traQ Study:

Transparent Risk Assessment of Quarantine

Final Report

November 2020

Funding for this study and development of the traQ model was provided by a grant from the Minderoo Foundation.

Burnet Institute

Medical Research. Practical Action.

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EXECUTIVE SUMMARY

Despite rising prevalence of COVID-19 globally, Australia has managed to control the epidemic through considerable government and community effort. Various restrictions, including on travel, have substantially reduced transmission. However, there is growing evidence that many of the restrictions are impacting community health and economic wellbeing.

Australia, through the COVIDSAFE National Framework [21], is now looking to reopen borders nationally and internationally, whilst at the same time having a system in place to prevent the importation of COVID-19 into the country and between jurisdictions. The recent National review of hotel quarantine Report included two recommendations. Firstly, it called for new models of quarantine to be developed for consideration by National Cabinet, including a risk assessment of these options and an analysis of traveller suitability. Secondly, it suggested that National Cabinet consider exempting low-risk travellers from mandatory quarantine.

Consistent with these recommendations, the Burnet Institute has developed the Transparent Risk Assessment of Quarantine (traQ) model. The model examines the effectiveness of different quarantine and testing regimes and the circumstances in which quarantine length could be reduced without substantially increasing risk of COVID-19 transmission.

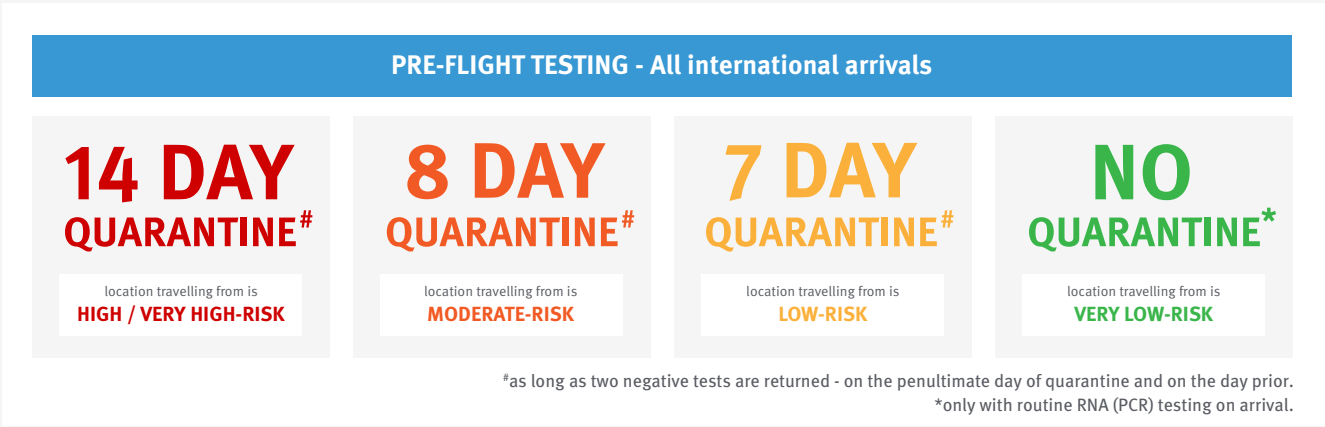
The model uses four key steps to identify and assess risk – Pre-travel, During travel, Quarantine and Post-quarantine (Figure 1a).

Figure 1a. Four steps to identify and assess risk

The model also allows the economic benefits of domestic and international travel from specific countries and the costs of various quarantine strategies to be estimated. Governments can use this tool to continuously test a range of quarantine and testing scenarios, enabling risk-based, real-time policy adaptation and tailored solutions for different countries/ states of traveller origin.

Key Findings

- A tailored quarantine approach that assesses pre-and during travel risk, combined with pre-travel and on arrival testing and/or enhanced testing, and risk mitigation strategies post-quarantine can reduce the length of quarantine in specific circumstances without significantly increasing the risk of COVID-19 transmission to the community.



- Quarantine is an effective and vital mechanism to reduce the risk of importing COVID-19 into Australia.
- Countries were assigned risk categories, based on the prevalence of COVID-19 in travellers from that country and the countries level of COVID-19 testing. Only two countries, New Zealand and Thailand, were considered very low-risk with adequate testing as of 13 October 2020.
- The risk of COVID-19 importation is considerably higher if there is substantial travel risk, but this can be partially mitigated through pre-travel testing.
- The timing of testing can reduce risk. The ideal timing of tests in quarantine is two tests near the end, regardless of quarantine duration (enhanced testing).
- 14-day quarantine is more effective than shorter-duration quarantine. However, a no quarantine or a shorter-duration quarantine is possible where the probability of infection at arrival is very low, low, or moderate.
- It may be possible for travellers with very low travel risk to have no quarantine if they undergo pre-travel testing and testing on arrival.
- The risk of COVID-19 importation increases with higher travel volumes, even when travellers are from very low-risk and low-risk settings. Ongoing monitoring and restriction of travel numbers may be required to control risk.
- Mitigation strategies such as social distancing, hand hygiene and masks are effective in reducing COVID-19 transmission and should be considered a central component of the quarantine strategy.
- The potential economic benefits of allowing the resumption of travel for the Australian economy are immense (up to $86 billion if travel resumes at pre-COVID levels) but the risk of COVID-19 importation from travel is substantial. This highlights the difficult choices for governments and communities alike.
- Allowing increased travel, with 14-day managed quarantine for long-term inbound international travellers (e.g. seasonal agricultural workers, international students, skilled migrants) is costly but the benefit-to-cost ratio is very high.
- Risk-based quarantine strategies (i.e. people coming from very low-risk and low-risk settings) offer substantial cost-reductions without increasing overall risk, if current travel volumes remain stable. Increasing travel volumes must be done with considerable caution.

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GLOSSARY

COVID-19: The respiratory illness causing a pandemic in 2020.

SARS-CoV-2: Severe Acute Respiratory Syndrome-Coronavirus-2 (SARS-CoV-2) is the coronavirus that causes coronavirus disease 2019 (COVID-19).

Quarantine: Separation of individuals who may have been exposed to SARS-CoV-2 prior to diagnosis with COVID-19 from other people in order to prevent onward transmission. In addition to people who have been in contact with known cases, quarantine is also used for inbound international and interstate travellers in Australia to prevent imported cases of COVID-19 from higher prevalence locations. Usually this is for 14-days from arrival for travellers.

Isolation: Separation of individuals who have been diagnosed with COVID-19 from other people to prevent onward transmission. This is usually for at least 10-days from diagnosis but release dates depend on symptoms.

Incubation period: The time from exposure until development of symptoms. For COVID-19, this includes the latent period (characterised by low levels of viraemia) and the presymptomatic infectious period. In the latent period, individuals are not yet infectious and infections are very unlikely to be detected through testing. In the presymptomatic infectious period (usually 1-2 days before symptom onset) individuals become infectious and virus starts to become detectable through testing.

Infectious period: The period where an individual may transmit their infection to others. For COVID-19, this includes the presymptomatic infectious period (prior to symptom onset) and the early symptomatic period (approximately 4-10 days after symptom onset).

Asymptomatic infection: A proportion of SARS-CoV-2 infections are asymptomatic meaning that they do not experience symptoms. Test sensitivity and infectiousness is likely to be lower among asymptomatic infections than symptomatic infections, but potential transmission from asymptomatic individuals can still be important to the propagation of the disease particularly as these infections can be harder to detect and therefore less likely to be managed through isolation.

PCR test: The most common type of test for SARS-CoV-2, usually using a naso-pharyngeal swab specimen.

RNA: Ribonucleic acid.

Sensitivity: The proportion of cases (infections) that test positive. This is a function of the quality of the sample (how likely it is to contain viral RNA if the person is infected) and the test itself. While PCR tests have very high sensitivity (close to 100 per cent) if the sample contains viral RNA, the clinical sensitivity taking into account the sample quality is closer to 70 per cent [1]. Test sensitivity varies depending on the level of viraemia in the nose and throat which varies by time since exposure. In the latent period, the test sensitivity is close to 0 per cent, and it peaks at approximately 80 per cent in the days following symptom onset [2].

Specificity: The proportion of people who are not infected with SARS-CoV-2 who test negative. This is very high for SARS-CoV-2 naso-pharyngeal swab PCR tests (close to 100 per cent).

Prevalence: The proportion of people currently infected with SARS-CoV-2. For the purpose of this report, prevalence does not include people who have already recovered or who are experiencing long COVID-19 (symptoms persisting after the infectious period) but who are no longer infectious. We use this term to refer to the proportion of people infected when they arrive in a jurisdiction after travel.

Incidence: The proportion of people with new infections over a particular time frame or observation period. For the purpose of this report, we refer to 10-day cumulative incidence of cases in jurisdictions of origin for travellers. This is the number of new cases reported over a 10-day period divided by the population.

Managed isolation or quarantine: Isolation or quarantine at facilities managed by government (such as in hotels). This is distinct from home quarantine or home isolation.

INTRODUCTION

The COVID-19 epidemic continues to have a major impact in Australia and globally. Despite rising COVID-19 cases globally, through considerable government and community effort, Australia has managed to control the number of cases of COVID-19. While the restrictions introduced by the Federal, State and Territory Governments have substantially reduced COVID-19 transmission, it is also acknowledged that these restrictions have had a considerable indirect impact on the community's health, social and economic wellbeing.

Australia, through the COVIDSAFE National Framework [21], is now looking to reopen nationally when and where possible, without the 're-opening' leading to increased cases of COVID-19. This requires broad public health preparedness including having a clear and transparent strategy for quarantine, considered the first line of defence in preventing the importation of COVID-19 into the country and between jurisdictions. Quarantine needs to be combined with robust testing and contact tracing in each jurisdiction and ongoing community behaviours that reduce transmission such as physical distancing, hygiene and the use of masks.

Key principles in the COVIDSAFE National Framework for re-opening include that measures introduced to control COVID-19 transmission are proportionate, consistent, protect national wellbeing, are well communicated and support confidence to allow economic activity to continue and/or restart.

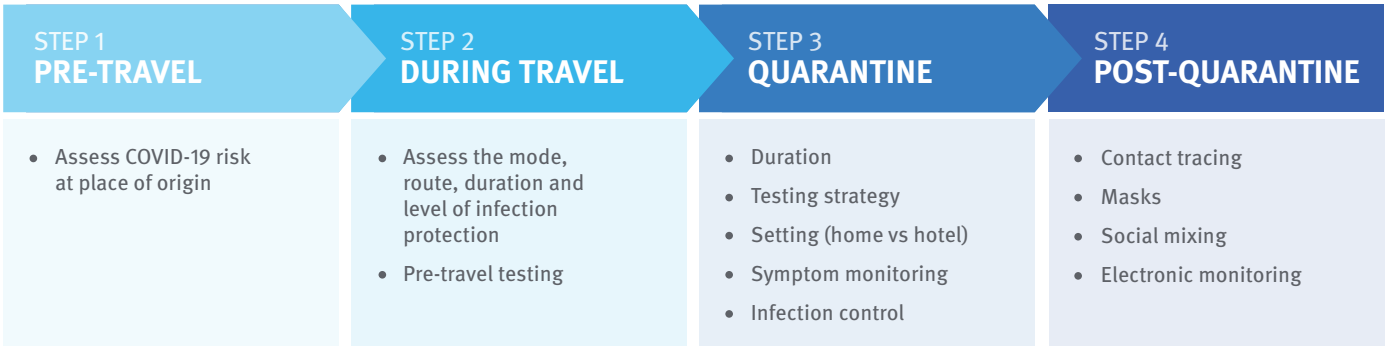
As outlined in the COVIDSAFE National Framework, quarantine is a critical component of the national response. Hence it is vitally important to have a transparent mechanism to assess the effectiveness of quarantine, and whether the quarantine measures are proportionate to the risk of COVID-19 infection and the economic and social impact of quarantine.

The recent National review of hotel quarantine report included the recommendations that options for new models of quarantine be developed for consideration by National Cabinet, including a risk assessment of these options and an analysis of traveller suitability. The review also recommended that National Cabinet should consider exempting low-risk cohorts, such as travellers from New Zealand, from mandatory quarantine.

The Transparent Risk Assessment of Quarantine (traQ) model addresses these issues. traQ uses a mathematical model, which was developed based on the best available evidence, to examine the effectiveness of quarantine and the circumstances in which quarantine could be reduced from 14 days without substantially increasing the risk of COVID-19 transmission. The traQ model also estimates the COVID-19 risk of allowing travel from specific countries and Australian states. It examines the effectiveness of quarantine in detecting cases in arrivals and reducing the risk of COVID-19 transmission from arrivals to the community. It also assesses the economic impact and costs of quarantine.

Four key steps are used to identify and assess risk – Pre-travel (Step 1), During travel (Step 2), Quarantine (Step 3) and Post-quarantine (Step 4) (Figure 1b).

Figure 1b. Four steps to identify and assess risk



Finally, the traQ model considered the economic benefits of allowing domestic and international travel; as well the model considered the cost of various quarantine strategies and the associated risks with importation of COVID-19 cases into the community.

Importantly, the traQ model is designed to allow for a range of quarantine and testing scenarios to be continuously applied to updated data, enabling real-time policy adaptation and tailored solutions for different countries of visitor origin.

What is Quarantine?

Quarantine measures aimed at reducing the transmission of infectious diseases by restricting people's movements are not new. They have been used for centuries to stop the transmission of disease pandemics such as the plague and Spanish influenza. Australia has intermittently used quarantine measures to limit the introduction of human and animal infections into the country.

Quarantine can mitigate COVID-related risk from international and domestic travel. In general, quarantine is designed to separate an individual from the community when they are at-risk of developing COVID-19 due to either exposure to a known case or exposure to a higher risk environment (such as a traveller from a high prevalence country). When individuals in quarantine are identified as cases, they are then isolated until they are no longer believed to be infectious (usually 10 days). However, depending on the monitoring and testing strategy during quarantine, a small proportion of people who develop COVID-19 will remain undetected at exit.

The length of quarantine varies, depending on the disease for which it is introduced. In Australia, to reduce the spread of COVID-19, there is currently a 14-day quarantine period for people:

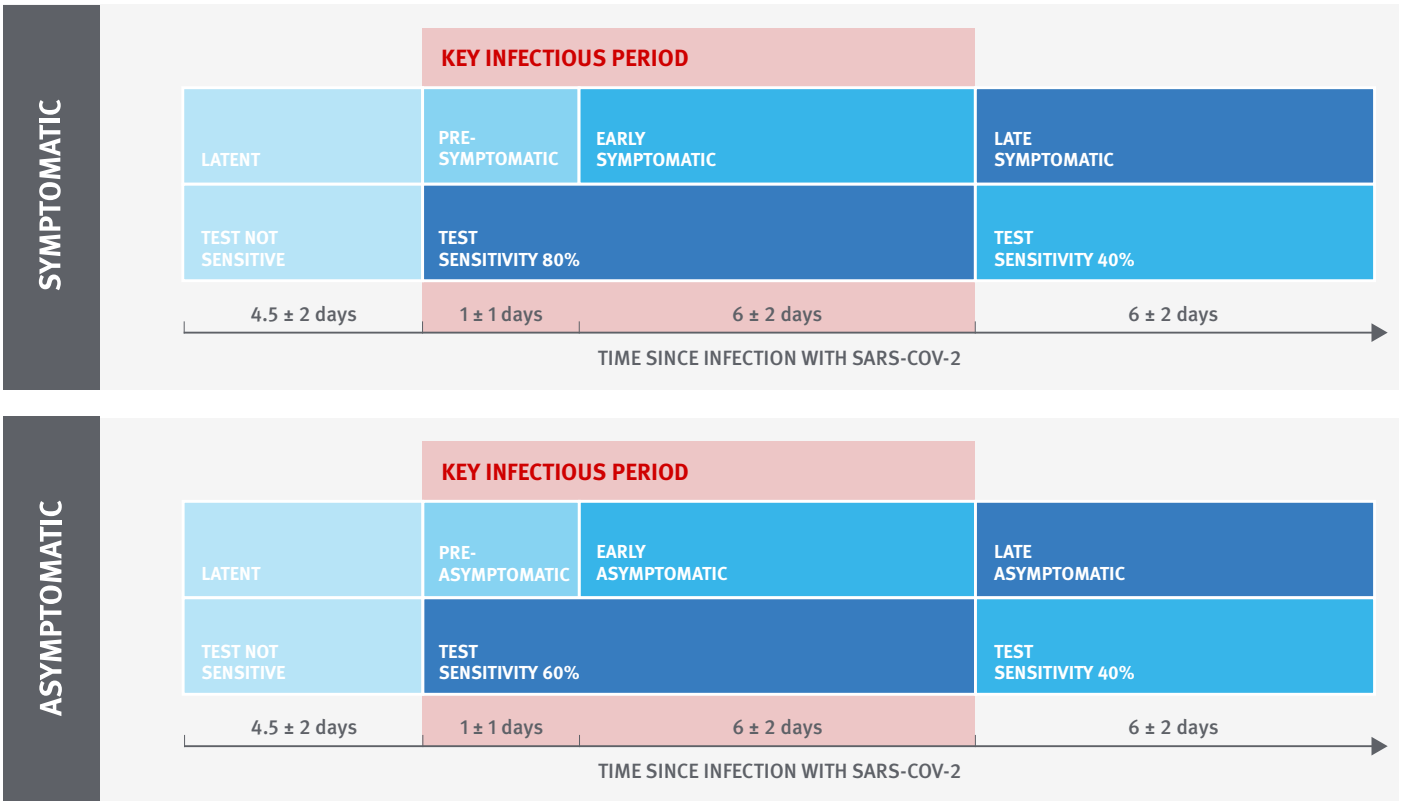
- in contact with a person infected with COVID-19 in a community setting
- travelling to Australia from overseas
- travelling between selected states and territories.

