0.83684	0.862148	0.863779	0.799347	0.46397	0.115252	0.02064

Estimates of available clinical capacity for management of COVID-19 cases

National health care capacities were defined based on current operations and envisaged sustainable capacity under an ongoing community transmission scenario. It should be noted that these figures are substantially lower than peak surge estimates in early 2020 when a single epidemic wave was considered a likely scenario.

Appendix Table S6: Estimated national and per-jurisdiction healthcare capacities for ward beds, ED and GP consultations based on AIHW data, under the assumption that 50% of total capacity in each healthcare setting could possibly be devoted to COVID-19 patients*. Estimates of ICU capacity are taken directly from the National COVID-19 Common Operating Picture#.

Healthcare resource	National	ACT	NSW	NT	QLD	SA	TAS	VIC	WA
COP ICU beds	1,964	37	737	24	298	197	39	515	117
Ward beds	25,756	448	8,832	276	5,099	1,915	557	6,158	2,471
ED consultations	10,935	202	3,945	172	2,071	694	222	2,456	1,173
GP consultations	202,999	2,607	66,616	1,582	43,627	14,005	3,935	51,338	19,289

*ED and GP capacities reflect maximum number of daily consultations.
https://www.health.gov.au/sites/default/files/documents/2021/07/coronavirus-covid-19-common-operating-picture-8-july-2021.pdf

Addendum to Doherty Modelling Report for National Cabinet 30 July 2021

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Executive summary

- Models of COVID-19 infection and vaccination were used to define a target level of vaccine coverage for transition to Phase B of the National Plan. The model was based on the simplifying assumption of a single national epidemic, with COVID-19 transmission, severity and vaccine effectiveness as for the Delta variant.
- Our report for 30th July 2021 National Cabinet considered hypothetical age-based vaccine allocation scenarios underpinning coverage targets of 50, 60, 70 and 80%, to explore the population level impacts of strategies focused either primarily on direct protection or transmission reduction.
- From the starting point of age-based coverage in Australia as of 12 July 2021, an 'All adults' allocation strategy that achieved high coverage in key transmitting populations (20-39 years) resulted in greatest reductions in harms across all age groups, regardless of vaccination status.
    - This hypothetical scenario was mapped to an *implementable strategy consistent with the national COVID-19 immunisation programme*, under which vaccines would be opened up to 30-39 year olds on 31 August 2021, and 16-29 years olds from 11 October, called 'Transmission reducing';
    - This strategy captured the benefits achieved under the previous preferred strategy, achieving a slightly lower TP by 70% coverage, and equivalence at 80%;
    - Epidemic dynamics assuming baseline restrictions and partial TTIQ were very similar to the 'all adults' strategy;
    - Corresponding clinical outcomes were similar or improved at coverage of 60% or above.

- Our main report highlighted the importance of maintaining optimal TTIQ responses in the context of ongoing 'low' public health and social measures to minimise rapid epidemic growth and escalation of severe disease outcomes, even in a highly immunised population;
    - This report compared epidemic dynamics and clinical outcomes for the 'Transmission reducing' strategy assuming either 'baseline measures with partial TTIQ' or 'low PHSMs with optimal TTIQ';
    - Infections and corresponding adverse consequences were reduced by several orders of magnitude, assuming ongoing light restrictions and sustained highly effective public health response capacity;
    - The ability to deliver this capacity is greatly assisted by the more even distribution of reported cases over the 6 months time window of reporting, given an absence of rapid epidemic escalation.

- *As in our previous report, the contingency of these outcomes on population behaviours including vaccine acceptance, co-operation with behavioural restrictions and active engagement and compliance with public health responses is critically important for achieving programmatic outcomes.*

- *Our models assume a point source outbreak as the key initiating event for transmission. Given the low caseloads achieved under the 'optimal TTIQ' scenario and considered desirable in Phase B, the influence of imported infections on local epidemic dynamics merits further exploration in the next phase of modelling.*

Exploring vaccine thresholds for transition to Phase B of the National Plan

Our report for 30th July 2021 National Cabinet considered hypothetical age-based vaccine allocation scenarios underpinning coverage targets of 50, 60, 70 and 80%, to explore the population level impacts of strategies focused either primarily on direct protection or transmission reduction. From the starting point of age-based coverage in Australia as of 12 July 2021, an 'All adults' allocation strategy that achieved high coverage in key transmitting populations (20-39 years) resulted in greatest reductions in harms across all age groups, regardless of vaccination status. This hypothetical scenario was mapped to an *implementable strategy consistent with the national COVID-19 immunisation programme*, under which vaccines would be opened up to 30-39 year olds on 31 August 2021, and 16-29 years olds from 11 October, called 'Transmission reducing'.

Defining the transmission reducing strategy

The 'transmission reducing' strategy is defined in relation to previously modelled vaccination allocation scenarios in Table 1.1.

Table 1.1: Vaccine allocation strategies by age, assuming current recommendations for Astra Zeneca vaccine age eligibility (60+ years) and dosing interval (12 weeks)

Strategy	Allocation sequence
Oldest first	Vaccinations are prioritised from oldest to youngest. Specifically, prioritization occurs in the following order: 80+, 70-79, 60-69, 50-59, 40-49, 30-39, 20-29, 16-19
40+ years first	Vaccinations are prioritised from 40+ upwards, then 16+. Specifically, prioritization occurs in the following order: 40-49, 50-59, 60-69, 70-79, 80+, 16-19, 20-29, 30-39
All adults	Vaccinations are not prioritised in any particular order by age
Transmission reducing	As for national program, under which all individuals 40+ are currently eligible. Within the simulation timeframe, the 30-39 years cohort becomes eligible from 30 August, and 16-29 year olds on 11 October.

Timeliness of achieving coverage targets by vaccine allocation scenario

The indicative dates of achieving differing coverage thresholds for the 'transmission reducing' strategy are shown relative to the previously explored scenarios in Table 1.2. Under the revised scenario, there is an anticipated one week delay to achieving the 70% coverage threshold, but all other target dates are unchanged. Not that achievement of any of these thresholds by the given date is contingent on population acceptance.

Table 1.2: Date of achieving a given vaccine coverage threshold by allocation strategy, assuming a start date and population completed doses (AIR) as of 12th July 2021, assuming Astra Zeneca is recommended only for 60+ years and delivered at a 12 week interval

	Coverage threshold			
Strategy	**50%**	**60%**	**70%**	**80%**
Oldest/40+ first and All ages	4 October	18 October	1 November	22 November
Transmission reducing	4 October	18 October	**8 November**	22 November