Rationale and Objectives

COVID-19 importation from travel has been recognised as a significant risk in Australia and elsewhere. Existing modelling studies suggest that travel restrictions reduce the spread of COVID-19 across international borders, and that symptom screening measures alone are unlikely to be effective for preventing imported cases from seeding outbreaks in destination countries. However, if symptom screening is combined with quarantine, observation and RNA testing, these measures are likely to be more effective [1].

Australia's 14-day quarantine is based on research showing that the incubation period (the time between exposure to an infection and symptoms appearing) for COVID-19 ranges from one to 14 days (most incubations take 5–7 days)[2-4]. Only one in 100 people who develop COVID-19 will develop symptoms more than 14 days after exposure.

Figure 2. Timeline of infection stages and test sensitivity for symptomatic and asymptomatic infection



Some European countries require travellers from selected countries to quarantine for fewer than 14 days [5, 6]. However, none of these countries have successfully controlled COVID-19 at low levels. In addition, Australia's 14-day quarantine is consistent with most countries' practice, and with current World Health Organization and Centers for Disease Control recommendations [7, 8].

Key assumptions informing the length of COVID-19 quarantine

- Fourteen days after exposure to COVID-19, about 27 per cent of cases remain infectious (model output based on distribution of latent and infectious periods). A key assumption of 14-day quarantine is that symptom monitoring during this period will identify cases. These cases are isolated for longer until they are no longer infectious.
- More than half of COVID-19 cases have no symptoms (asymptomatic) or symptoms so mild that they are not recognised as infections. Hence, in Australia, all people in quarantine must undergo regular COVID-19 testing.

As outlined above the traQ Study uses a mathematical model to examine the effectiveness of quarantine and the circumstances in which quarantine could be reduced from 14 days without substantially increasing the risk of COVID-19 transmission. The model estimates the COVID-19 risk of allowing travel from specific countries and Australian states. In particular it examines whether COVID-19 quarantine could be reduced from 14 days in some circumstances without substantially increasing the risk of virus importation. The model identifies and quantifies risk factors and considers combinations of increased testing and other mitigation strategies, such as mask wearing and contact tracing. It also considers the economic costs and benefits of quarantine.

Brief Model Description

The traQ Model:

- provides updated estimates of the COVID-19 point prevalence (the per cent of the population infected) in >150 countries, adjusting for country-specific estimates of under-ascertainment of cases
- provides updated estimates of the expected number of infections among arrivals to Australia based on the country-specific estimates and observed COVID-19 positivity rates in arrivals from May to July 2020
- based on these estimates, classifies countries into risk groups
- provides similar estimates for interstate travel within Australia.

The model also estimates the effectiveness of quarantine and COVID-19 RNA testing strategies for detecting cases in arrivals and reducing risk of transmission from arrivals to the community, taking into account:

- pre-flight testing (1 or 3 days before travel)
- duration of quarantine
- testing during quarantine, including timing of tests
- setting of quarantine (home or managed).

Finally the model calculates the costs and benefits of allowing travel for specific scenarios and industries, taking into account the quarantine strategy.

CHAPTER 1
PRE-TRAVEL | STEP 1

STEP 1 **PRE-TRAVEL**	STEP 2 **DURING TRAVEL**	STEP 3 **QUARANTINE**	STEP 4 **POST-QUARANTINE**
• Assess COVID-19 risk at place of origin	• Assess the mode, route, duration and level of infection protection • Pre-travel testing	• Duration • Testing strategy • Setting (home vs hotel) • Symptom monitoring • Infection control	• Contact tracing • Masks • Social mixing • Electronic monitoring

Key Findings

- Countries were assigned risk categories based on the estimated prevalence of COVID-19 travellers from that country, as well as the level of COVID-19 testing within a country.
- Only two countries, New Zealand and Thailand, were considered very low-risk with adequate testing (as of 13 Oct 2020). Other countries identified as potentially very low-risk but without evidence of adequate testing are Vanuatu, China and Vietnam.

Pre-travel risk assessment is the first of four steps in assessing and mitigating travel risk. It consists of assessment of COVID-19 risk at the place of origin, be that a country or Australian state or territory.

Assessment of COVID-19 risk at the place of origin

The overall assessment of COVID-19 risk in international arrivals was derived from case numbers among international arrivals to Australia for May–July 2020 (Table 1). Australian arrival data were only available until July. Months prior to May were excluded due to cases from cruise ships during the previous months. Overall, the prevalence of COVID-19 among arrivals during May–July was 1.0 per cent (95% CI: 0.9-1.1).

Table 1. COVID-19 cases among international arrivals to Australia, June - July 2020

Month	Cases	Arrivals	Prevalence (%) (95% CI)
May	177	19,120	0.9 (0.8–1.1)
June	200	25,120	0.8 (0.7–0.9)
July	221	17,260	1.3 (1.1–1.6)
TOTAL	**598**	**61,500**	**1.0 (0.9–1.1)**

We then considered the varying risk depending on the country of origin of the traveller. We considered five potential risk classifications (Table 2); countries were assigned to risk categories based on the estimated prevalence of COVID-19 in travellers from that country on 13 October 2020. Prevalence was estimated by correcting for under-ascertainment based on a publicly available mathematical model developed by Russell and colleagues [9], asymptomatic infection, and to account for selection bias of people who are travelling, and the potential risk during travel. The latter two corrections were undertaken using a multiplier to account for the prevalence observed in arrivals to Australia being consistently higher than the expected prevalence based on the data from the countries of origin. Notably, even after making all of these corrections, there is likely to be a lag to detect increases in prevalence due to the lagged nature of the case and mortality data inputs. This highlights the need to take a cautious approach to assessing risk of importation from travel. Refer to Chapter 8 for details.

Table 2. Potential risk classifications for countries of origin

Risk Classification	Estimated Prevalence Thresholds[a]	Testing Criteria	Examples of Countries meetings these criteria[b]
Very Low	‹ 0.01%	Public testing data ≥ 50 tests per case	New Zealand, Thailand
Low	0.01 - 0.05%	Public testing data ≥ 50 tests per case	Cuba, Singapore, South Korea, Sri Lanka, Togo
Moderate	0.05 - 0.1%	Public testing data ≥ 50 tests per case	Uruguay
High	0.1 - 0.5%	Public testing data ≥ 50 tests per case	Estonia, Malaysia, Norway
Very High	› 0.5%	No criteria	Denmark, Germany, India, Pakistan, UK, USA, UAE

a. Prevalence estimated for 7 October 2020, adjusted for under-ascertainment, and observed high prevalence of COVID-19 in travellers.
b. These countries meet the prevalence thresholds and publish data on negative tests, and have undertaken at least 50 tests per case, suggesting adequate testing.

Similar classifications were considered for domestic travel. Applying the model to Australia, all states and territories are currently classified as very low-risk (Table 3). To note, given we are not aware of evidence that domestic travellers have higher rates of infection than other Australians, we corrected the Australian data for under-ascertainment of cases but not for additional risk of COVID-19 in travellers compared to other Australians.

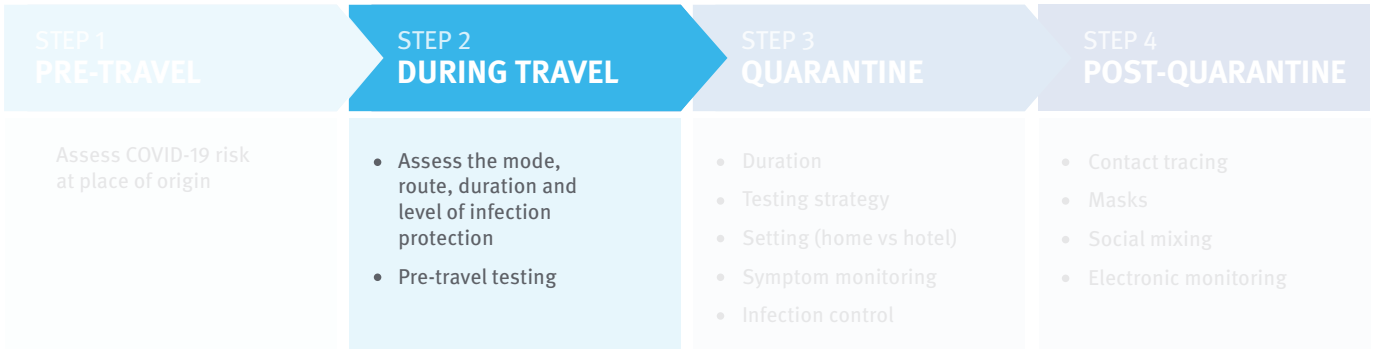
Table 3. Risk classifications based on estimated prevalence of COVID-19 (27 Oct 2020) in states and territories

State / Territory	Risk Classification
Australian Capital Territory	Very low-risk
New South Wales	Very low-risk
Northern Territory	Very low-risk
Queensland	Very low-risk
South Australia	Very low-risk
Tasmania	Very low-risk
Victoria	Very low-risk

In addition, some domestic travel is by private car, eliminating the risk from mass transit. Domestic air travel is also likely to be safer than international air travel, given travellers are effectively separated from international arrivals through separate domestic terminals and flights, and travel (and thus exposure) times are usually much shorter.

Risk from domestic travel is discussed in more detail in the economic evaluation section (chapters 5 and 17). Briefly, domestic travel for purposes other than tourism is very low risk with current case numbers. Nonetheless, there are risks from domestic tourism, mainly from high volumes of travel with very low per-traveller risk, and lack of practicality of testing and quarantine. In addition, tourists may have a high level of mobility, potentially making contact tracing and control challenging if there were an outbreak. These risks are discussed in more detail in chapters 5 and 17.

CHAPTER 2
DURING TRAVEL | STEP 2



Key Findings

- The risk of COVID-19 transmission during air travel is not well understood and difficult to calculate. The model considered two potential situations; minimal travel risk and substantial travel risk where the risk of COVID-19 exposure could not be controlled. The risk of COVID-19 importation is considerably higher if there is the potential of substantial travel risk but this risk could be partially mitigated through pre-travel testing.
- Pre-travel testing can reduce the risk of COVID-19 transmission during travel. However neither pre-travel testing, nor testing on arrival at the destination, nor a combination of the two are sufficient to mitigate the risk from international travel. Quarantine is required, except when the prevalence of COVID-19 is very low and verifiable in the country of origin (i.e. the country has a very low risk classification).

The number of infections acquired during travel is a key determinant for the level of risk to the community from arrivals. This is because infections acquired during travel have the most recent exposure. It is important to note there is a very low probability of detection of infections through PCR testing in the latent period, directly after exposure (close to 0 per cent probability of a positive test result) [10]. This means that as well as taking longer to resolve (become non-infectious), these infections are also likely to take longer to identify through testing. Therefore, infections acquired during travel are likely to require a longer quarantine period than those acquired earlier.

It is important to consider that the risk of infection may be greater during travel than in the preceding period. This is possibly the case for all air travel (currently there is no clear evidence either way), but certainly the risk of infection for individuals travelling from a low-risk country together with people from higher-risk countries of origin is likely to increase. Therefore, the risk assessment should include whether someone is travelling by air (low level of evidence but potentially high-risk), other forms of long-distance mass transit (evidence of high-risk), or by private car (very low-risk). The duration and route (including whether the travel is direct or through hubs) should also be considered. Given the current uncertainty around COVID-19 transmission during air travel, we considered a range of assumptions for risk during travel.

Importance of travel risk led to the number of cases expected in the community

In the traQ model substantial travel risk led to considerable increases in risk compared to the assumption of minimal travel risk, as measured by the number of people expected to leave quarantine infectious and the number of infectious person-days expected in the community. This continued to be the outcome in the model even with a relatively long quarantine (14 days) but the relative risk was higher for shorter duration quarantine strategies and strategies where there was zero days in quarantine (detailed results are included in Chapter 12).

Pre-travel testing

Pre-travel testing is increasingly becoming a requirement for international travel imposed by airlines. The potential role of pre-travel testing for mitigation of travel risk was evaluated. We found that the main value of pre-travel testing was in reducing the number of infectious people travelling together on mass transit, such as air travel, and therefore reducing the risk of COVID-19 transmission during travel. In the absence of substantial travel risk, for example people travelling directly from very low-risk and low-risk regions who are unlikely to have contact with people from higher risk locations during their journey, pre-travel testing did not impact on the need for quarantine or duration of quarantine. Detailed methods and results for this finding are included in chapter 13.

CHAPTER 3
QUARANTINE | STEP 3

STEP 1 PRE-TRAVEL	STEP 2 DURING TRAVEL	STEP 3 QUARANTINE	STEP 4 POST-QUARANTINE
• Assess COVID-19 risk at place of origin	• Assess the mode, route, duration and level of infection protection • Pre-travel testing	• Duration • Testing strategy • Setting (home vs hotel) • Symptom monitoring • Infection control	• Contact tracing • Masks • Social mixing • Electronic monitoring

Key Findings

- The timing of testing can have an impact on reducing risk. As was discovered in this study, the current standard testing regime can be optimised using an enhanced testing strategy. The ideal timing of tests is two tests near the end of quarantine, regardless of the duration of quarantine. This is most likely to identify people who would be infectious after release.
- 14-day quarantine is more effective than shorter-duration quarantine. However a no quarantine or a shorter-duration quarantine is possible where the probability of infection at arrival is very low, low, or moderate.
- It may be possible travellers with very low travel risk to have no quarantine, particularly if they undertake pre-travel testing and testing on arrival. As of 13 October 2020 only travellers from New Zealand and Thailand meet this criterion.
- The risk of COVID-19 importation increases with increased travel volumes, even when travellers are from very low risk and low risk settings. Ongoing monitoring and restriction of travel numbers may be required to control risk.
- If a risk-based quarantine strategy and enhanced testing strategy were used, and travel volumes stayed the same, the number of person-days of managed quarantine required could be reduced by up to 49,000 per month without any discernible increase in the risk of COVID-19 importation over the same period.

The third step of the traQ model examines the quarantine period it itself. It considers six key issues:

- Effectiveness of quarantine for minimal travel risk. This most likely represents a scenario where people are travelling directly from their home country and are unlikely to be exposed to people from higher risk locations during travel, for example the airport they are using is not a travel hub
- Effectiveness of quarantine for substantial travel risk. This most likely represents scenarios where travel is through hubs and there is exposure of people from lower risk countries to those from higher risk countries during travel)
- Testing strategies – their frequency and timing
- Risk-based quarantine strategies.
- Number of infectious days in the community
- Quarantine setting – hotel or home based

The results described in this chapter are based on a quarantine model that we developed described in detail in Chapter 10. Briefly, the model is based on published data on the distributions of durations of the infectious (including pre-symptomatic and symptomatic) and symptomatic periods, as well as data on the probability of a false negative PCR test result during these periods of infection in clinical settings. The model methodology and parameters are described in detail in Chapter 10. For the purpose of this chapter, we consider a range of quarantine durations that are reasonably evenly spaced out (0 days, 7 days, 10 days, 14 days and 21 days) in order to better understand the effect of quarantine duration and to understand the effects of timing of tests for those quarantine durations.

Figure 3. Mean and distribution for the infection stage by day since exposure

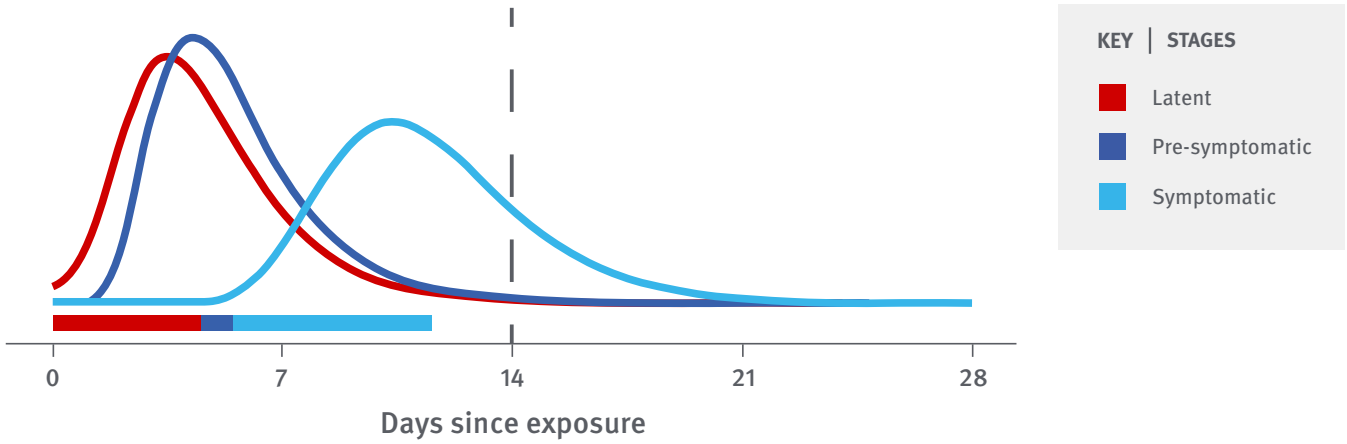
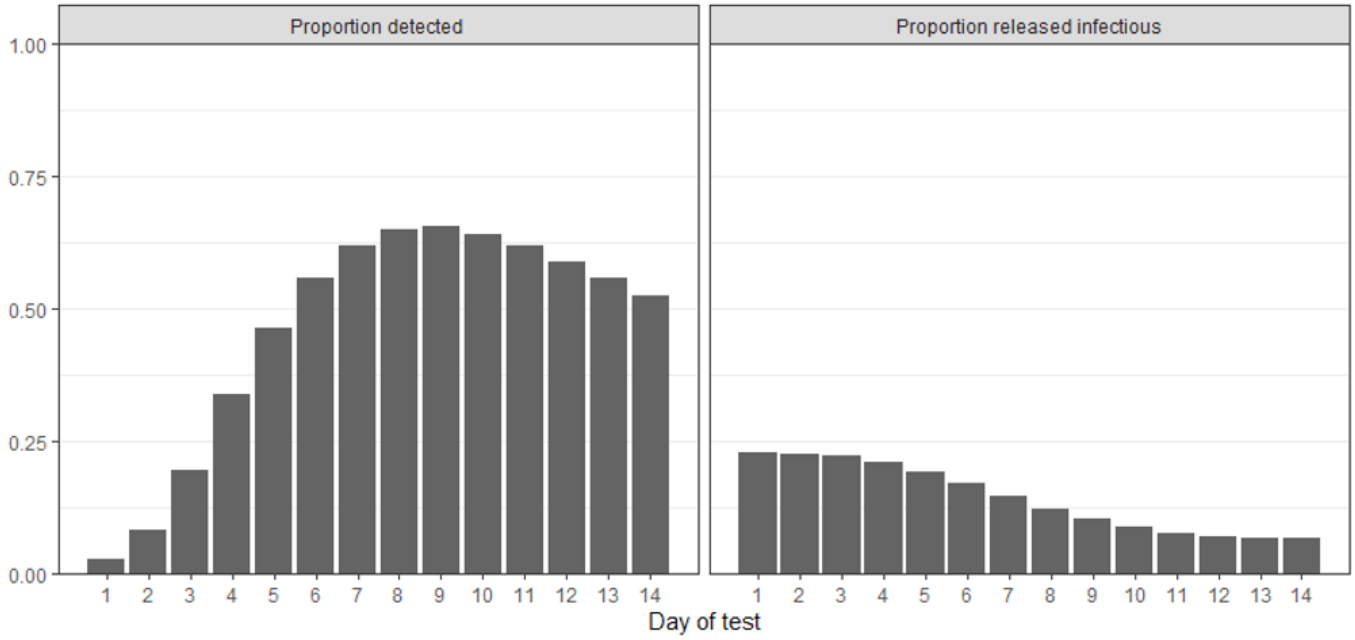


Figure 4. Proportion detected and released from quarantine infectious by days of test among those infected on the day prior to entry in a 14-day quarantine.



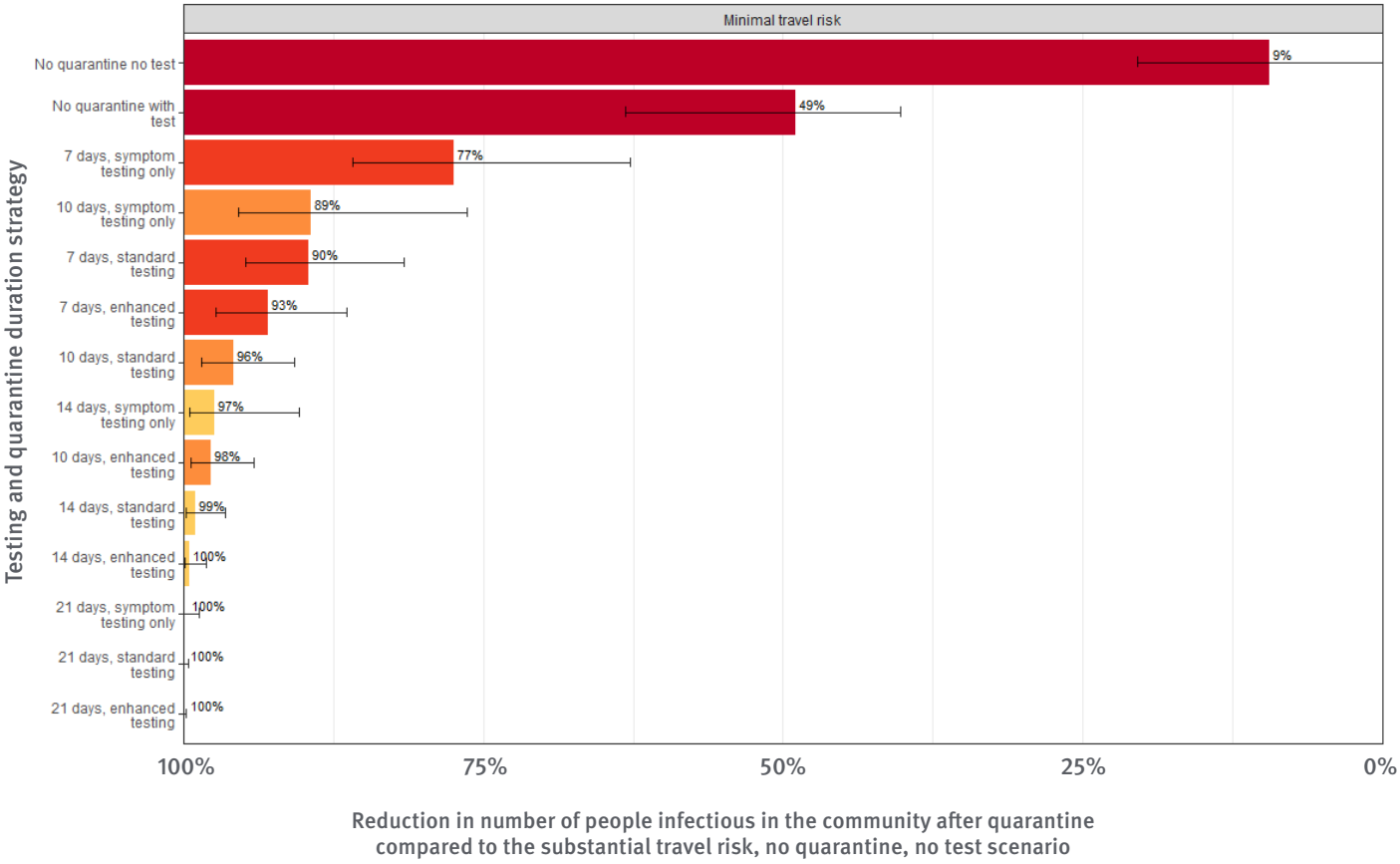
Effectiveness of quarantine for minimal travel risk

For scenarios where there is minimal risk of exposure during the journey to Australia, having a routine RNA test on arrival detected only around 45 per cent of cases that would otherwise be infectious in the community, compared to a "do nothing" strategy (no quarantine, no testing).

In comparison, a 7-day quarantine with two routine tests and symptom monitoring could detect about 90 per cent of cases. The 14-day quarantine with two routine tests and symptom monitoring (currently considered the standard for quarantine) detected is approximately 99 per cent of cases (Figure 5).

Pre-travel testing, when there is minimal travel risk, does not substantially change the risk to the community (Chapter 13).

Figure 5. Comparison of quarantine durations and testing strategies - Minimal Travel Risk



KEY | No quarantine | 7 day quarantine | 10 day quarantine | 14 day quarantine | 21 day quarantine

Standard testing: Symptom monitoring, routine tests on day 3 and 3 days before exit
Enhanced testing: Symptom monitoring, routine tests 1 and 2 days before exit

Percentages are rounded to the nearest percentage point. Note: 100% means >99.95% reduction in risk.

Effectiveness of quarantine for substantial travel risk

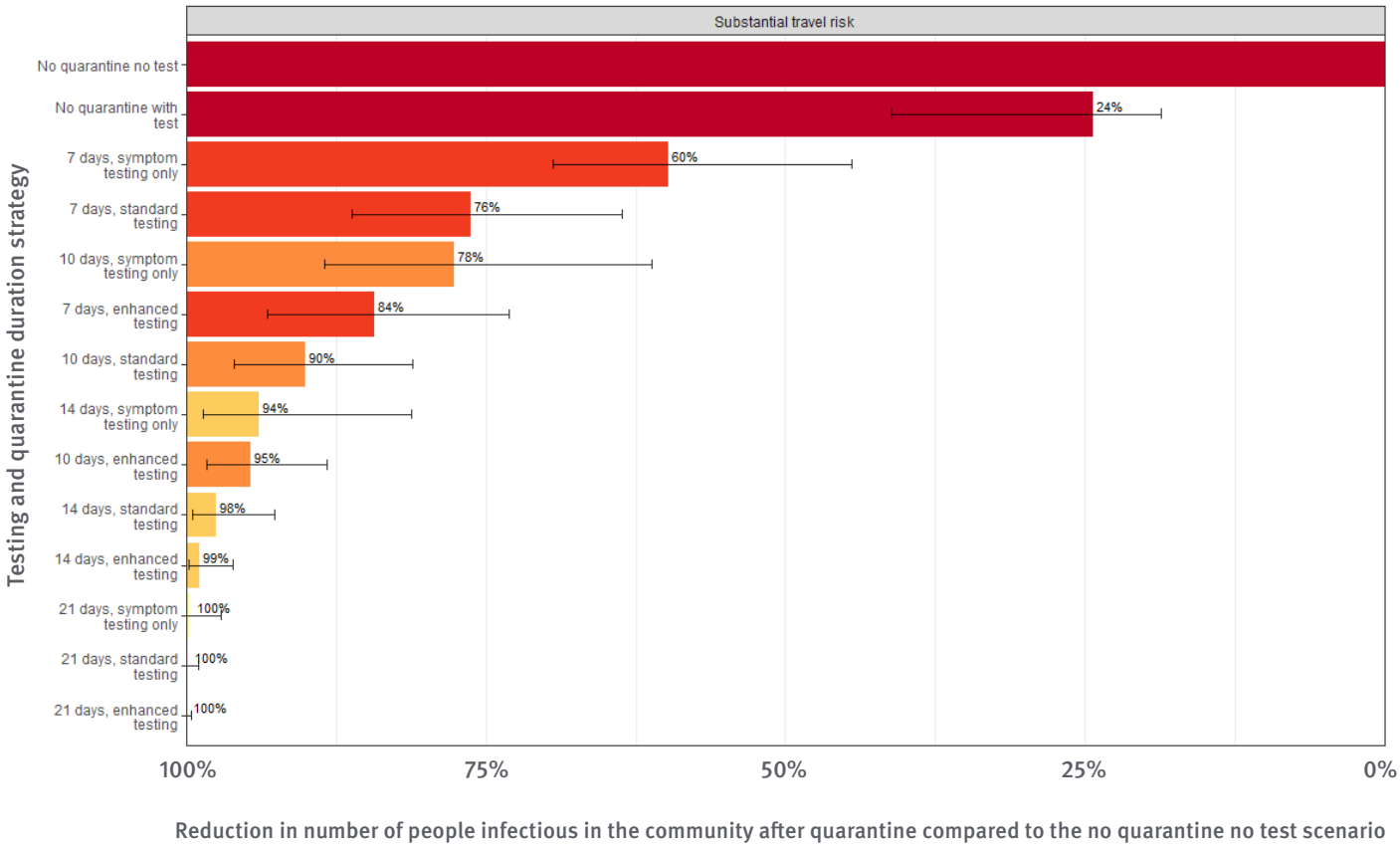
For scenarios where there is substantial risk of exposure during the journey to Australia, the effect of routine testing on arrival is reduced to 24 per cent.

The effect of 7-day quarantine is reduced to about 80 per cent. The 14-day quarantine is still very effective at identifying potentially infectious cases, with 99 per cent detected (Figure 2). If travel risk is substantial, pre-travel testing is effective for reducing this risk somewhat and therefore reducing the risk to the community (detailed results in chapter 13).

Testing strategies

The duration of quarantine is more important than the testing strategy, but routine testing can also reduce COVID-related risk. We considered two routine testing strategies for each duration of quarantine. The standard strategy includes routine tests on day three and three days prior to quarantine exit (e.g. for 14-day quarantine, this would be on days 3 and 11 consistent with current Australian recommendations). The enhanced testing strategy includes two tests, one and two days prior to quarantine exit (e.g. for 14-day quarantine this would be days 12 and 13). The enhanced strategy reduces risk compared to standard testing for all quarantine durations, but the benefit is greater for shorter durations of quarantine. For example, for a 7-day quarantine, enhanced testing leads to an approximately 92 per cent reduction in the number of cases with ongoing infection after quarantine, compared to an 89 per cent reduction with standard testing (Figure 6).

Figure 6. Comparison of quarantine durations and testing strategies - Substantial Travel Risk



KEY | No quarantine | 7 day quarantine | 10 day quarantine | 14 day quarantine | 21 day quarantine

Standard testing: Symptom monitoring, routine tests on day 3 and 3 days before exit
Enhanced testing: Symptom monitoring, routine tests 1 and 2 days before exit

Percentages are rounded to the nearest percentage point. Note: 100% means >99.95% reduction in risk.

Risk-based quarantine strategies

While a 14-day quarantine period is always relatively more effective than shorter-duration quarantine, we considered whether a shorter-duration quarantine might be appropriate for a situation where the probability of infection at arrival is relatively low due to the low rate of infection in the country of origin. For this section, because we were looking for cut-points where shorter quarantine met a low-risk threshold, we considered a different set of quarantine durations to the previous section. We considered only durations less than 14 days given we were looking for potentially shorter duration quarantine. Specifically, we considered all durations ranging from 4-10 days. The low-risk threshold was defined as the risk to the community from a 14 day quarantine with standard testing for a group of arrivals with 1 per cent COVID-19 prevalence. Using the five potential classifications of risk presented in Table 2, we devised potential quarantine and testing recommendations for 18 countries of origin (Table 4).

Table 4. Potential risk classifications and quarantine / testing recommendations for countries of origin

Risk Classification	Estimated Prevalence Thresholds[a]	Testing Criteria	Examples of Countries meetings these criteria[b]	Quarantine / Testing Recommendation
Very Low	‹ 0.01%	Public testing data ≥ 50 tests per case	New Zealand, Thailand	Pre-travel testing No quarantine Test on arrival
Low	0.01 - 0.05%	Public testing data ≥ 50 tests per case	Cuba, Singapore, South Korea, Sri Lanka, Togo	Pre-travel testing 7-day quarantine for individuals quarantining alone Enhanced testing in quarantine
Moderate	0.05 - 0.1%	Public testing data ≥ 50 tests per case	Uruguay	Pre-travel testing 8-day quarantine for individuals quarantining alone Enhanced testing in quarantine
High	0.1 - 0.5%	Public testing data ≥ 50 tests per case	Estonia, Malaysia, Norway	Pre-travel testing 14-day quarantine Enhanced testing in quarantine
Very High	› 0.5%	No criteria	Denmark, Germany, India, Pakistan, UK, USA, UAE	Pre-travel testing 14-day quarantine Enhanced testing in quarantine

For each risk classification, we considered the number of infectious cases released into the community and the number of infectious person-days per 10,000 arrivals based on a range of shorter quarantine durations with enhanced testing strategy. Quarantine and testing strategies were selected to ensure that the expected risk is similar or lower than estimated for returning residents (approx. 1 per cent risk of infection) based on a 14-day quarantine period with standard testing. Enhanced testing is recommended in each case based on the advantage over standard testing. Pre-travel testing is recommended for each scenario in the context of air or other mass transit due to unclear levels of risk, expected heterogeneity of risk, and difficulty controlling risk during travel.