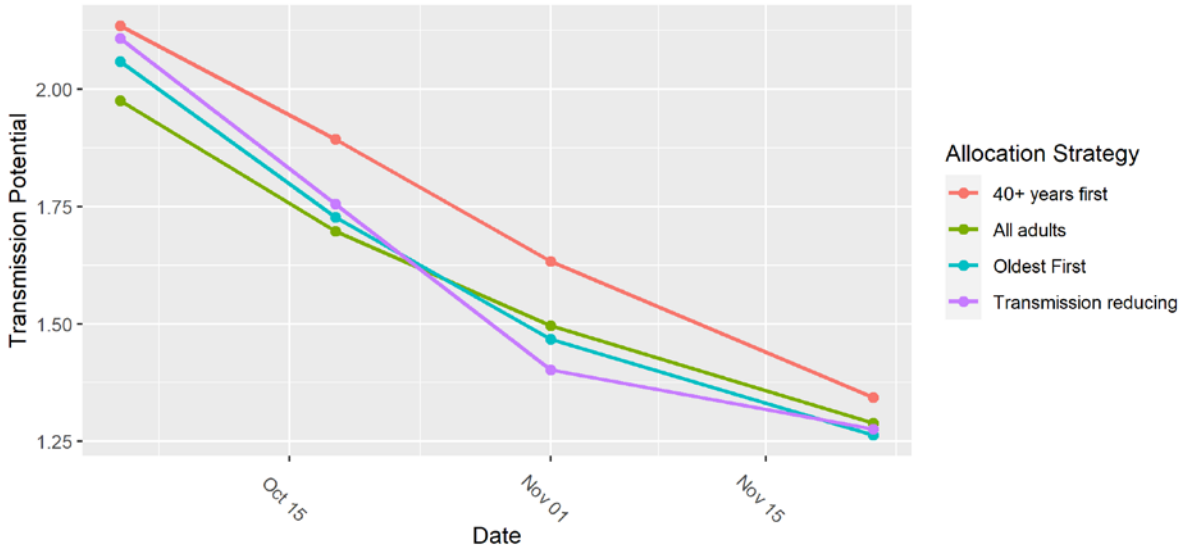
Transmission potential (TP) by vaccine coverage and allocation strategy

The reduction in TP achieved for each strategy by the coverage threshold is shown in Table 2.1 and Figure 1. As shown in the static table, the greatest gains of the transmission reducing strategy relative to others is demonstrable at the 70% coverage threshold, by which point it outperforms the 'all adults' strategy.

Table 2.1: Scaled values of Delta variant transmission potential (TP) for 50%, 60%, 70% and 80% population coverage for each allocation strategy, assuming AZ is delivered to individuals aged 60+ years, with a 12-week dosing interval. We use a starting TP of 3.6.

	Eligible population coverage (16+)			
Allocation Strategy	**50%**	**60%**	**70%**	**80%**
Oldest first	2.1	1.7	1.5	1.3
40+ years first	2.1	1.9	1.6	1.3
All adults	2	1.7	1.5	1.3
Transmission reducing	2.1	1.8	1.4	1.3

Figure 1: Rate of change in TP over time, by vaccine allocation strategy



Impact of public health response and bundled social measures on TP

Figure 2.1: Combined effects of vaccination and PHSM scenarios on COVID-19 transmission potential under the 'Transmission reducing' vaccination scenario assuming only *partial TTIQ effectiveness*, due to high caseloads. Standard age (60+) and dosing interval (12 weeks) recommendations are assumed for the AZ vaccine.

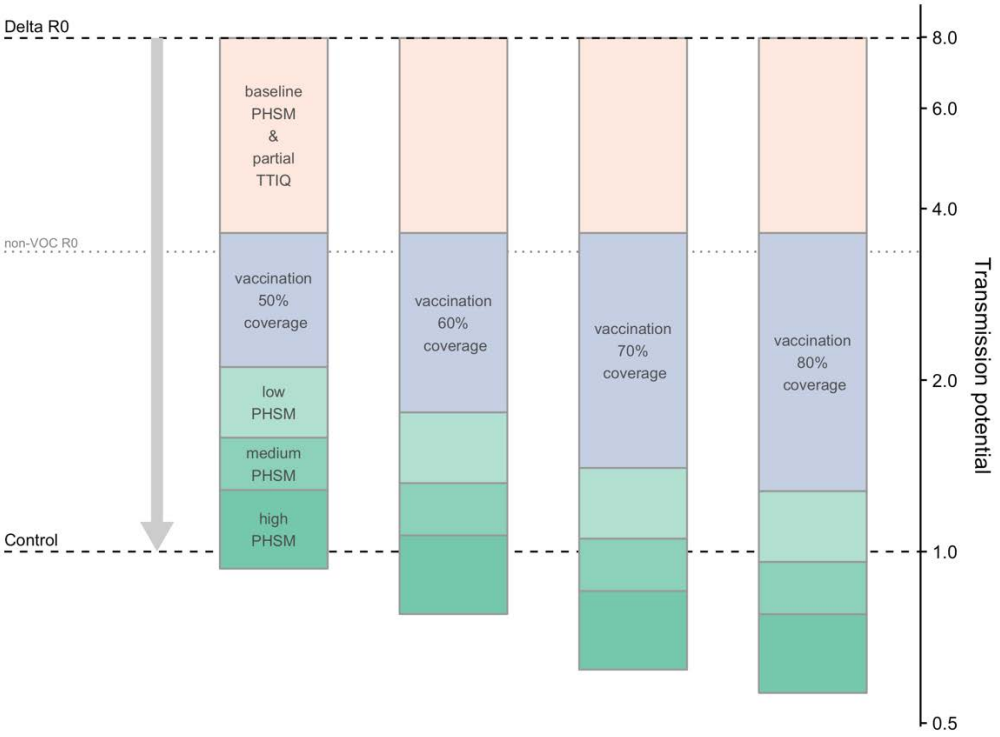
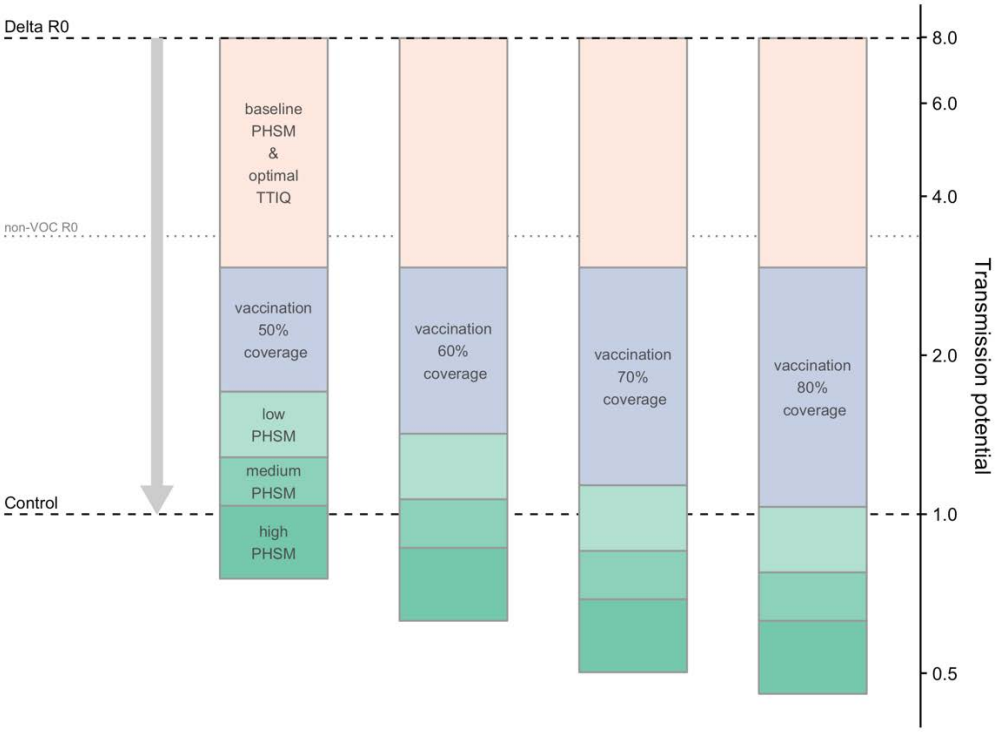


Figure 2.2: As for Figure 2.1 but assuming *optimal TTIQ effectiveness*



Anticipated requirements for social measures, by coverage scenario

Table 3.1: Percentage of time high PHSM would need to be in place for long-term control, with reversion to low PHSM at other times, for 50%, 60%, 70% and 80% population coverage achieved under the three age-based allocation strategies. These scenarios assume *partial* TTIQ effectiveness, under high caseloads. Standard age (60+) and dosing interval (12 weeks) recommendations are assumed for AZ vaccine.