Some countries broadly considered low risk are not included in Table 4 above due to a lack of information on testing and/or mortality; see Table 5 for discussion.

Table 5. Countries widely considered low risk but not classified as such by our model

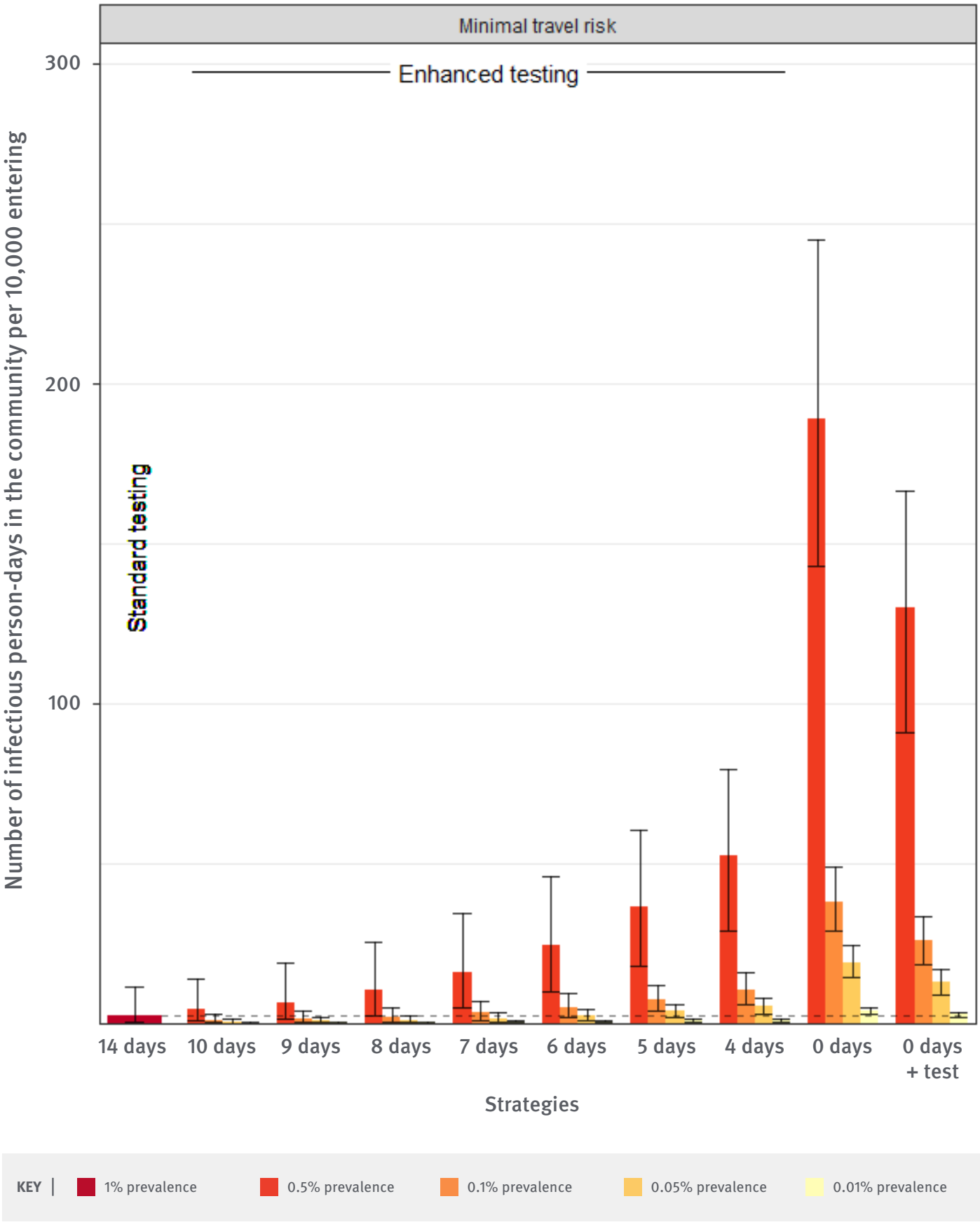
Countries	Criteria	Implications
China **Vietnam**	Meet estimated prevalence criteria for **very low risk** Do not publish testing data	Testing data provide confidence that case and mortality data are sufficiently accurate to underpin model-based prevalence estimates.
Vanuatu and similar Pacific Islands	No publicly available case, mortality or testing data	Credible (but not public) data demonstrate no excess pneumonia presentations and no diagnosed cases. Island nations with current travel restrictions are likely to pose very low risk. However, their capacity to detect an outbreak may be low, which implies a higher risk than countries such as New Zealand or Thailand (which have similarly low case numbers but more capacity to detect new cases in a timely manner).

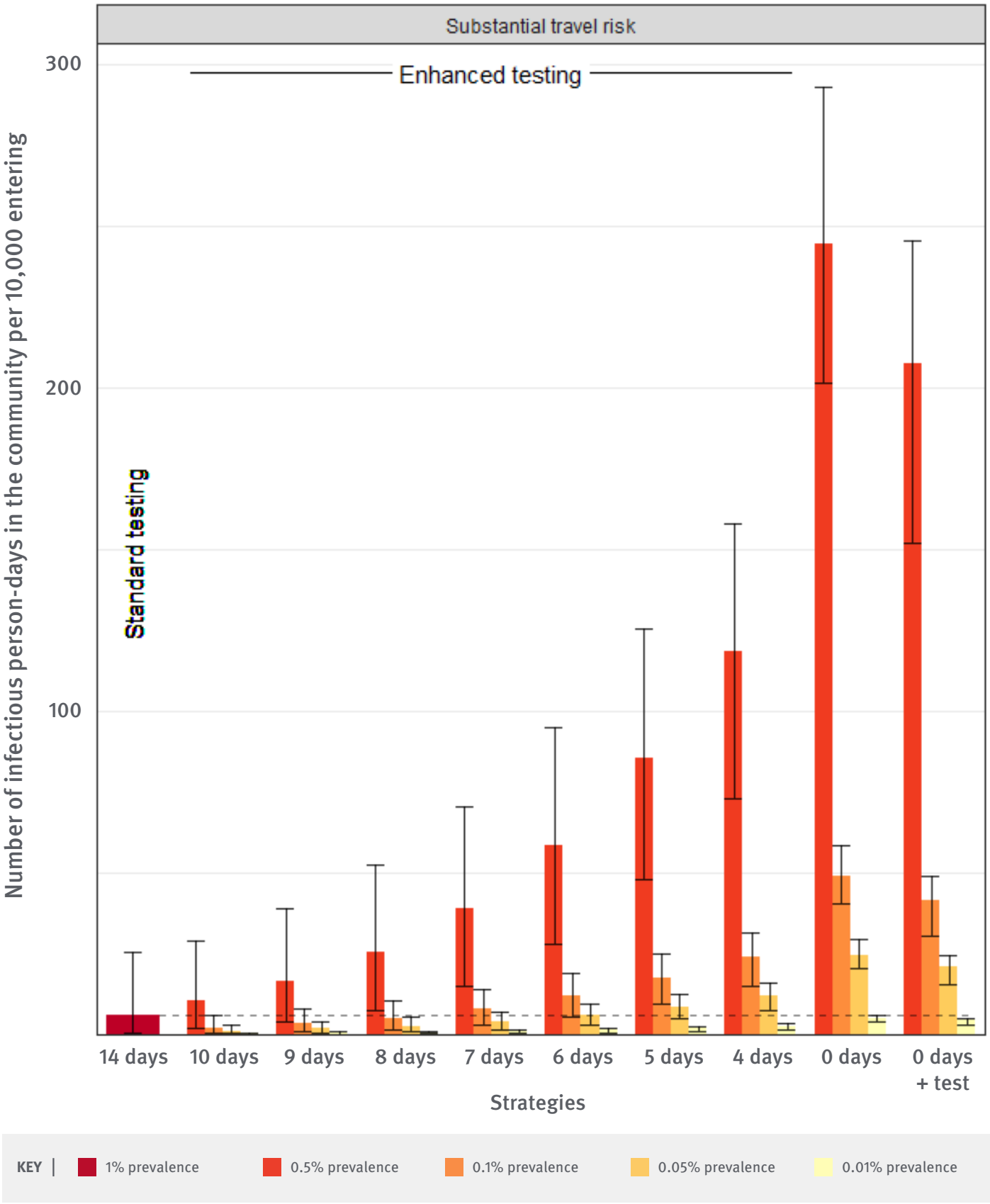
Number of infectious days in the community

In addition to the number of people with ongoing infection after quarantine, we considered the number of infectious person-days in the community. This considers not only how many people are released infectious, but also the number of days left in their infection at the time of release. This measure is likely to be a better indicator of the risk to the community than the number of people with ongoing infection, because in the lengthier quarantine durations most of the infections that are not detected are nearing the end of their infectious period by the end of quarantine. These results are presented in detail in chapter 12.

Figure 7 illustrates the number of person-days in the community per 10 000 entrants for each of the prevalence cut-offs in Table 4 for no quarantine (with and without a routine RNA test on arrival), and 4–10 days of quarantine with enhanced testing. These are compared to the expected number of infectious days in the community per 10 000 arrivals to Australia with an overall COVID-19 prevalence of 1 per cent and current quarantine and testing strategies (14-day quarantine, standard testing).

Figure 7. Number of person-days in the community by infection prevalence and quarantine and testing strategy





The results provide an evidence-based strategy where quarantining and testing is commensurate with the COVID-19 risk. Specifically, 8 days of quarantine with enhanced testing for arrivals from countries with 0.1 per cent probability of infection, 7 days of quarantine with enhanced testing for arrivals from countries with 0.05 per cent probability of infection, and no quarantine with a routine RNA test at entry for arrivals, from countries with 0.01 per cent probability of infection, are expected to result in equivalent risk to the community as 14-day quarantine with standard testing for

1 per cent probability of infection. Note that this is for individuals quarantining alone and cannot be generalised to family or other groups quarantining together.

Number of people travelling per month

The number of people travelling per month is a key parameter determining the level of risk from travel. Reduced (and particularly, waived) quarantine may lead to increased numbers of travellers.

Arrivals to Australia in May and June 2020 numbered less than 1 per cent of those at the same time period the previous year. If the volume of travellers from low-risk countries were to substantially increase, this would lead to higher risk estimates. This is shown in the international tourism scenario in the economic evaluation section of this report in chapters 5 and 17.

The prevalence estimates for each country and the consequent risk classifications can be updated regularly, providing timely information for policy. Notably, risk classifications can change rapidly. For example, over the past few weeks, the classification for Malaysia has changed from low risk to high risk due to increases in cases. While the ability to provide updated information is a strength of this approach, the rapidly changing situation may be challenging for policy and can be expected to continue to contribute to uncertainty for potential travellers.

Quarantine settings

Most of the work in this report assumes that the quarantine setting is managed quarantine. A key assumption is that there was no risk to the community until individuals were released from quarantine. That is, the model estimates of risk do not include the risk of transmission from individuals in quarantine to managed quarantine staff. While this potential risk should be considered, the reported number of transmissions from people in managed quarantine to staff has been very low. Notably, this work assumes that people are quarantined alone. It is likely that shorter quarantine durations in particular will be less effective for those quarantined in groups (such as couples and families), and different testing strategies are also likely to be required for family or group quarantine.

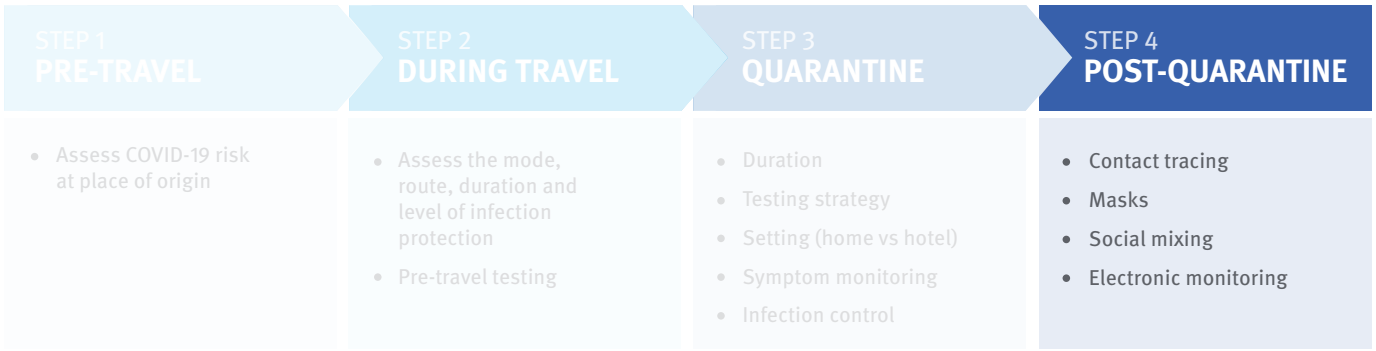
While most of this report pertains to managed quarantine settings, we also investigated the potential effectiveness of home-based quarantine. For this analysis, we assumed that 70 per cent of people quarantined cooperated with quarantine rules. We assumed that those not cooperating with quarantine would also not cooperate with isolation if they tested positive. This approach is also likely to be reasonable for estimating the number of people infectious in the community, because those that test positive and do not cooperate prior to receiving their test results are very likely to be infectious before receiving those results. This is because detectability of the virus is unlikely until around the time that infectiousness develops and there is a lag between the swab being taken and results becoming available (See figure 4). However, it may overestimate the number of infectious days in the community for home quarantine if those not cooperating with quarantine rules (a) present for testing, (b) isolate effectively between the test and receiving their result, and/or (c) isolate effectively after testing positive. For these scenarios, we assumed standard testing in 14-day quarantine and enhanced testing in 7-day quarantine. We did not consider transmission to other members of the household during home quarantine.

Assuming 70 per cent cooperation with quarantine rules, the reduction in numbers of infectious people entering the community relative to the “do nothing” (no quarantine, no testing) strategy is around 70 pe cent for 14-day home-based quarantine (irrespective of travel risk assumptions). This is considerably lower than the reduction in risk for 7 days of managed quarantine (92 per cent under the assumption of minimal travel risk and 82 per cent under the assumption of considerable travel risk). Detailed results in chapter 14.

Notably, this is based on the assumption that those not cooperating will not cooperate throughout the quarantine period. However, realistically, cooperation may vary with the number of days in quarantine. Behavioural research could provide more insight into behaviour in home-based quarantine, including the proportion cooperating throughout and among those not cooperating, whether this varies over time, and the influence of testing.

Electronic monitoring at home has been suggested as an alternative to managed quarantine. However, its effect on cooperation is not currently known. For example, the proportion of people quarantining at home with electronic monitoring who might invite visitors to the home would exert a powerful influence on infection risk.