Strategy	Eligible population coverage (16+)			
	50%	**60%**	**70%**	**80%**
Oldest first	82%	49%	18%	0%
Middle years first	89%	67%	39%	2%
All adults	75%	46%	22%	0%
Transmission reducing	87%	52%	10%	0%

Table 3.2: As for Table 4.1 but assuming *optimal* TTIQ effectiveness, given low caseloads

Strategy	Eligible population coverage (16+)			
	50%	**60%**	**70%**	**80%**
Oldest first	42%	9%	0%	0%
Middle years first	49%	27%	0%	0%
All adults	35%	6%	0%	0%
Transmission reducing	47%	12%	0%	0%

More detailed breakdowns of the level of time likely required under differing degrees of social restrictions for the various coverage thresholds and allocation strategies are shown in Tables S2.2 and 2.3 (assuming partial/optimal TTIQ), and S2.4 and 2.5 (for both levels of TTIQ in the context of ongoing 'light' restrictions).

Dynamics and consequences given timing of transition to Phase B

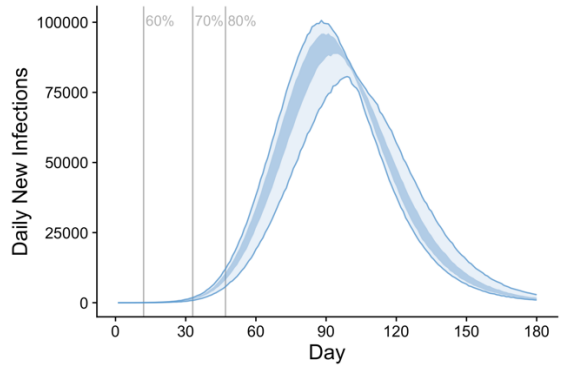
Epidemic simulations assume a population size of 24 million. Infection outputs reflect the range of results observed across 20 separate model runs for each scenario. We assume that a single outbreak involving 30 individuals initiates community transmission at the time of transition to Phase B once target vaccine coverage is achieved. Each simulation is run for 180 days after this initiating date. As immunisation rollout is ongoing, achievement of future vaccine targets is indicated as relevant, in relation to evolving epidemics. Outputs are compared for partial and optimal TTIQ.

Early epidemic growth given established transmission, for Transmission reducing strategy

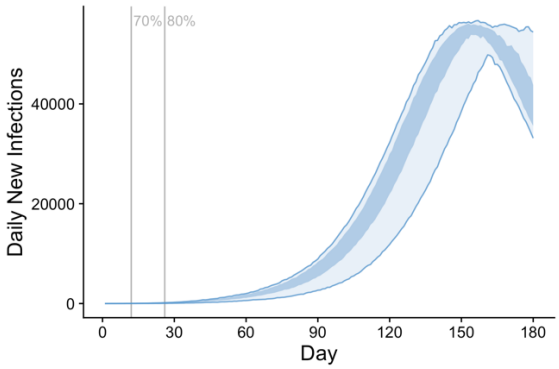
Figures 3.1-3.2 demonstrate the rate of increase in all infections over time, including those which are asymptomatic and regardless of subsequent clinical severity for the symptomatic proportion.

Figure 3.1: Epidemic growth to 180 days given transition to Phase B leading to established community transmission for the threshold coverage targets of 50, 60, 70 and 80%, assuming <u>partial TTIQ</u> (*note different y axes)

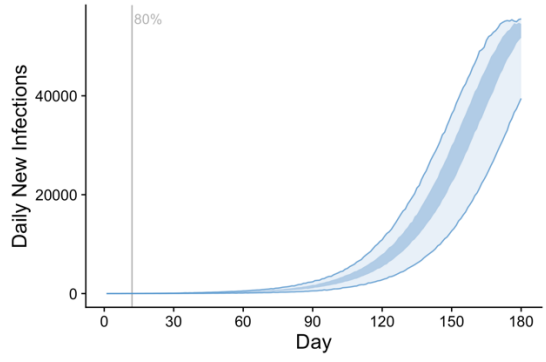
50% vaccine coverage



60% vaccine coverage



70% vaccine coverage



80% vaccine coverage

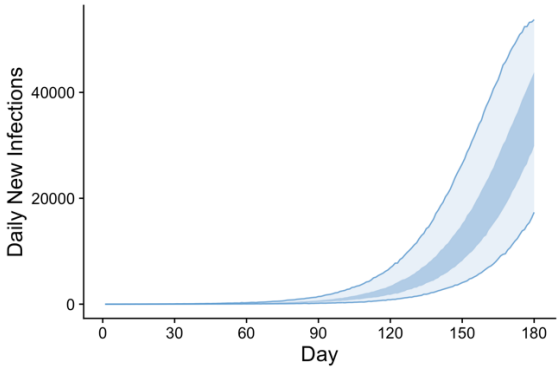
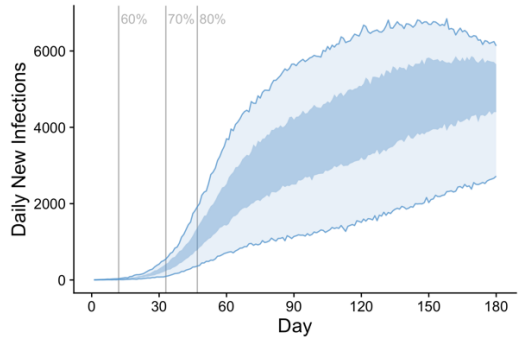
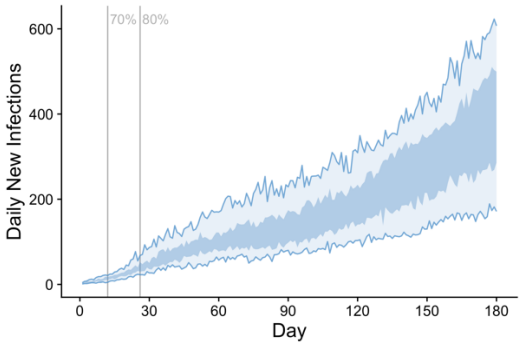