CHAPTER 4
POST-QUARANTINE | STEP 4



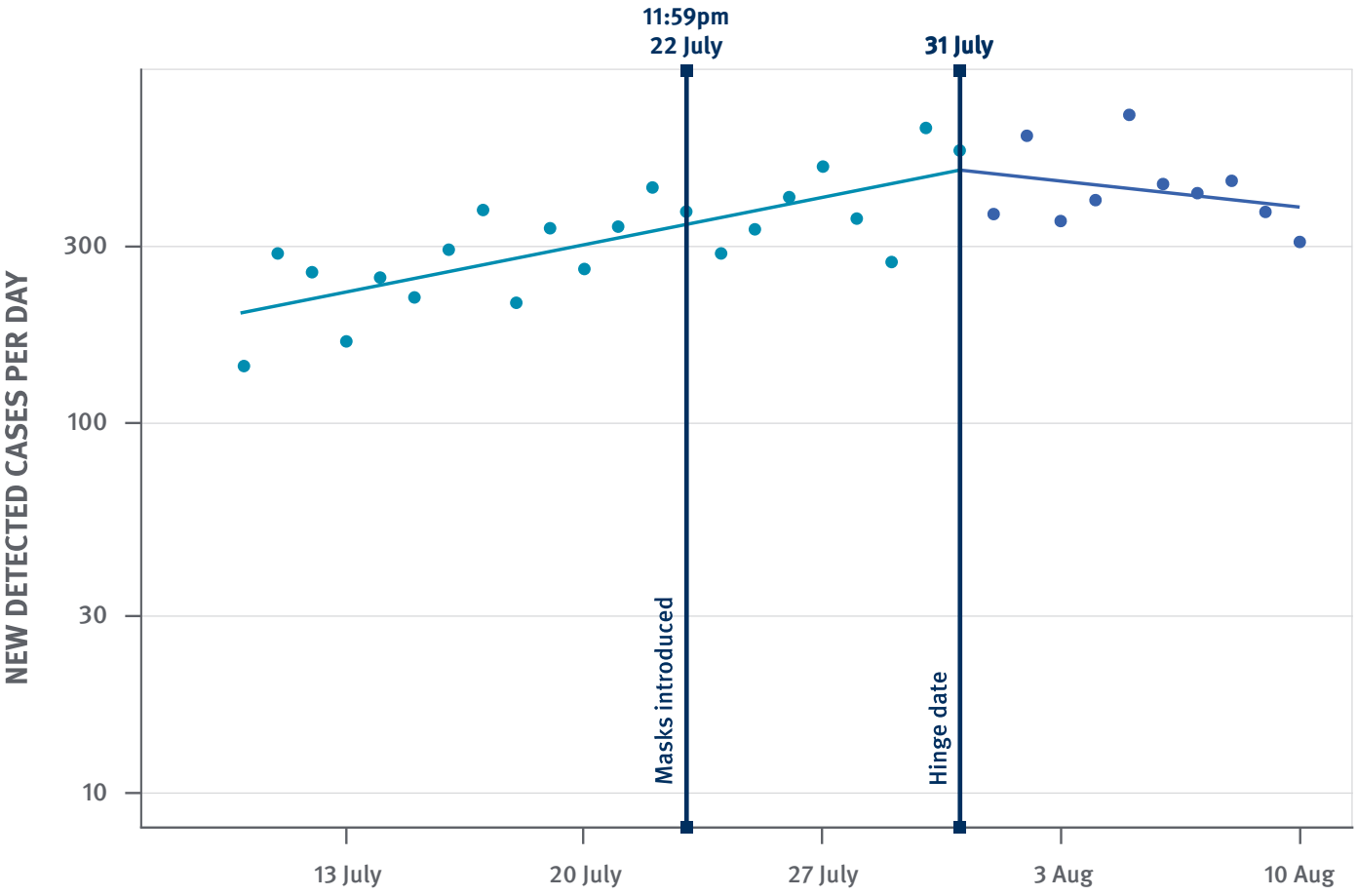
Key Point

- Mitigation strategies such as social distancing, hand hygiene and masks are effective in reducing COVID-19 transmission and should be considered a central component of the quarantine strategy.

Mitigation strategies such as social distancing and hand hygiene are effective in reducing COVID-19 transmission. Recent work by the Burnet Institute work suggests that community use of masks – when both the potential source and potential infectee are instructed to wear masks – reduces transmission by over 20 per cent. All three interventions should be built into all quarantine strategies to reduce the risk between individuals undergoing quarantine and staff supporting the quarantine program.

In some contexts, it may also be possible to implement these strategies after quarantine. For example, where people are travelling to a fixed location for work (such as seasonal agricultural workers) it may be feasible to build these into workplace processes. In other contexts, some inbound traveller education may be possible through providing materials at airports and other entry points. For example, travellers could be asked not to travel to particular high-risk locations. However, outside of a closed context it is unclear to what extent social distancing, hand hygiene and masks will be effective if practiced only by travellers and not by the community they are travelling to.

Figure 8. COVID-19 cases detected per day in Victoria in 2020. Observed daily cases (dots) and fitted linear spline model with a hinge day on 31 July. Teal: analysis period for pre-masks; Blue: analysis period for post- masks.

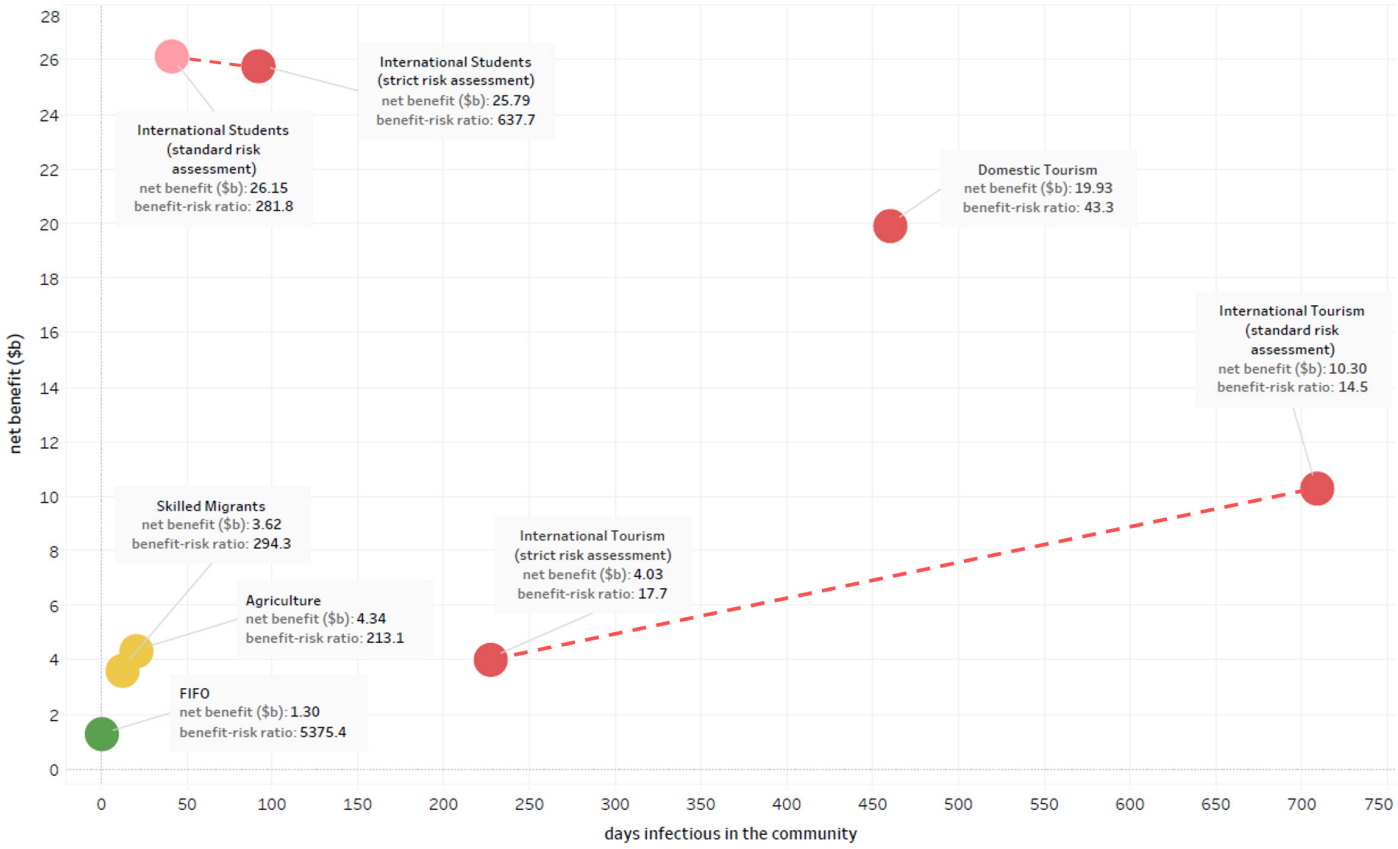


Electronic monitoring after quarantine may have a benefit if the length of quarantine has been reduced. However electronic monitoring through the COVID-safe app or similar can only be effective if there is a reasonable probability that both the potential source and the potential infectee have the app activated. Although all of these strategies will reduce risk to a certain extent, none is a substitute for quarantine. They are likely to be most effective when used in combination with a high-efficacy quarantine strategy such as the standard strategy or the proposed risk-based strategy.

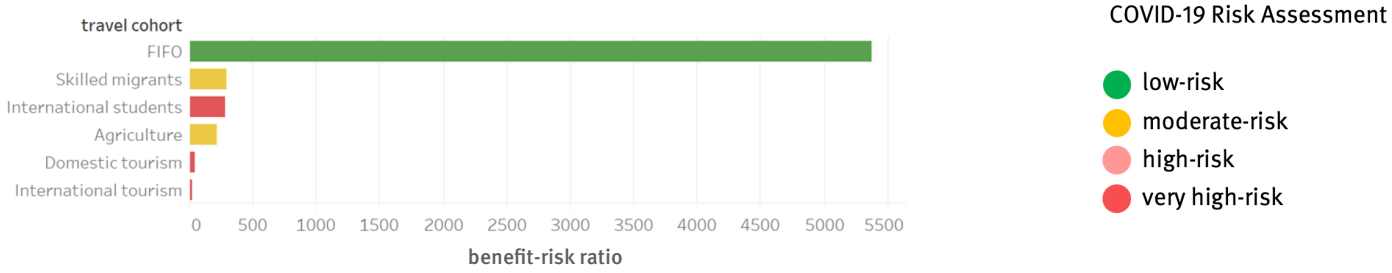
Home quarantine (discussed above) following reduced length of hotel quarantine could be another effective mechanism to reduce risk; however mechanism to monitor compliance would need to introduced if such an approach was to be adopted.

CHAPTER 5
COST-CONSEQUENCE OF COST-EFFECTIVENESS ANALYSIS

Figure 9. Risks and benefits of selected strategies for six potential traveller cohorts



Benefit-risk ratio for travel cohorts



Explanatory Notes

- International student and international travel risks are calculated using two different sets of assumptions:
  - **Strict risk assessment:** includes higher data quality threshold to secure low- or very low-risk rating.
  - **Standard risk assessment:** based on estimates of prevalence alone.
- International tourism is limited to very low-risk jurisdictions (e.g. New Zealand) with pre-travel and on arrival testing.
- Domestic tourism assumes interstate travel with no testing between very low-risk states and territories.
- All other cohorts are subject to risk-based quarantine and testing.

Key Findings

- Our risk-return analysis of COVID-19 importation from travel supports selective resumption of high value travel, including skilled migration, seasonal agricultural workers and FIFO workers.
- Of the scenarios evaluated, international students make the greatest contribution to the national economy and should resume with robust testing and quarantine strategies.
- It will be difficult to resume mass international tourism while global COVID-19 prevalence remains high.
- It is difficult to manage the risks from domestic tourism due to lack of feasibility of quarantine or testing. Resumption of domestic tourism depends on effective domestic suppression of COVID-19.
- The potential economic benefits of allowing resumption of travel for the Australian economy are immense. The total benefit of the seven scenarios considered was estimated to be AUD$86 billion if 2019 travel volumes could be resumed. However, the risk of COVID-19 importation from travel is substantial, and it is likely that ongoing volume controls on travel will be required.
- Allowing increased travel with 14-day managed quarantine for long-term inbound international travellers (e.g. seasonal agricultural workers, international students, skilled migrants), is costly, but the benefit-to-cost ratio is very high, indicating that investment in quarantine may provide substantial value to the Australian economy).
- Risk-based quarantine strategies (i.e. people coming from very low-risk and low-risk settings) offer substantial cost-reductions without increasing overall risk, if current travel volumes remain stable.
- However, volume controls are likely to be required for travel, including from very low-risk settings because although the per-person risk is very low, substantial increases in travel volumes without a 14-day quarantine result in substantial risks to the community.
- Volume controls are likely to impact most on the tourism industry which has previously relied on high volumes of short-term travel to contribute to overall earnings, but may also have to be applied to other forms of travel to maintain low levels of risk.
- Jurisdictions can mitigate the potential risks of importing COVID-19 cases through travel by ensuring robust public health capacity including testing, contact tracing and case management of potential cases, as well as through mandating mask wearing, low levels of social distancing, and encouraging ongoing COVID-19 testing in the community (based on results from the Burnet agent-based COVASIM model). This may be considered worthwhile for jurisdictions that benefit from travel.

We considered the economic benefits of allowing travel for two potential cohorts of domestic travellers and five potential cohorts of international travellers:

Domestic

- Fly-in-fly-out (FIFO) workers in the mining industry
- Domestic tourism.

International

- Returning Australian residents
- Seasonal workers for agriculture (through the Seasonal Workers Program and Backpackers program)
- Skilled migrants
- International students
- Inbound international tourism.

For each cohort, as well as considering economic benefits of allowing travel, we considered the costs of six potential quarantine strategies and the associated risks to importation of COVID-19 cases into the community. The six strategies were chosen to minimise the per-traveller risk of COVID-19 importation. They were:

1. Open entry (allowing the cohort to travel) with standard quarantine (14-days, standard testing)
2. Open entry with risk-based quarantine (pre-travel testing three days prior to departure for all travellers to minimise potential risk during travel, 14-day quarantine with enhanced testing for those coming from very-high or high-risk jurisdictions, 8-day quarantine with enhanced testing for those coming from moderate-risk jurisdictions, 7-day quarantine with enhanced testing for those coming from low-risk jurisdictions, and no quarantine with testing on arrival for those coming from very low-risk jurisdictions)
3. Moderate-risk entry (allow those from moderate or lower-risk jurisdictions to enter), risk-based quarantine
4. Very-low risk entry (allow those from very low-risk jurisdictions to enter), no quarantine, pre-travel testing and testing on arrival
5. Low-risk entry, no quarantine, no testing
6. Very low-risk entry, no quarantine, no testing

Two systems were used for classification of risk in the jurisdiction of origin. For international jurisdictions, one was a stricter system that required a high level of data to classify a jurisdiction as very low or low risk, and the other a more relaxed system that defined jurisdictions based on the estimated prevalence and multiplier for the higher prevalence of COVID-19 observed in international arrivals. For domestic jurisdictions (i.e., Australian states and territories), the strict classification system was based on the estimated prevalence and multiplier for the higher prevalence of COVID-19 observed in international arrivals, and the relaxed classification system was based on the estimated prevalence alone without applying the multiplier for the higher prevalence of COVID-19 observed in international arrivals.

The risk of COVID-19 importation from each cohort and quarantine strategy was quantified in terms of the expected number of infectious days in the community among travellers in Australia over a one-year period. This does not include onward transmission. These numbers were then classified into overall risk scores:

- **Low:** ≤1 infectious day per Australian jurisdiction per year for the cohort (that is, ≤7 in Australia in total)
- **Medium:** ≤3 infectious days per Australian jurisdiction per year for the cohort (that is, ≤21 in Australia in total)
- **High:** ≤5 infectious days per Australian jurisdiction per year for the cohort (that is, ≤35 in Australia in total)
- **Very high:** >5 infectious days per Australian jurisdiction per year for the cohort.

These thresholds were chosen given that multiple cohorts may be allowed entry, and the overall risk is additive. Notably, these thresholds include infectious days from index cases only and do not include any days from potential onward transmission.

SUMMARY

CHAPTER 1 TO 5

This analysis provides an evidence base to ensure quarantine and testing is commensurate with risks and considers the risks/reward trade off. A tailored quarantine approach that assesses pre- and during travel risk, combined with pre-travel and on arrival testing and/or enhanced testing as required, and risk mitigation strategies post-quarantine can reduce the length of quarantine in specific circumstances without significantly increasing the risk of COVID-19 transmission to the community.

Tailoring Australia's quarantine strategy to these risk classifications (risk-based quarantine strategy) could include:

- pre-flight testing for all international arrivals to reduce risk of transmission during travel
- 14-day managed quarantine for people travelling from high and very high-risk locations
- 8-day managed quarantine for people travelling from moderate-risk locations
- 7-day managed quarantine for people travelling from low-risk locations
- routine RNA testing on arrival but no quarantine for people traveling from very low-risk locations.

However, these policies will likely need to be combined with ongoing restrictions on travel volumes in order to minimize the risk of importation of COVID-19 cases. Jurisdictions can further mitigate the potential risks of importing COVID-19 cases from travel through ensuring robust public health capacity including testing, contact tracing and case management of potential cases, as well as through mandating mask wearing, ensuring appropriate social distancing, and encouraging ongoing COVID-19 testing in the community.

RISK-BASED QUARANTINE STRATEGIES

Tailoring Australia's quarantine strategy to these risk classifications could include:

PRE-FLIGHT TESTING - All international arrivals

14 DAY QUARANTINE#	8 DAY QUARANTINE#	7 DAY QUARANTINE#	NO QUARANTINE*
location travelling from is HIGH / VERY HIGH-RISK	location travelling from is MODERATE-RISK	location travelling from is LOW-RISK	location travelling from is VERY LOW-RISK

#as long as two negative tests are returned - on the penultimate day of quarantine and on the day prior.
*only with routine RNA (PCR) testing on arrival.

Limitations

- These estimates and recommendations apply to **individuals quarantining alone**. It does not assess the risk for families and groups quarantining after travel from low and moderate-risk countries and states.
- Country and state-specific estimates of imported cases could be improved by integrating empirical data on COVID-19 positivity in arrivals by country of origin. This could inform a risk-based travel strategy.