Figure 3.2: As for Figure 3.1, but for optimal TTIQ

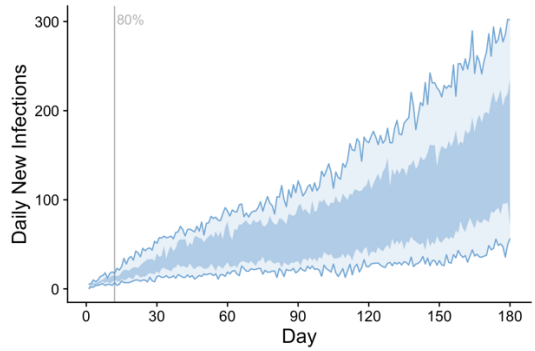
50% vaccine coverage



60% vaccine coverage



70% vaccine coverage



80% vaccine coverage

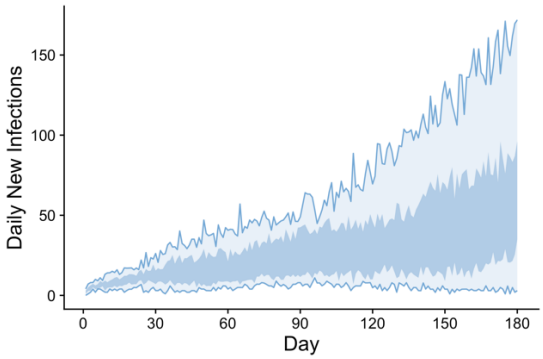
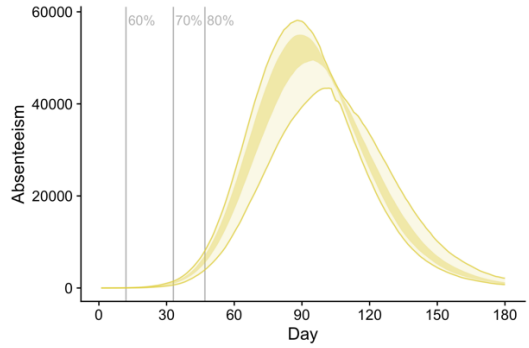
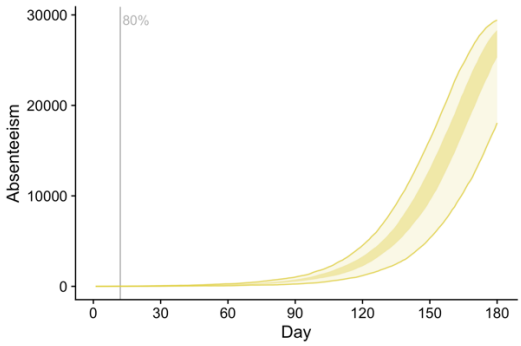


Figure 3.3: Prevalence of individuals absent from the workforce due to symptomatic infection and mandatory isolation (10 days) for the 50 and 70% coverage scenarios (*note y axes differ)

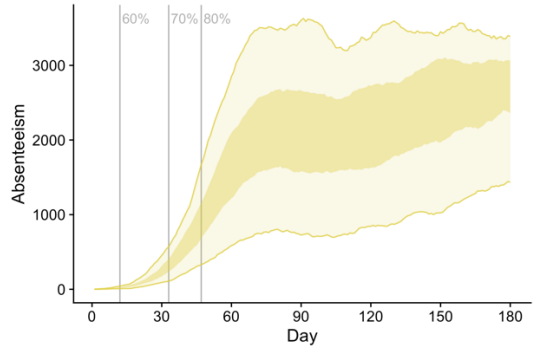
50% coverage, partial TTIQ



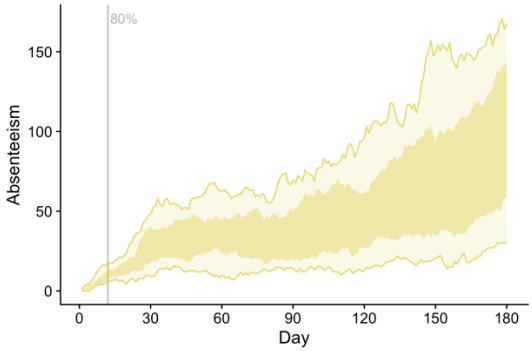
70% coverage, partial TTIQ



50% coverage, optimal TTIQ



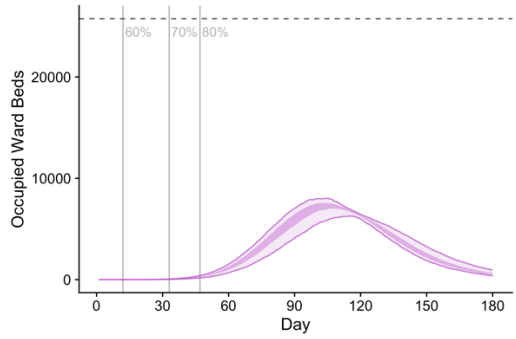
70% coverage, optimal TTIQ



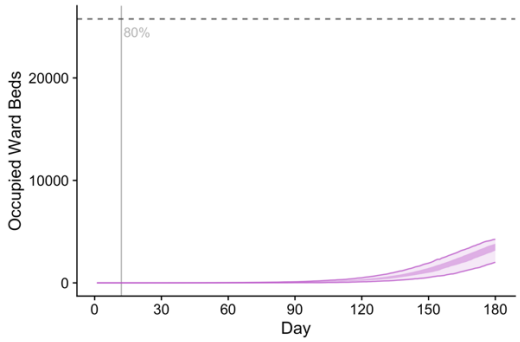
Associated health impacts of transmission, relative to health sector capacity

Figure 4.1: Occupied hospital ward beds over the course of the epidemic, in relation to stated national capacity, which represents 50% of the total. Scenarios shown are for 50% achieved coverage at epidemic onset

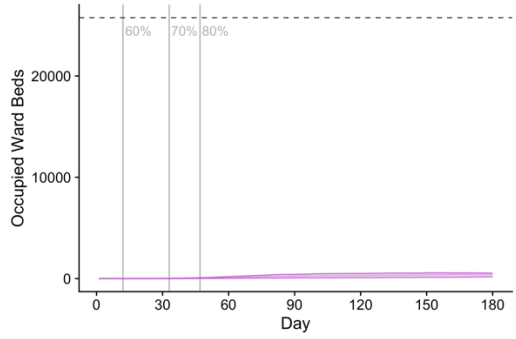
50% coverage, partial TTIQ



70% coverage, partial TTIQ



50% coverage, optimal TTIQ



70% coverage, optimal TTIQ

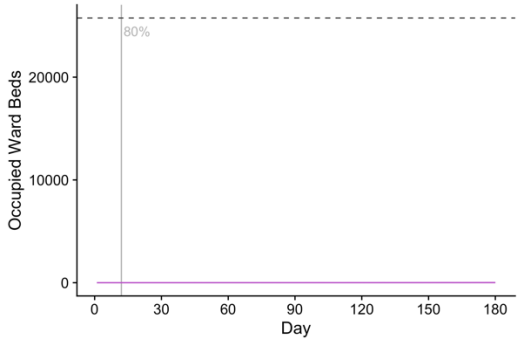
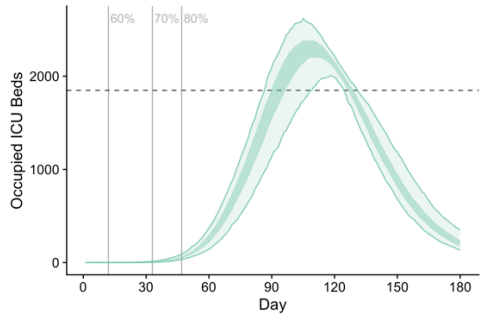
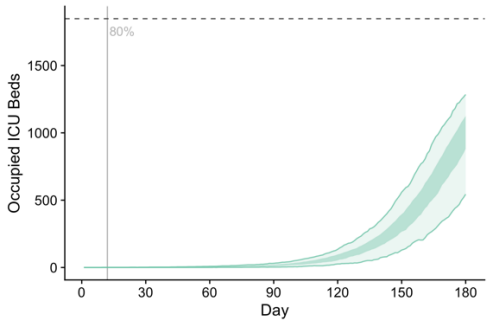


Figure 4.2: As for Figure 3.1 but for occupied ICU beds in relation to national capacity

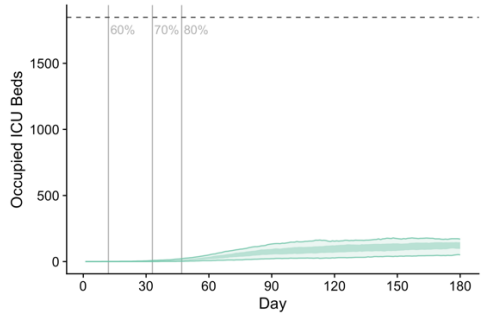
50% coverage, partial TTIQ



70% coverage, partial TTIQ



50% coverage, optimal TTIQ



70% coverage, optimal TTIQ

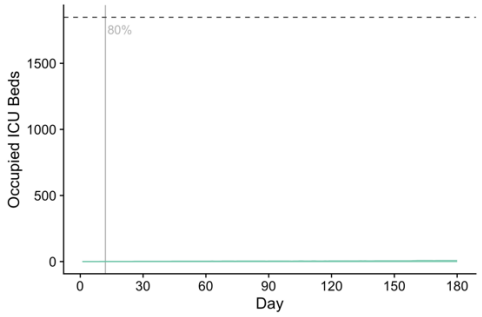
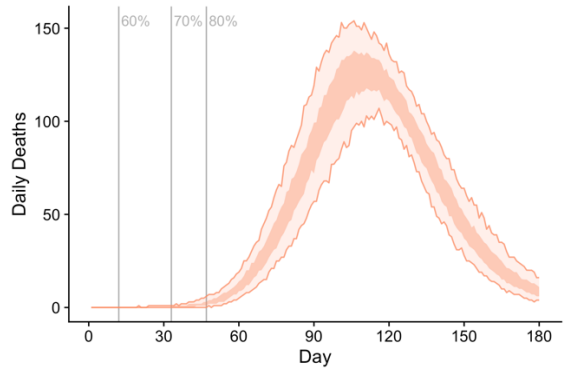
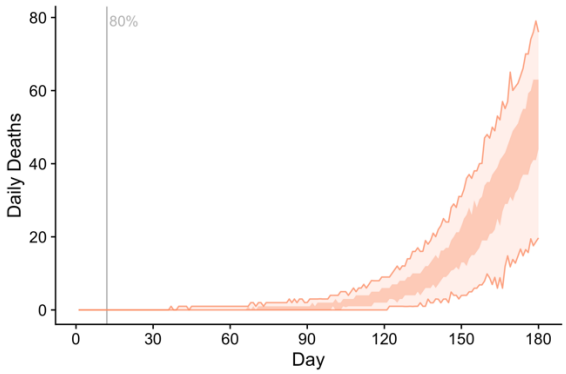


Figure 4.3: As for Figure 3.1 but reporting daily deaths (*note y axes differ)

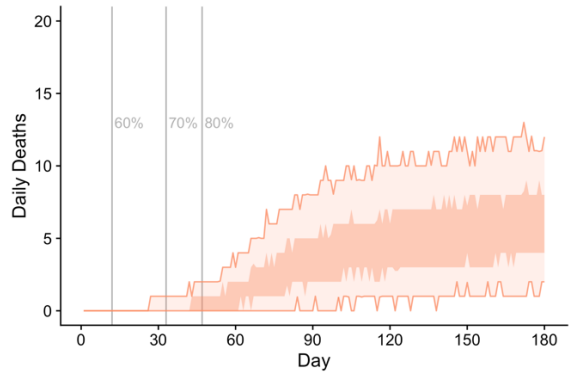
50% coverage, partial TTIQ



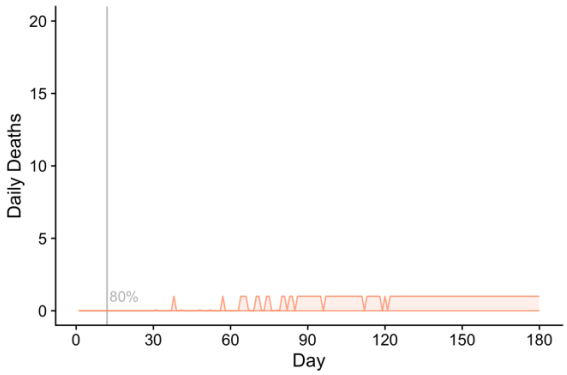
70% coverage, partial TTIQ



50% coverage, optimal TTIQ



70% coverage, optimal TTIQ



Health impacts by age group and vaccine status

Central estimates of these health impacts over the first 180 days following established community transmission are provided in the tables below, for ease of comparison across coverage thresholds, vaccination status and age group. Note that given epidemic stochasticity and uncertainty, these estimates are drawn from a broader range of possible values as demonstrated by the Figures above. **All scenarios assume only baseline restrictions and 'partial' TTIQ effectiveness.**

Table 4.1 Cumulative outcomes of interest over the first 180 days by achieved coverage threshold prior to transmission, for the 'Transmission reducing vaccine allocation strategy with <u>partial TTIQ</u>

	Vaccine Coverage			
	50%	**60%**	**70%**	**80%**
Symptomatic infections	1,124,136	703,688	309,362	230,164
Ward admissions	49,242	27,542	13,698	7,699
ICU admissions*	11,844	6,295	2,966	1,629
Deaths	10,443	4,702	1,908	996

**ICU admissions are reported here and below assuming unconstrained capacity, even when national thresholds are anticipated to be reached or exceeded, so reflect 'true' requirements*

Table 4.2 As for Table 4.1 but for <u>optimal TTIQ</u>

	Vaccine Coverage			
	50%	**60%**	**70%**	**80%**
Symptomatic infections	113,553	6,551	2,762	1,160
Ward admissions	4,132	227	96	40
ICU admissions*	953	52	22	9
Deaths	726	39	17	7

Table 4.3: Cumulative symptomatic infections, ward admissions, ICU admissions and deaths over the first 180 days for coverage thresholds of 50%, 60%, 70% and 80% achieved assuming partial or optimal TTIQ, broken down by vaccination status[#]

	Partial TTIQ		Optimal TTIQ*	
Achieved eligible population coverage	**Vaccinated**	**Unvaccinated**	**Vaccinated**	**Unvaccinated**
50%				
Symptomatic infections	215,541	908,594	17,112	96,441
Ward admissions	15,386	33,856	1,169	2,963
ICU admissions	4,053	7,791	297	656
Deaths	3,708	6,735	246	480
60%				
Symptomatic infections	112,488	591,119	914	5,637
Ward admissions	8,410	19,132	62	165
ICU admissions	2,112	4,183	16	36
Deaths	1,656	3,046	13	26
70%				
Symptomatic infections	57,319	333,044	380	2,382
Ward admissions	4,063	9,635	27	70
ICU admissions	969	1,997	7	15
Deaths	672	1,237	6	11
80%				
Symptomatic infections	32,403	197,761	151	1,008
Ward admissions	2,245	5,454	11	29
ICU admissions	523	1,106	3	6
Deaths	347	649	2	5

**At high caseloads as anticipated in the 50% scenario, consistent maintenance of 'optimal TTIQ' is deemed highly unlikely*

 # Note that in the case of emergence of a 'vaccine escape' variant, both the total number of infections and the proportion of severe cases occurring in fully immunised individuals would increase dramatically.