Future Work

- The model structure enables easy updates of estimates and risk classifications, which is important given the changing epidemiology of COVID-19 globally. However, changes in risk classifications will create uncertainty among potential travellers.
- Current country-specific estimates of prevelence of COVID-19 among travellers are based on country-specific case, mortality and death data, but not on country-of-origin specific data on prevalence of COVID-19 among arrivals to Australia. The addition of the latter data to the model would improve the quality of estimates.
- Countries that have never had COVID-19 epidemics and have reported fewer than 10 deaths in total from COVID-19 are currently not included in our prevalence estimates due to the method relying on mortality data to estimate underascertainment of cases. For example, these include Taiwan and Vanuatu, which are very likely to be very low-risk. Further work is required to estimate risk for countries with no or minimal mortality data.
- Further work is required to examine jurisdiction-specific risk for inbound domestic travel within Australia. For example, specific risk for each State and Territory.
- The recommended enhanced testing strategy involves tests 1 and 2 days before quarantine exit, but it is not clear that results can be returned quickly enough to implement it. Information on the minimum time for returning tests could be used to refine recommendations.
- Managed quarantine is very effective for reducing risk of COVID-19 importation but is resource intensive for government and difficult for individuals, with implications for mental health. More work is needed to test strategies for home-based quarantine (e.g. electronic monitoring) while maintaining compliance with quarantine protocols.
- Behavioural research is needed to understand levels of cooperation in home-based quarantine, including uptake of testing, compliance with isolation protocols if COVID-positive, and the impact of interventions such as case management, financial support and electronic monitoring.
- Model estimates for quarantine efficacy are based on the distributions of the timing of the latent and infectious periods derived from the literature, not empirical Australian data.

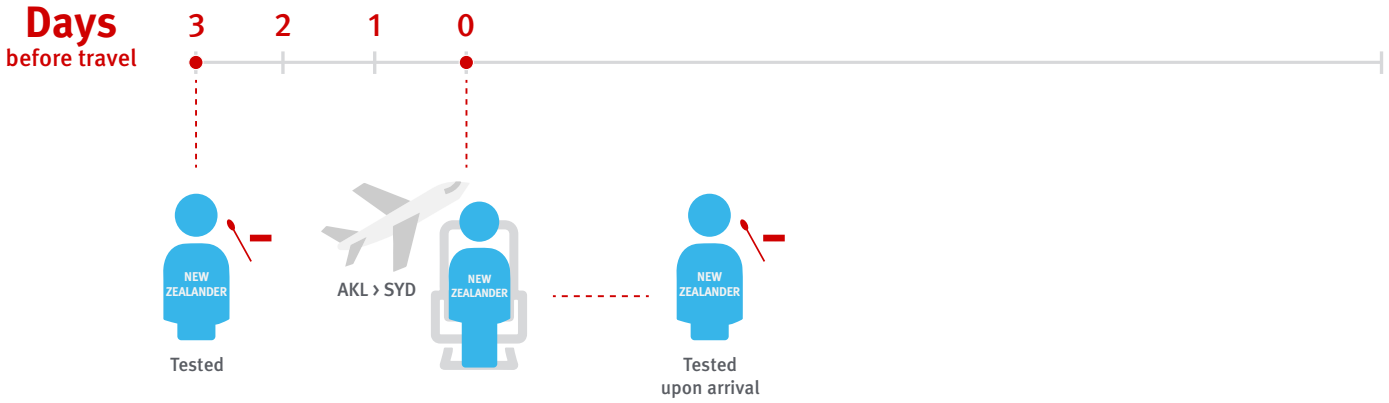
CHAPTER 6
SCENARIOS

Ongoing COVID-19 infection risk for travellers from overseas or crossing a jurisdictional border

Note that these scenarios are designed to illustrate the range of risk profiles among community quarantine cases and are not representative of average risks.

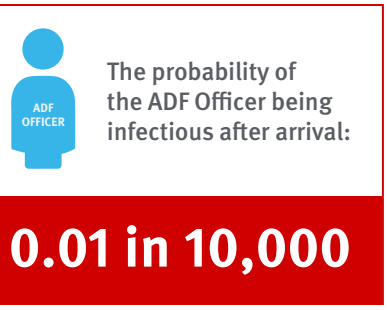
SCENARIO 1

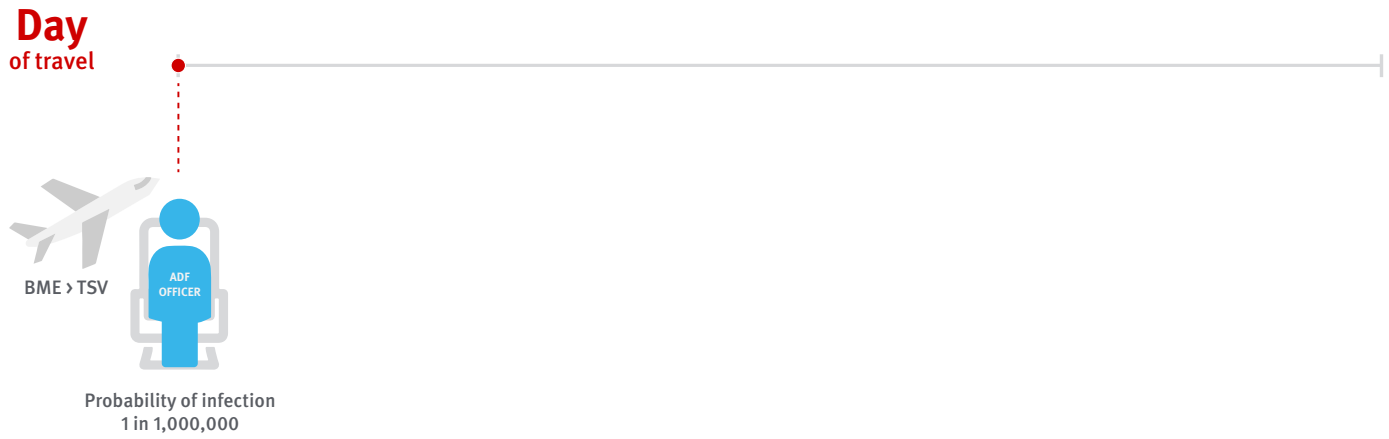
A New Zealand resident flies from Auckland to Sydney on an Air New Zealand flight. There are no transit passengers at the terminal or on the flight, the New Zealand resident only has contact with people from New Zealand and Australia during travel. If he tests negative 3 days prior to travel and on arrival in Sydney, the probabilty he will be infectious after arrival is**: 0.3 in 10,000.**



SCENARIO 2

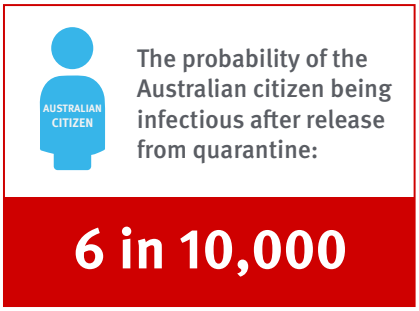
An Australian Defence Forces officer who has been working in Broome supporting cyclone management, flies back to his base in Townsville. No community-acquired cases have been reported in Western Australia for more than two months. Let's imagine that a public health directive has prevented international passengers from transiting through the domestic terminal. It is possible but unlikely that they will come into contact with a passenger who has flown to Broome from the eastern states, given people are only allowed to fly to Broome from other states in specific circumstances and the volume of travel is low. Let's assume the probability of infection at the airport or during the flight was **1 in 1,000,000**. If the Officer is not quarantined or tested after arrival in Townsville, the probability she will be infectious on arrival in Townsville is **0.01 in 10,000.**

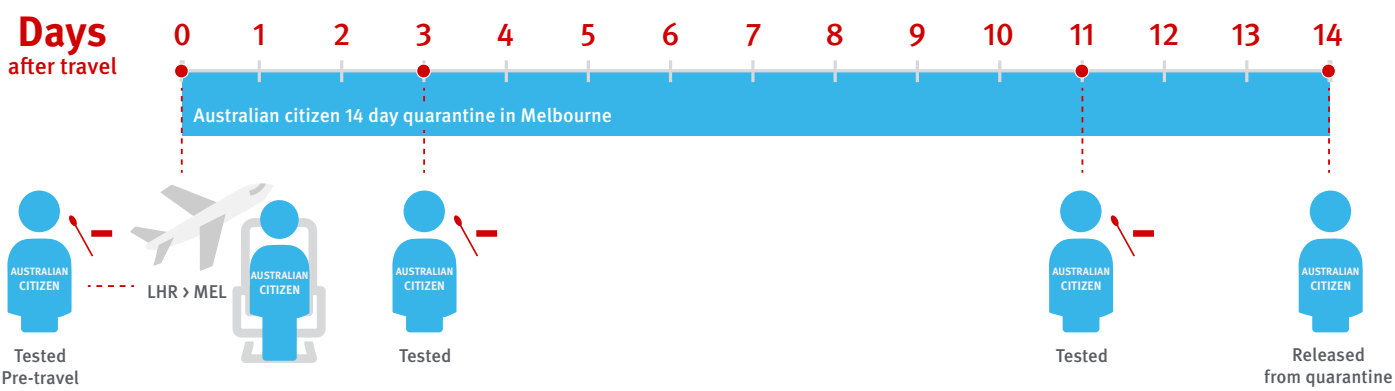




SCENARIO 3

An Australian citizen is returning to Australia from London. Let's assume the probability of infection at the airport or during the flight was **similar to the probability of infection throughout the UK.** If the returning citizen is tested pre-flight, quarantined for **14 days** after arrival in Melbourne and tested at day 3, day 11, and symptom onset if he develops symptoms, the probability he will be infectious after release from quarantine, if he does not return any positive test results, is: **6 in 10,000.**



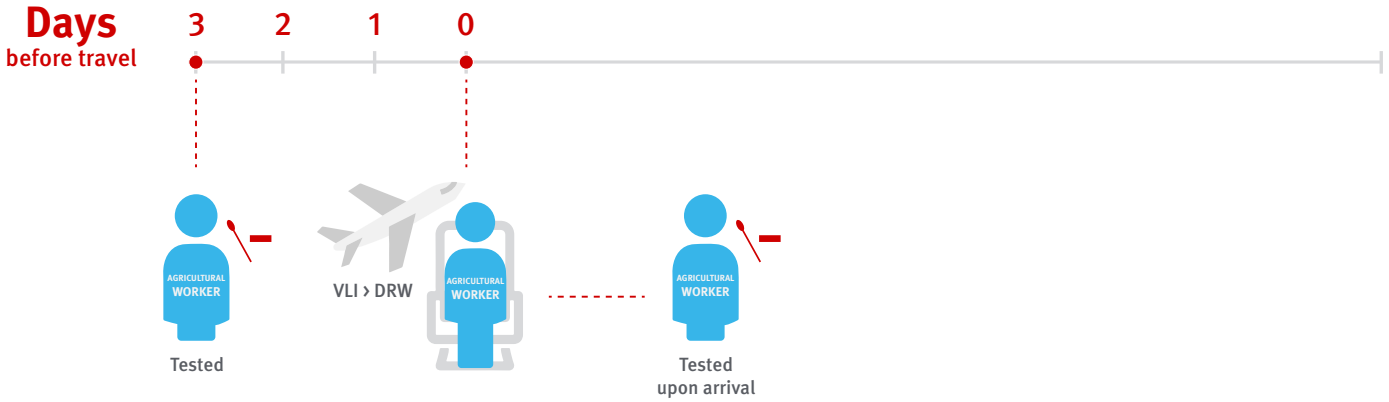


SCENARIO 4

An agricultural worker flies from Vanuatu to Darwin. There have been no community-acquired cases reported in Vanuatu for several months and no increase in mortality or pneumonia. It should be noted that there is no routine COVID-19 testing being done, so if a case was introduced there is a significant risk that detection would be delayed. However, borders are closed so the risk of introduction is currently very low. The worker is flying directly to Darwin airport and is unlikely to be exposed during travel. If the worker is not quarantined but is tested three days before travel and after arrival in Darwin the probability she will be infectious after arrival is: **0.4 in 10,000.**

The probability of the agricultural worker being infectious after arrival:

0.4 in 10,000

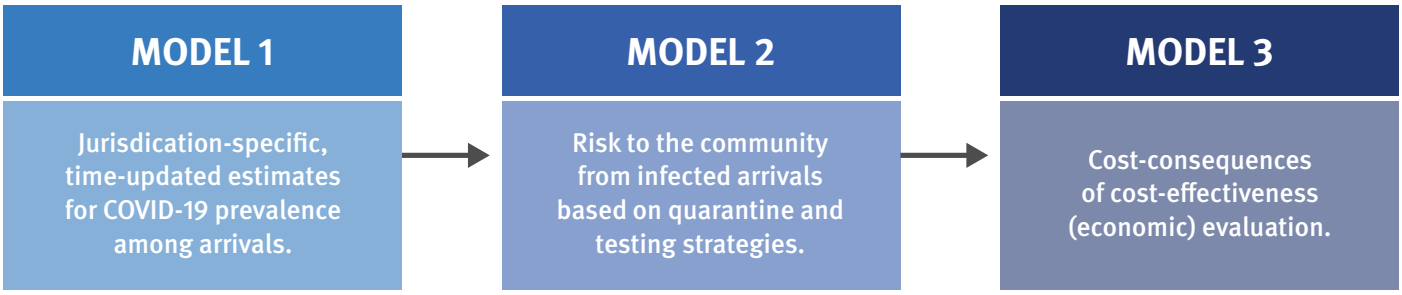


Risk-based quarantine strategies:

Taking a risk-based approach to quarantine length and testing results in low per-traveller risk of COVID-19 importation for a range of scenarios with different quarantine lengths.

CHAPTER 7
MODEL OVERVIEW

The work in this report is based on three related models as illustrated in the figure below:



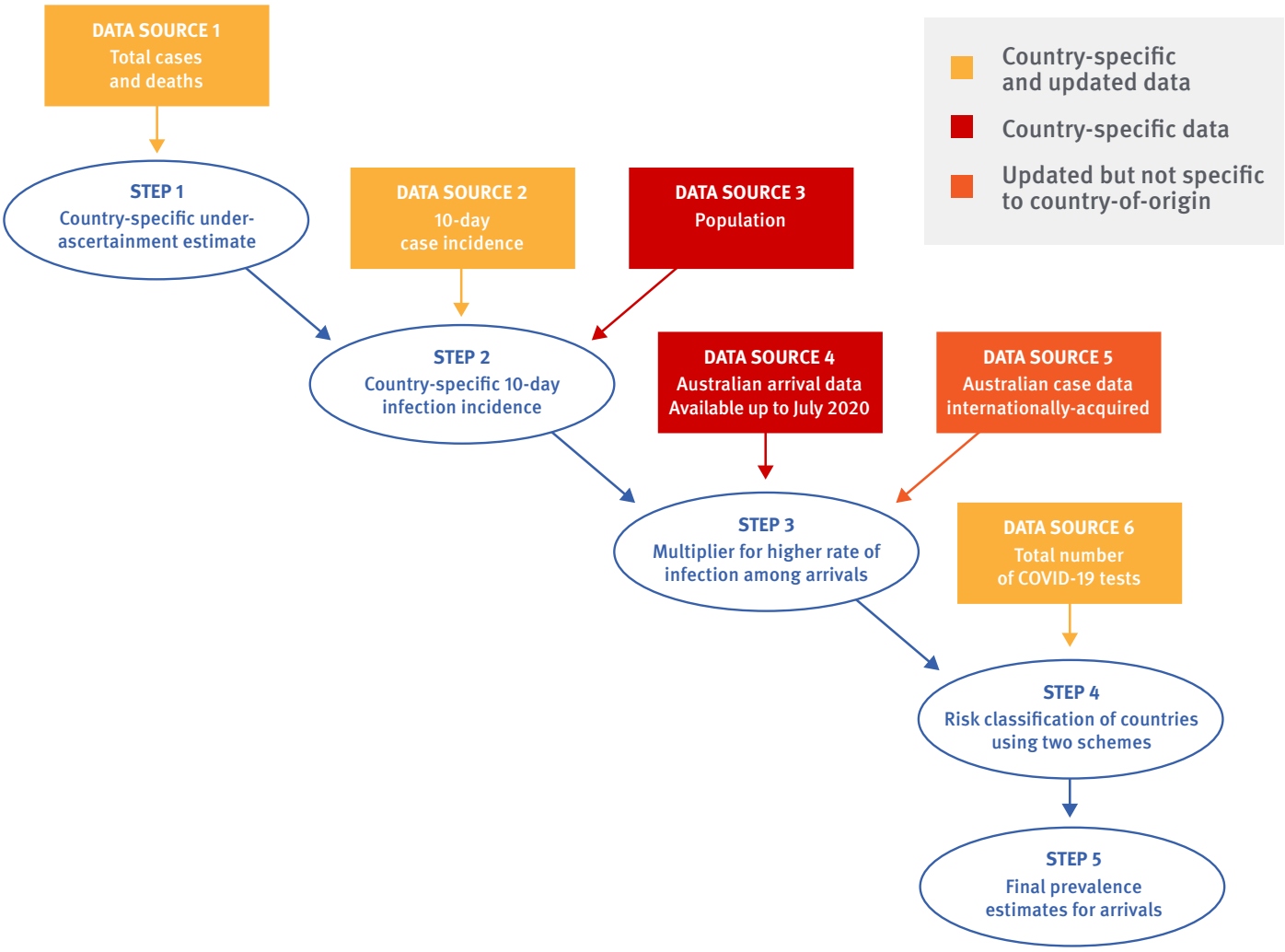
The following six Chapters describe detailed Results and Methods for each of these three models.