As can be seen from Tables 4.4 and 4.5 (and the corresponding pair 4.6 and 4.7), the transmission reducing strategy's effectiveness at reducing symptomatic infections and severe outcomes across all age groups is markedly enhanced by maintenance of optimal TTIQ in the presence of ongoing 'low' restrictions.

Table 4.4: Cumulative symptomatic infections, ward admissions, ICU admissions and deaths over the first 180 days for the coverage threshold of 70% assuming partial TTIQ, broken down by vaccination status and age

	<16 yrs		16-39 yrs		40-59 yrs		60+ yrs		70+ yrs	
	Vacc'd	Unvac	Vacc'd	Unvac	Vacc'd	Unvac	Vacc'd	Unvac	Vacc'd	Unvac
Denominator population*	0	5,075,816	4,599,519	3,930,112	5,505,295	3,237,854	5,161,851	506,030	2,736,171	224,478
Symptomatic infections	0	226,084	21,032	64,770	20,775	35,837	12,175	5,309	3,337	1,043
Ward admissions	0	1,983	478	2,125	1,151	3,108	1,691	1,801	743	618
ICU admissions	0	164	85	369	333	896	420	465	131	103
Deaths	0	46	13	84	86	338	365	524	207	245

**Note that 'denominator population' refers to numbers of persons at the time when 70% threshold coverage is achieved – vaccination continues during the simulations to 80% threshold values*

Table 4.5: As for table 4.4, assuming optimal TTIQ

	<16 yrs		16-39 yrs		40-59 yrs		60+ yrs		70+ yrs	
	Vacc'd	Unvac	Vacc'd	Unvac	Vacc'd	Unvac	Vacc'd	Unvac	Vacc'd	Unvac
Denominator population*	0	5,075,816	4,599,519	3,930,112	5,505,295	3,237,854	5,161,851	506,030	2,736,171	224,478
Symptomatic infections	0	1,606	149	487	137	250	75	33	19	6
Ward admissions	0	14	3	17	8	23	11	12	4	4
ICU admissions	0	1	1	3	3	7	3	3	1	1
Deaths	0	0	0	1	1	3	3	4	2	2

**Note that 'denominator population' refers to numbers of persons at the time when 70% threshold coverage is achieved – vaccination continues during the simulations to 80% threshold values*

Table 4.6 Cumulative symptomatic infections, ward admissions, ICU admissions and deaths over the first 180 days for the coverage threshold of 80% assuming partial TTIQ, broken down by vaccination status and age

	<16 yrs		16-39 yrs		40-59 yrs		60+ yrs		70+ yrs	
	Vacc'd	Unvac	Vacc'd	Unvac	Vacc'd	Unvac	Vacc'd	Unvac	Vacc'd	Unvac
Denominator population	0	5,075,816	5,847,392	2,682,239	5,656,653	3,217,835	5,269,008	398,730	2,783,769	176,800
Symptomatic infections	0	135,408	11,943	37,803	11,724	20,931	6,861	3,031	1,875	587
Ward admissions	0	1,128	265	1,218	634	1,762	937	1,006	408	340
ICU admissions	0	93	46	208	180	496	228	255	70	54
Deaths	0	25	6	45	44	176	190	276	107	128

Table 4.7: As for table 4.6, assuming optimal TTIQ

	<16 yrs		16-39 yrs		40-59 yrs		60+ yrs		70+ yrs	
	Vacc'd	Unvac	Vacc'd	Unvac	Vacc'd	Unvac	Vacc'd	Unvac	Vacc'd	Unvac
Denominator population	0	5,075,816	5,847,392	2,682,239	5,656,653	3,217,835	5,269,008	398,730	2,783,769	176,800
Symptomatic infections	0	687	57	199	56	105	31	14	8	3
Ward admissions	0	6	1	7	3	10	4	5	2	2
ICU admissions	0	1	0	1	1	3	1	1	0	0
Deaths	0	0	0	0	0	1	1	2	1	1

TECHNICAL APPENDIX

Vaccine allocation scenario

Table S1.1: Distribution of vaccination coverage by age band by achievement of the 70% vaccination coverage threshold (1st November) for standard AZ dosing indications (60+, 12 week interval between doses) and the three age-based allocation strategies.

Age band	Eligible population	Oldest first	40+ years first	All adults	Transmission reducing
16-19	1190616	4.2%	86.1%	57.1%	34.3%
20-29	3577491	18.9%	52.6%	58.8%	38.4%
30-39	3761524	74.8%	16.6%	60.6%	74.9%
40-49	3295699	90.4%	90.6%	69.0%	84.4%
50-59	3127124	92.1%	92.0%	74.6%	87.1%
60-69	2707232	87.3%	93.8%	84.0%	89.6%
70-79	1897838	96.1%	93.3%	89.4%	93.1%
80+	1062811	95.2%	83.0%	86.3%	91.2%

**Note that for the first three allocation scenarios, the date on which 70% coverage is achieved in the simulation is 1st November, compared with the 'transmission reducing' strategy for which that date is 8th November*

Table S1.2: As for Table S3.1 but for an 80% achieved coverage threshold (16+ years population)

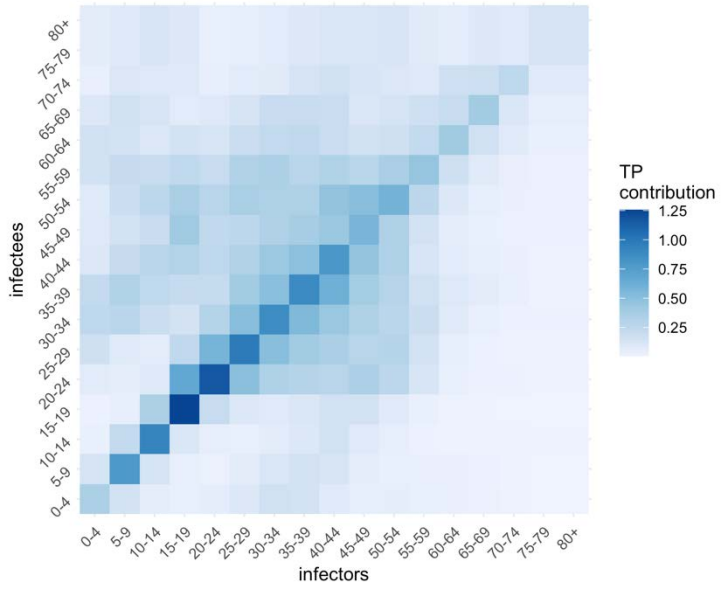
Age band	Eligible population	Oldest first	40+ years first	All adults	Transmission reducing
16-19	1190616	8.6%	86.9%	73.5%	57.1%
20-29	3577491	64.1%	87.1%	74.6%	59.7%
30-39	3761524	88.1%	41.4%	75.6%	80.6%
40-49	3295699	90.5%	90.6%	80.8%	87.0%
50-59	3127124	92.1%	92.0%	84.2%	89.2%
60-69	2707232	91.7%	94.2%	90.0%	91.8%
70-79	1897838	96.2%	95.9%	93.4%	94.6%
80+	1062811	95.2%	89.2%	91.4%	93.0%

**This coverage threshold is achieved by 22 November across all allocation strategies*

Population mixing assumptions

Population mixing within and between age groups is configured based on widely accepted social contact matrices published by Prem et al (PLoS Computational Biology 2017)(Figure S2.1). It has been expanded to include an 80+ age class (assumed to have the same mixing rates as 75-79 years). Age-specific susceptibility and transmissibility estimates from Davies et al. (Nature Medicine 2020) are used and transmission rates have been calibrated to our baseline population-wide TP (here denoted R) of 3.6. Of note, the greatest mixing intensities are anticipated between individuals aged from 15-24 years, remaining high through adults of working age. While intense school-based mixing is anticipated between children aged 5-14, the transmission matrix accounts for the relatively low observed infectiousness of this age group, associated with a high proportion of asymptomatic infections.