CHAPTER 8
MODEL 1: INTERNATIONAL ARRIVALS

MODEL 1	MODEL 2	MODEL 3
Jurisdication-specific, time-updated estimates for COVID-19 prevalence among arrivals.	Risk to the community from infected arrivals based on quarantine and testing strategies.	Cost-consequences of cost-effectiveness (economic) evaluation.

Pre-arrival risk is likely to vary significantly depending on country of origin. However, reported case numbers likely underestimate the actual COVID-19 prevalence in a country due to inadequate testing in some countries, and mild and asymptomatic cases going unrecognised. As direct data were not available, a multiplier method was used to estimate the prevalence and number of infections among arrivals by country of origin. A schema of data sources and modelling steps for international jurisdictions is included in Figure 10.

Figure 10. Schema of data sources and steps to calculate jurisdiction-specific, time-updated estimates for COVID-19 infection among international arrivals.



Step 1: Country-specific under-ascertainment estimates

The under-ascertainment of cases is a multiplier to account for symptomatic cases that were never diagnosed or reported, and was calculated using a publicly available (although not yet peer-reviewed) model developed by the London School of Hygiene and Tropical Medicine [11]. Briefly, this model uses a delay-adjusted case fatality ratio to estimate under-ascertainment of cases in each country. These estimates were then further adjusted to account for asymptomatic infection. The advantage of this model is that minimal data are required to estimate prevalence (cases and deaths), and regularly updated data are publicly available for most countries. A key limitation is the assumption that mortality data are accurate, and for those countries with significant under-ascertainment of COVID-19 related mortality, prevalence will be underestimated.

Step 2: Country-specific 10-day infection incidence estimates

In Step 2, under-ascertainment estimates are applied to updated country-specific 10-day case incidence data and country-specific population estimates. This is in order to calculate country-specific 10-day infection incidence estimates that have been adjusted for under-ascertainment of symptomatic cases and asymptomatic infection.

Step 3: Multiplier for higher rate of infection in travellers

Country-specific 10-day infection incidence estimates were calculated for May and June 2020 (July was excluded as the total number of arrivals were not available by country of origin at the time of analysis). For the 15 countries of origin most likely to have exported cases to Australia in May 2020, the resulting multipliers to account for under-ascertainment of cases and corresponding estimates for in-country prevalence are presented in Table 7. This model suggests that reported cases in the countries of origin in May and June should be multiplied by a factor of 2-31, depending on the month and the reporting country, to obtain a more accurate estimate of in-country prevalence, which suggests that there may be substantial under-reporting in some cases (Table 7). Notably, for most countries with seroprevalence data, the model-derived case-multipliers appear reasonable when considering gaps between cumulative incidence of reported COVID-19 cases and seroprevalence studies [12]. Nonetheless, the resulting estimates were considerably lower than the observed prevalence among arrivals to Australia over the same period (Tables 6 & 7).

Table 6. COVID-19 cases among international arrivals to Australia, June - July 2020

Month	Cases	Arrivals	Prevalence (%) (95% CI)
May	177	19,120	0.9 (0.8–1.1)
June	200	25,120	0.8 (0.7–0.9)
July	221	17,260	1.3 (1.1–1.6)
TOTAL	**598**	**61,500**	**1.0 (0.9–1.1)**

The high prevalence of COVID-19 in arrivals to Australia from May to June 2020 could not be completely explained by the incidence of infection in the countries of origin, even after adjusting for under-ascertainment of cases. This discrepancy may be explained in part by selection. That is, arrivals to Australia may be more likely to be exposed to COVID-19 compared to the populations of their countries of origin. For example, this could be due to arrivals being more likely to live in urban centres. It could also be explained in part by exposure to COVID-19 during the journey from the country of origin to Australia, including on flights, at airports, or during transport from the airport to the managed quarantine facility in Australia. Given that the high prevalence of COVID-19 in arrivals to Australia from May to June 2020 could not be completely explained by the incidence of infection in the countries of origin, even after adjusting for under-ascertainment of cases, an additional 'traveller multiplier' was calculated for international arrivals (Table 7).

Table 7. COVID-19 cases among international arrivals to Australia, June - July 2020

Country	Arrivals to Australia[b]		10-day case incidence %[c]		Under-ascertainment multiplier[d]		Estimated prevalence[c] % (95% CI)		Traveller multiplier[e]	Expected imported cases[f] n (95% PI)	
	May	June	May	June	May	June	May	June		May	June
UK	1,050	1,644	0.05	0.02	31.2	23.9	1.49 (0.53 - 2.93)	0.36 (0.15 - 0.71)	4.2	65 (23 - 128)	25 (10 - 49)
USA	1,627	2,597	0.07	0.07	12.9	10.0	0.93 (0.33 - 1.81)	0.67 (0.26 - 1.31)	4.2	63 (22 - 123)	72 (28 - 141)
Qatar	252	343	0.42	0.55	2.0	2.0	0.84 (0.47 - 1.40)	1.10 (0.61 - 1.84)	4.2	9 (5 - 15)	16 (2 - 26)
Canada	232	451	0.03	0.01	16.4	14.1	0.55 (0.19 - 1.09)	0.19 (0.07 - 0.37)	4.2	5 (2 - 11)	4 (1 - 7)
Singapore	470	654	0.13	0.06	2.0	2.0	0.25 (0.14 - 0.42)	0.13 (0.07 - 0.21)	4.2	5 (3 - 8)	3 (2 - 6)
Brazil	108	232	0.04	0.12	22.9	12.8	1.02 (0.30 - 2.02)	1.52 (0.50 - 2.99)	4.2	5 (1 - 9)	15 (5 - 29)
Sweden	59	52	0.06	0.09	28.8	19.9	1.78 (0.61 - 3.56)	1.87 (0.69 - 3.73)	4.2	4 (2 - 9)	4 (1 - 8)
France	181	222	0.01	0.01	34.3	29.5	0.50 (0.19 - 0.98)	0.22 (0.09 - 0.42)	4.2	4 (1 - 7)	2 (1 - 4)
Ireland	161	180	0.04	0.00	12.4	10.5	0.53 (0.18 - 1.08)	0.03 (0.01 - 0.07)	4.2	4 (1 - 7)	0 (0 - 1)
India	3,000	2,359	0.00	0.01	10.3	7.5	0.03 (0.01 - 0.05)	0.06 (0.02 - 0.11)	4.2	3 (1 - 7)	6 (2 - 11)
Italy	129	201	0.02	0.00	24.5	22.2	0.45 (0.18 - 0.89)	0.11 (0.05 - 0.21)	4.2	2 (1 - 5)	1 (0 - 2)
UAE	276	555	0.06	0.05	2.6	2.0	0.17 (0.07 - 0.37)	0.11 (0.06 - 0.18)	4.2	2 (1 - 4)	2 (1 - 4)
Spain	106	201	0.02	0.01	20.3	17.0	0.43 (0.17 - 0.85)	0.11 (0.05 - 0.22)	4.2	2 (1 - 4)	1 (0 - 2)
Netherlands	107	121	0.02	0.01	23.4	19.7	0.37 (0.14 - 0.74)	0.21 (0.09 - 0.42)	4.2	2 (1 - 3)	1 (0 - 2)
Pakistan	798	1,095	0.01	0.03	6.6	5.3	0.05 (0.01 - 0.10)	0.13 (0.04 - 0.27)	4.2	2 (0 - 3)	6 (2 - 12)

Table Notes. a. Prevalence (%) per population estimated for the 15th day of each month. Fifteen most likely countries for imported cases to Australia based on May data. b. Source: Australian Department of Home Affairs. Country of origin defined as country of residence or country where traveller spent most time if that field was completed, or country of embarkment if country of residence was missing (approximately 25% were missing country of residence). c. Source for 10-day cumulative case incidence: European Centre for Disease Prevention and Control. 10-day cumulative case incidence (that is, number of cases reported from 5th-15th of the month) divided by the population size and estimated infection prevalence in the country of origin. Population size source: X d. Model derived multipliers for adjustment of cases to account for under-ascertainment, including adjustment to include asymptomatic infection [11]. e. Additional multiplier to account for the substantially higher prevalence of COVID-19 detected in arrivals to Australia compared to the prevalence in the countries of origin, even after adjustment for under-ascertainment of symptomatic and asymptomatic infection. f. Model derived expected number of imported infections from arrivals to Australia during that month [11]. CI=confidence interval. PI=predictive interval.

Steps 4 and 5: Risk classification of countries of origin using two schemas and assignment of final prevalence for each risk classification schema

We used two schemas to classify countries by risk. Both schemas classified countries into five strata ranging from very low to very high risk (Table 8). Risk classification system 2 (more relaxed) classified countries by estimated prevalence. Where prevalence could not be estimated (usually due to <10 deaths reported in total throughout the epidemic, making it difficult to estimate the level of under-ascertainment of cases), countries were classified as very low-risk. For this risk classification system, we assumed that the prevalence was the estimated prevalence or if prevalence could not be estimated, then we assumed 0.01 per cent prevalence (the upper bound of the very low risk category). Risk classification system 1 (our primary system of classification) took testing data into account as well as the estimated prevalence. Countries with adequate testing (>50 tests per diagnosed case) were classified according to the estimated prevalence (the same classification as risk classification system 2) and the prevalence was assumed to be the estimated prevalence. Countries without adequate testing were penalised and classified as two classifications higher than they would have been based on estimated prevalence (e.g., very low prevalence classified as moderate-risk, low as high-risk, and moderate to very high prevalence as very high-risk). The assumed prevalence for those without adequate testing was the upper bound of the prevalence range for that risk classification. For example, if they were classified as moderate-risk then 0.1 per cent. For very high-risk (where there was no upper bound), we conservatively assumed 1.5 per cent prevalence. The reason we took testing data into account was that the prevalence estimates rely on good quality mortality data which may not be the case in countries with inadequate testing.

Table 8. Risk Classification Schemas

Estimated prevalence[a]	Adequate testing?[b]	Example countries	Risk classification scheme 1	Assumed prevalence (scheme 1)[c]	Risk classification scheme 2	Assumed prevalence (scheme 2)
<0.01%	Yes	New Zealand, Thailand	Very Low	Estimated	Very Low	Estimated
<0.01%	No	China, Vietnam, Rwanda, South Sudan	Moderate	Upper bound	Very Low	Estimated
0.01 - 0.05%	Yes	Singapore, Cuba, South Korea, Sri Lanka, Togo	Low	Estimated	Low	Estimated
0.01 - 0.05%	No	Pakistan, Yemen, Cameroon, Mali, Senegal, Haiti	High	Upper bound	Low	Estimated
0.05 - 0.1%	Yes	Uruguay	Moderate	Estimated	Moderate	Estimated
0.05 - 0.1%	No	Japan, Bangladesh, Algeria, Syria, Ethiopia	Very High	Upper bound	Moderate	Estimated
0.1 - 0.5%	Yes	Estonia, Malaysia, Norway	High	Estimated	High	Estimated
0.1 - 0.5%	No	Indonesia, Philippines, South Africa, Turkey	Very High	Upper bound	High	Estimated
>0.5%	Yes	Denmark, Finland, Germany, Greece, UAE	Very High	Estimated	Very High	Estimated
>0.5%	No	Brazil, USA, UK	Very High	Conservative	Very High	Estimated
Cannot estimate	N/A	Vanuatu, Taiwan, Cambodia, Fiji, Iceland, Papua New Guinea	Moderate	Upper bound	Very Low	Upper bound

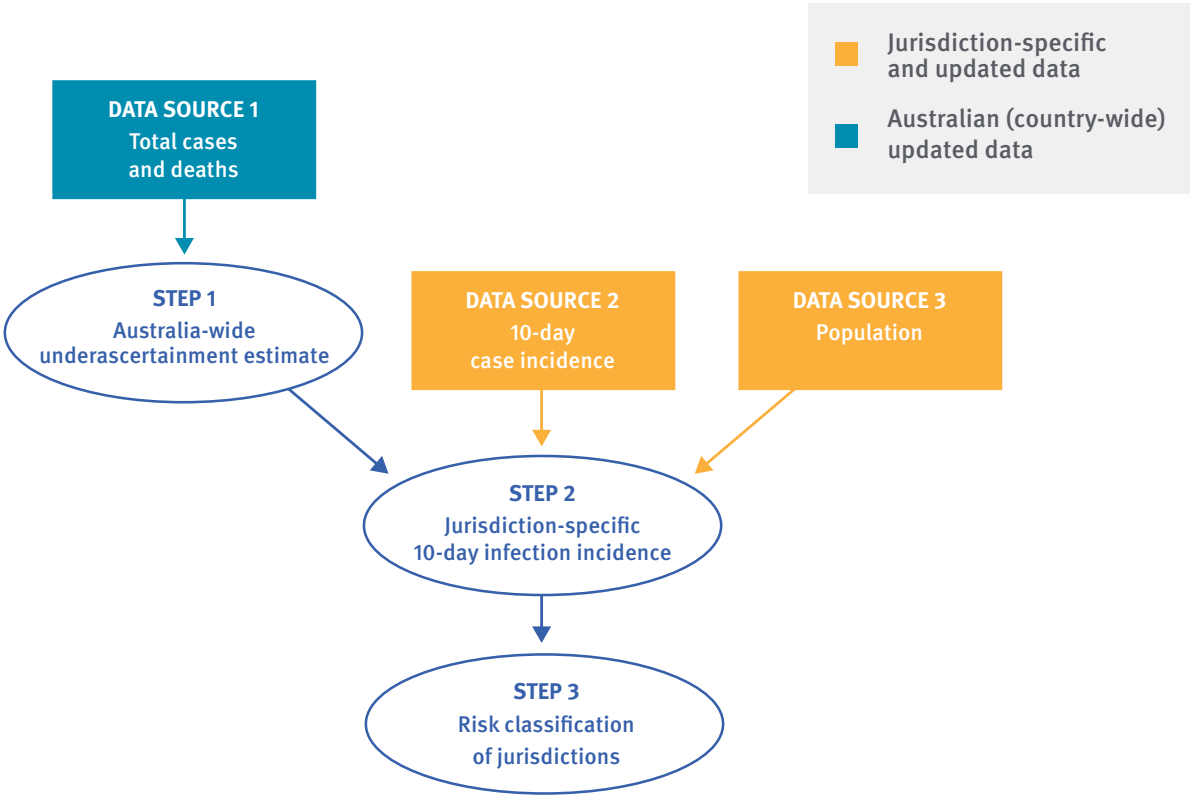
Table Notes. b. Prevalence estimated for 13 October 2020, adjusted for under-ascertainment, and observed high prevalence of COVID-19 in travellers using the approach described in Part 2 of this report. b. Testing data is available, and countries have undertaken at least 50 tests per case. c. Upper bound is the upper bound of the prevalence for the risk classification bracket and conservative is 1.5% prevalence.

CHAPTER 9
MODEL 1: DOMESTIC ARRIVALS

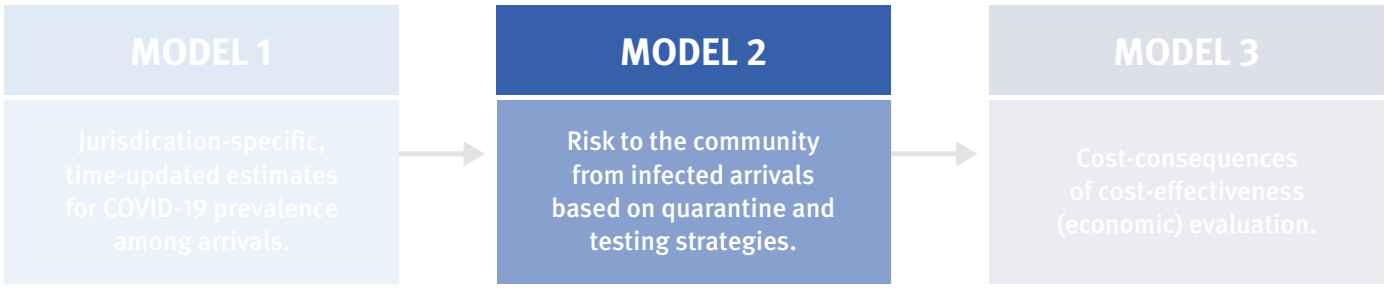
MODEL 1	MODEL 2	MODEL 3
Jurisdication-specific, time-updated estimates for COVID-19 prevalence among arrivals.	Risk to the community from infected arrivals based on quarantine and testing strategies.	Cost-consequences of cost-effectiveness (economic) evaluation.