Figure S1.1: Age-based transmission matrix derived from Prem et al (2017)



The key message of Figure S2.1 is that in the absence of vaccination, individuals of different ages do not contribute equally to the spread of infection in the population.

The impact of vaccination on overall transmission will therefore be substantially influenced by the rate of vaccine uptake achieved **within distinct population age cohorts.** Table S3.2 shows the range of values for achieved coverage by age group underpinning 80% 'age eligible coverage' for our three hypothetical vaccine allocation strategies.

Figures S1.2-S1.5 provide a visual demonstration of the reduction in transmission achieved for each age band depending on the rollout scenario. Light grey bars show the contribution of each age group to transmission potential given different numbers of contacts and age differences in both susceptibility and infectiousness, in the absence of vaccination. Dark grey bars show the contribution of each age group to transmission potential for that vaccine allocation strategy and coverage. The 'all ages' strategy consistently produces the greatest proportional reductions in infectiousness across peak transmitting age groups.

Figure S1.2: Impact of the four different allocation strategies on TP by age category, resulting in the overall TP achieved by 50% age eligible population coverage

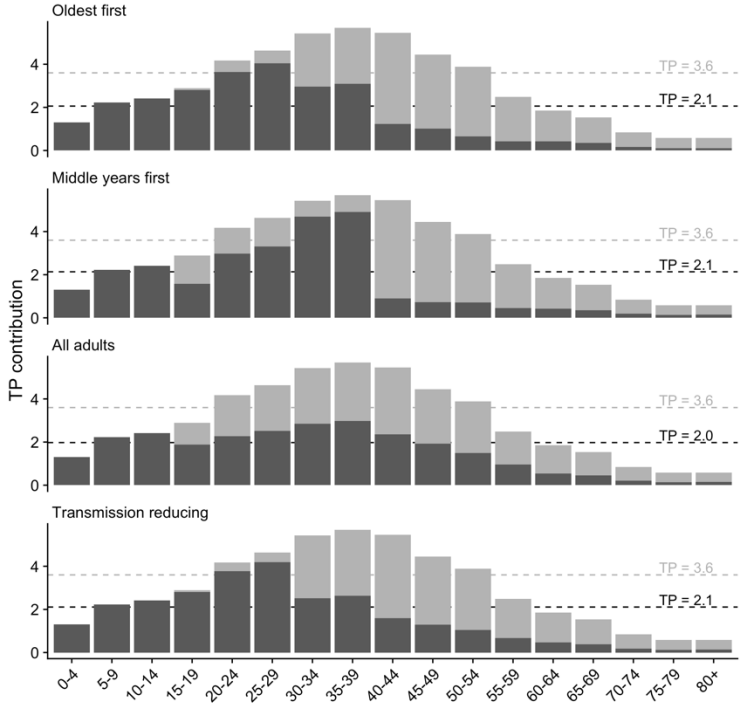


Figure S1.3: As for Figure S1.2, but for 60% age eligible population coverage

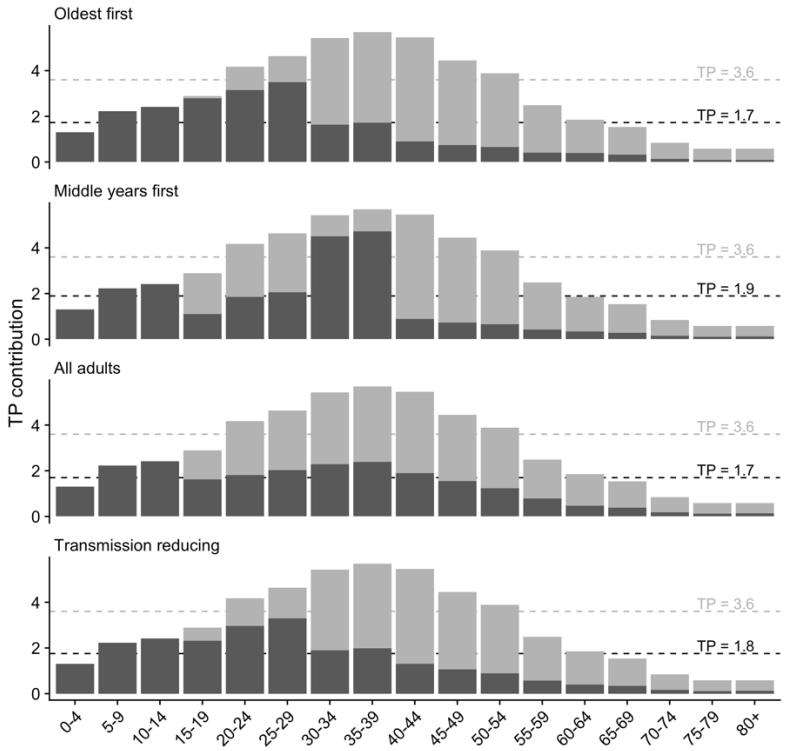


Figure S1.4: As for Figure S1.2, but for 70% age eligible population coverage

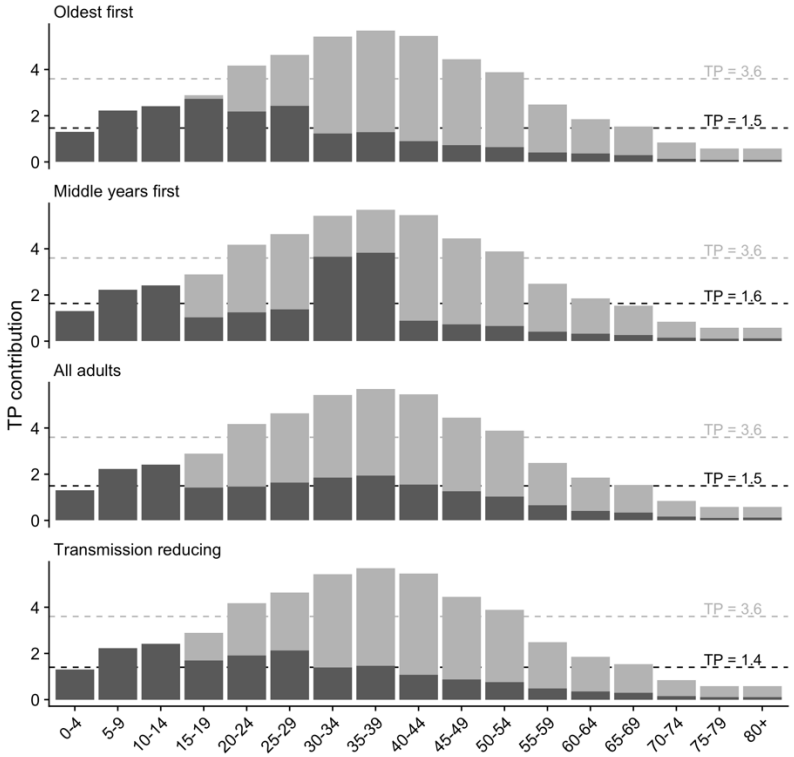
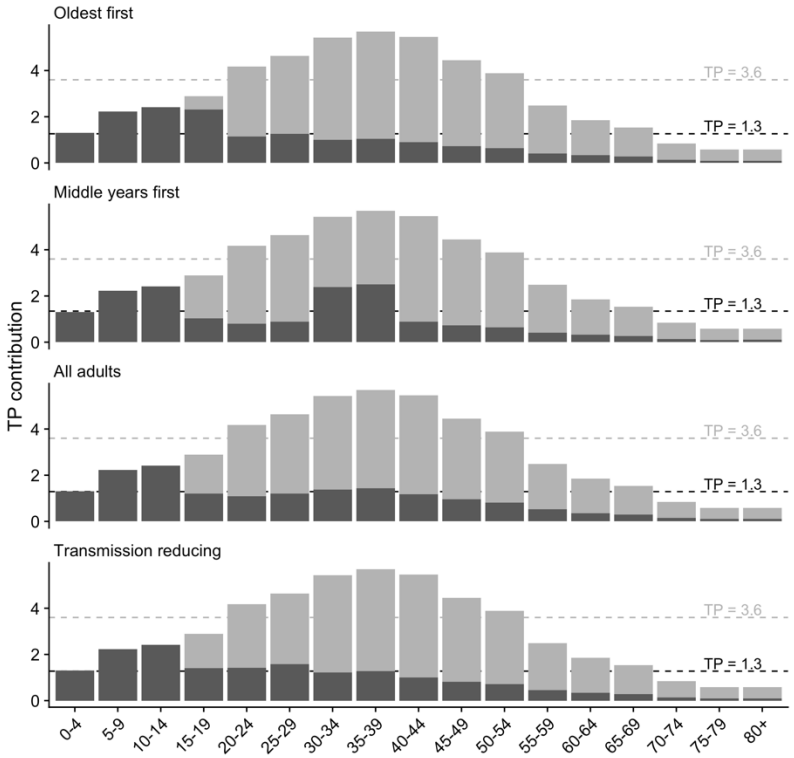


Figure S1.5: As for Figure S1.2, but for 80% age eligible population coverage



Impact of public health response and bundled social measures on TP

Table S2.2: Proportion of time lockdowns are needed to constrain transmission when the TTIQ public health response is only *partially effective,* due to high caseloads

Vaccine coverage	Allocation scenario	Light restrictions only	Moderate lockdowns only	Strict lockdowns only
50%	Oldest first	Not possible to constrain outbreak with light restrictions	Not possible to constrain outbreak with moderate lockdown	89%
	40+ years first	Not possible to constrain outbreak with light restrictions	Not possible to constrain outbreak with moderate lockdown	93%
	All adults	Not possible to constrain outbreak with light restrictions	Not possible to constrain outbreak with moderate lockdown	84%
	Transmission reducing	Not possible to constrain outbreak with light restrictions	Not possible to constrain outbreak with moderate lockdown	92%
60%	Oldest first	Not possible to constrain outbreak with light restrictions	Not possible to constrain outbreak with moderate lockdown	67%
	40+ years first	Not possible to constrain outbreak with light restrictions	Not possible to constrain outbreak with moderate lockdown	78%
	All adults	Not possible to constrain outbreak with light restrictions	Not possible to constrain outbreak with moderate lockdown	65%
	Transmission reducing	Not possible to constrain outbreak with light restrictions	Not possible to constrain outbreak with moderate lockdown	69%
70%	Oldest first	Not possible to constrain outbreak with light restrictions	77%	47%
	40+ years first	Not possible to constrain outbreak with light restrictions	99%	60%
	All adults	Not possible to constrain outbreak with light restrictions	81%	49%
	Transmission reducing	Not possible to constrain outbreak with light restrictions	68%	41%

80%	Oldest first	82%	47%	29%
	40+ years first	Not possible to constrain outbreak with light restrictions	59%	36%
	All adults	89%	51%	31%
	Transmission reducing	85%	49%	30%

Table S2.3: As for Table S2.2, but for an *optimally effective* TTIQ response

Vaccine coverage	Allocation scenario	Light restrictions only	Moderate lockdowns only	Strict lockdowns only
50%	Oldest first	Not possible to constrain outbreak with light restrictions	Not possible to constrain outbreak with moderate lockdown	63%
	40+ years first	Not possible to constrain outbreak with light restrictions	Not possible to constrain outbreak with moderate lockdown	67%
	All adults	Not possible to constrain outbreak with light restrictions	94%	58%
	Transmission reducing	Not possible to constrain outbreak with light restrictions	Not possible to constrain outbreak with moderate lockdown	66%
60%	Oldest first	Not possible to constrain outbreak with light restrictions	67%	41%
	40+ years first	Not possible to constrain outbreak with light restrictions	86%	52%
	All adults	Not possible to constrain outbreak with light restrictions	64%	39%
	Transmission reducing	Not possible to constrain outbreak with light restrictions	71%	43%
70%	Oldest first	60%	34%	21%
	40+ years first	97%	56%	34%
	All adults	67%	38%	23%
	Transmission reducing	44%	25%	15%

80%	Oldest first	7%	4%	3%
	40+ years first	29%	17%	10%
	All adults	15%	8%	5%
	Transmission reducing	11%	6%	4%

Table S2.4: Proportion of time lockdowns are needed to constrain transmission when the TTIQ public health response is only *partially effective,* due to high caseloads, and where light restrictions are always in place.

Vaccine coverage	Allocation scenario	Moderate lockdowns only	Strict lockdowns only
50%	Oldest first	Not possible to constrain outbreak with moderate lockdown	82%
	40+ years first	Not possible to constrain outbreak with moderate lockdown	89%
	All adults	Not possible to constrain outbreak with moderate lockdown	75%
	Transmission reducing	Not possible to constrain outbreak with moderate lockdown	87%
60%	Oldest first	Not possible to constrain outbreak with moderate lockdown	49%
	40+ years first	Not possible to constrain outbreak with moderate lockdown	67%
	All adults	Not possible to constrain outbreak with moderate lockdown	46%
	Transmission reducing	Not possible to constrain outbreak with moderate lockdown	52%
70%	Oldest first	46%	18%
	40+ years first	97%	39%
	All adults	55%	22%
	Transmission reducing	25%	10%
80%	Oldest first	0%	0%
	40+ years first	4%	2%
	All adults	0%	0%
	Transmission reducing	0%	0%

Table S2.5: As for Table S2.4, but for an *optimally effective* TTIQ response

Vaccine coverage	Allocation scenario	Moderate lockdowns only	Strict lockdowns only
50%	Oldest first	Not possible to constrain outbreak with moderate lockdown	42%
	40+ years first	Not possible to constrain outbreak with moderate lockdown	49%
	All adults	87%	35%
	Transmission reducing	Not possible to constrain outbreak with moderate lockdown	47%
60%	Oldest first	23%	9%
	40+ years first	66%	27%
	All adults	15%	6%
	Transmission reducing	31%	12%
70%	Oldest first	0%	0%
	40+ years first	0%	0%
	All adults	0%	0%
	Transmission reducing	0%	0%
80%	Oldest first	0%	0%
	40+ years first	0%	0%
	All adults	0%	0%
	Transmission reducing	0%	0%