Prevalence estimates for Australian states were calculated using a similar method to the method described in Chapter 8 for international jurisdictions. The method was simplified slightly due to no available evidence of higher prevalence of COVID-19 in domestic travellers compared to the average Australian resident. Therefore, step 3 from the method for international jurisdictions was omitted (multiplier for higher prevalence of COVID-19 observed in international arrivals). In addition, given that testing rates in Australia are classified as adequate in all jurisdictions, only one final risk classification was required and prevalence estimates were used for the 'assumed prevalence' in all cases. Figure 11 shows the simplified method used. For domestic travel, the 10-day case incidence was based on locally acquired cases only and did not include internationally acquired cases in hotel quarantine.

Figure 11. Schema of data sources and steps to calculate jurisdiction-specific, time-updated estimates for COVID-19 infection among Australian domestic interstate travellers.

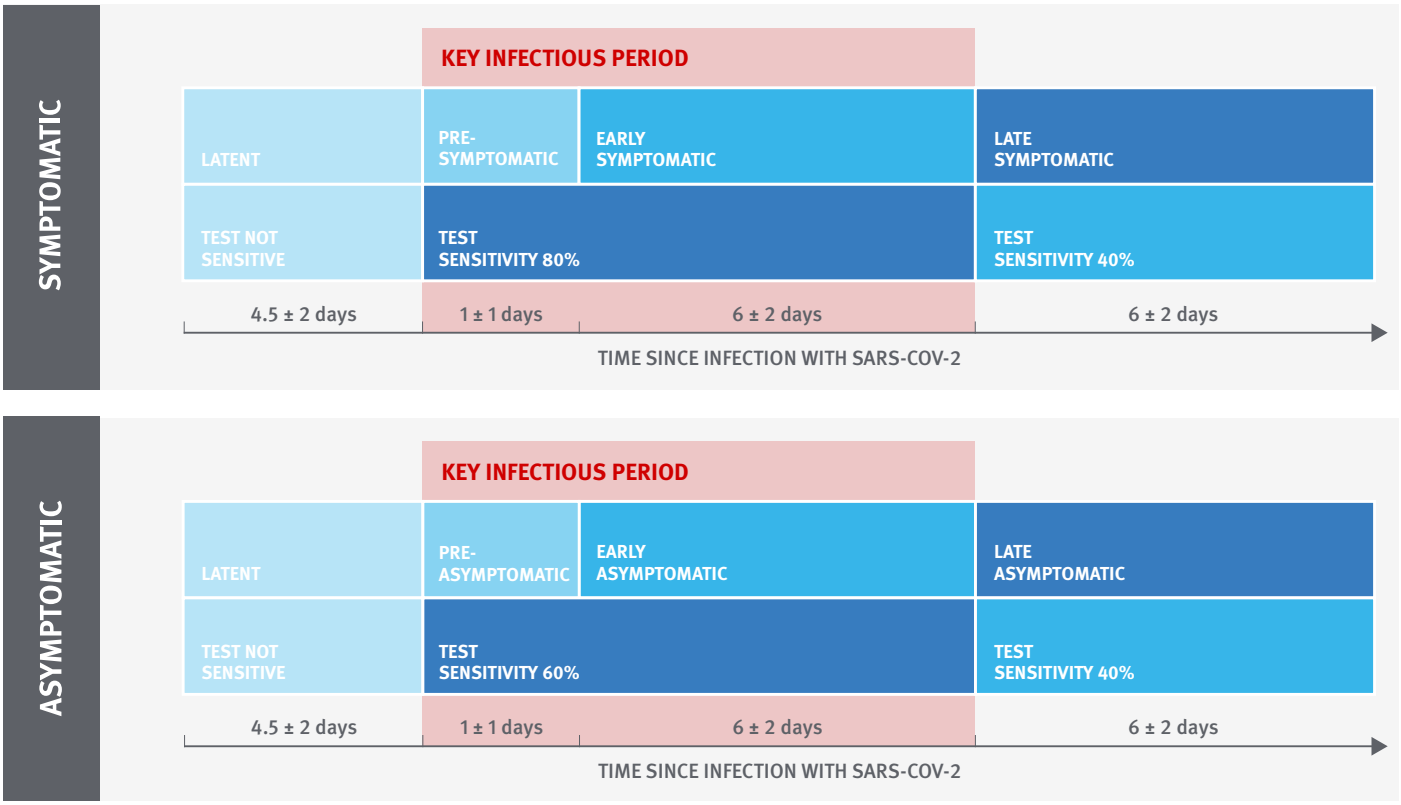


CHAPTER 10
MODEL 2: MODEL DEVELOPMENT



A Bayesian Network model was constructed In RNetica. The model is based on the schema of infection depicted in Figure 12. There are four stages of infection; the latent stage, pre-symptomatic stage, early symptomatic stage and late symptomatic stage. Infections are assumed to be transmissible (infectious) in the pre-symptomatic and early symptomatic stages. Symptom onset is at the beginning of the early symptomatic stage. The viral load is assumed to be low in the latent stage, high in the pre-symptomatic and early symptomatic stages, and moderate in the late symptomatic period, with test sensitivity varying accordingly.

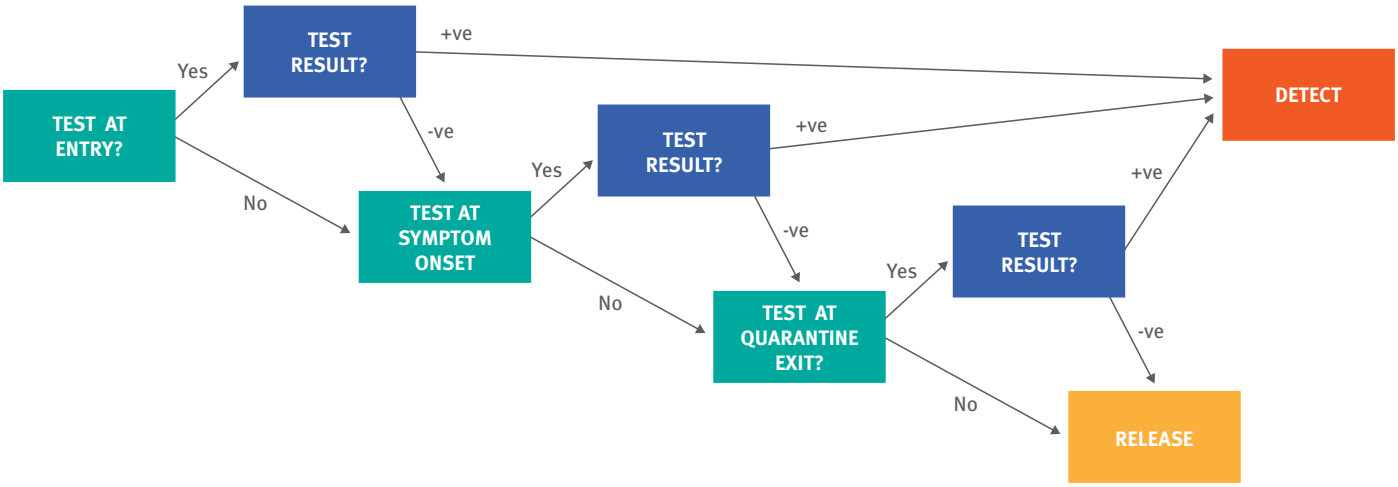
Figure 12. Timeline of infection stages and test sensitivity for symptomatic and asymptomatic infection



Three opportunities for testing are considered during quarantine as depicted in Figure 13. In addition, a test prior to travel was considered with the assumption that those testing positive would not travel. If no tests are administered, then all individuals are released after the quarantine duration irrespective of symptoms. If testing is done at symptom onset (which requires symptom monitoring procedures to be in place), quarantine entry or prior to quarantine exit (including testing of asymptomatic individuals), detected cases are assumed to be isolated further as appropriate and therefore assumed not to result in risk of release of an infectious individual into the community. Infected individuals who are

not detected during the possible testing opportunities in quarantine are assumed to result in an infectious case in the community if they are released in the latent, pre-symptomatic or early symptomatic stages. If they are released in the late symptomatic stage or after recovery, it is assumed that they were no longer infectious on release.

Figure 13. SARS-COV-2 test decisions during quarantine

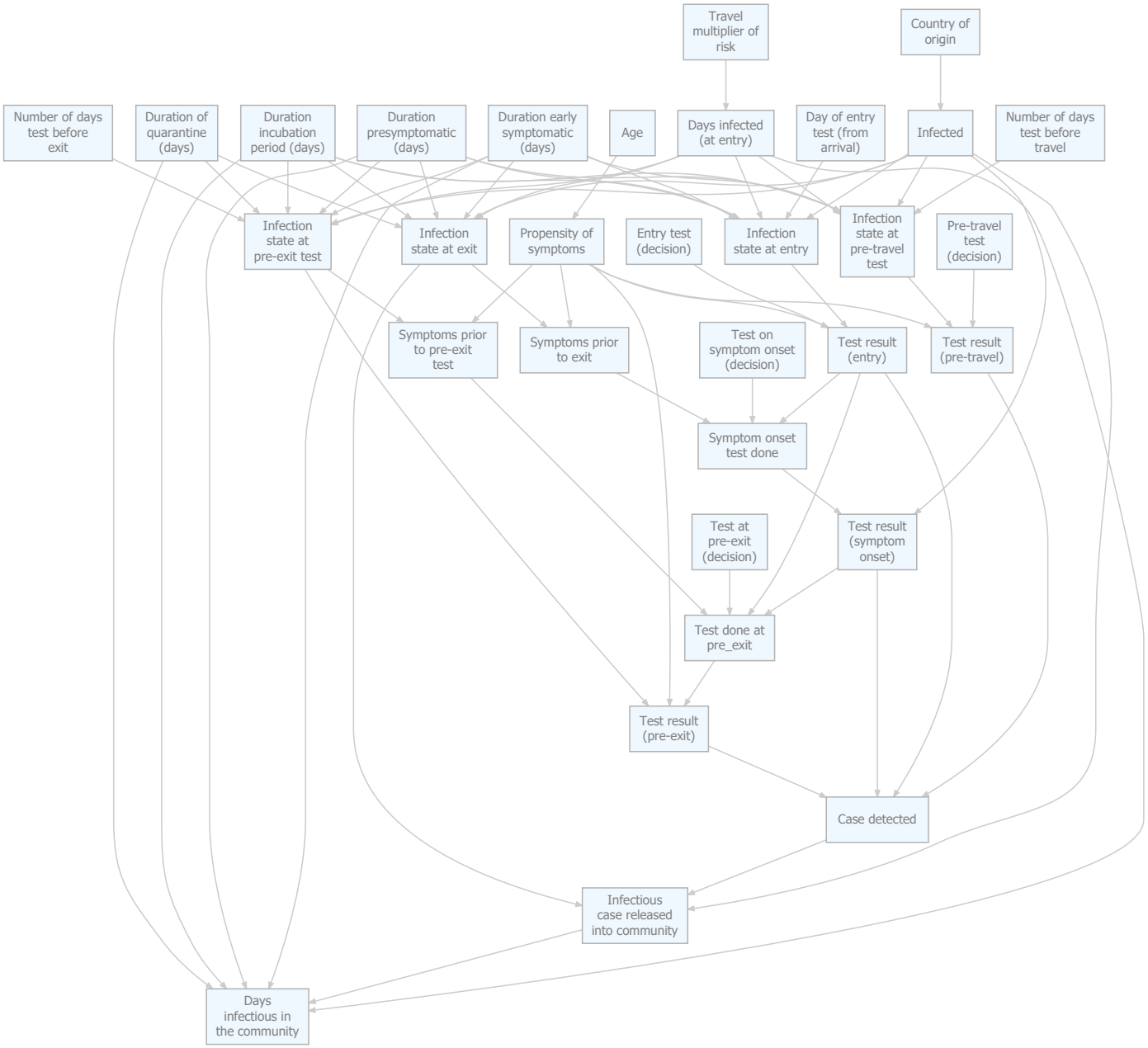


Model structure

The network model is depicted in Figure 14. Each circle represents a random variable (also called a node). Each line represents a link between nodes. The arrow determines the direction of the link where the arrow goes from the parent node to the child node. The probability distribution of each variable is conditional on the probability distributions of its parents. In this network, whether an infectious person is released into the community is determined by their infection stage (uninfected, latent, pre-symptomatic, early symptomatic, late symptomatic, recovered) and whether the infection was detected through testing (either prior to travel, on arrival, or during quarantine). Case detection is determined by infection status (uninfected, infected) and test results during quarantine. These are determined by the infection state at the time of testing, the test sensitivities, and specificities for those infection stages, and whether the tests were done. Infection stages at the test timepoints and at exit are determined by the duration of each of the infection stages, the number of days since infection at entry, the duration of quarantine and the timing of the exit test. The propensity toward experiencing symptoms if infected is based on age, and the probability of infection varies by jurisdiction of origin as described in Chapters 8 and 9 above.

The probability distribution for each of the infection state nodes (state at pre-travel test, state at first test, state at pre-exit test, and state at exit) is determined by the probability distribution of timing of exposure (the time from exposure to quarantine start), and the probability distributions of the durations of each infection period. The durations of the incubation period (including the latent and pre-symptomatic infectious periods), the pre-symptomatic infectious period, and the early symptomatic infectious period were modelled as lognormal distributions whose means and standard deviations are provided in Table 9 below. Networks were calculated for durations of quarantine ranging from 0-21 days, and all possible combinations of test timing from arrival on day 0 up until the final day of quarantine for each of the following quarantine duration scenarios (7 days, 10 days and 14 days) with a maximum of two routine tests in addition to testing on symptom onset.

Figure 14. Bayesian Network model diagram: quarantine and testing of arrivals for prevention of COVID-19 introduction into the community.



Each variable was assigned a prior probability distribution based on literature review or was determined using an equation based on the parent nodes and some constants. The key assumptions are outlined in Table 1 below.

Table 9. Prior probability distributions of key parameters

Variable	Distribution	Parameters	Lower bounds for sensitivity analysis	Upper bounds for sensitivity analysis	Reference
Duration of incubation period	Lognormal	5.5, 2	3.6, 1	5.7, 3.3	[4]
Duration of pre-symptomatic period	Lognormal	1, 1	0.7, 0.3	6.6, 22.6	[13, 14]
Duration of early symptomatic period	Lognormal	6, 2	4.5, 0.5	8.4, 4.5	[15, 16]
Test sensitivity (pre-symptomatic and early symptomatic period, symptomatic)	Bernouli	0.8	0.7	0.9	[2]
Test sensitivity (pre-symptomatic and early symptomatic period, asymptomatic)	Bernouli	0.6	0.5	0.8	Expert opinion and [17]
Test sensitivity (late symptomatic period)	Bernouli	0.4	0.2	0.6	[2]
Test specificity	Bernouli	0.99995	0.997	1.000	Expert opinion
Prevalence of symptoms from other respiratory infections	Bernouli	0.02	0.01	0.03	[18]

The propensity toward symptoms depends on age with the assumed probability table shown in Table 10. However, for the purpose of initial sensitivity analyses we assumed the propensity of symptoms was 65 per cent and tested the sensitivity of varying this from 30 per cent to 80 per cent.

Table 10. Assumed distribution of propensity of symptoms by age

Age Group	Propensity of symptoms
0 - 9	45%
10 - 19	50%
20 - 29	55%
30 - 39	60%
40 - 49	65%
50 - 59	70%
60 - 69	75%
70 - 79	80%
80 - 89	85%
90 +	90%

Travel risk and days infected at entry

Risk of COVID-19 acquisition during air travel is not well understood. It has been proposed that advanced air filtration systems on aeroplanes may reduce the risk of transmission during air travel relative to other forms of mass transit.[3] However, few empirical data on transmission risk during air travel are available. A case study examining a single five-hour flight from Sydney to Perth in which there were 11 passengers who were presumed to be infectious with COVID-19 during the flight, found confirmed flight-associated transmission to eight people using genomic sequencing and identified a further three passengers who may have acquired COVID-19 but were either not sequenced (n=2) or the sequence was not linked to a known case (n=1) [4]. A report on another flight (15-hour flight from Boston to Hong Kong in March) used genomic analysis to establish a link between the infections of two flight attendants and a married couple travelling business class on the flight. The report concluded that one or both of the couple likely acquired their infection in the US and transmitted to the two flight attendants during the flight [20]. Although those flights were in March prior to the introduction of strategies to reduce inflight transmission due to COVID-19, another report of a more recent seven hour, 17% per cent occupancy, flight to Ireland, where passengers were not seated close together and where adult passengers reported wearing masks, found that 13 passengers travelling from three continents had linked infections using genomic sequencing and this led to a cluster of 53 cases after onward transmission in Ireland [19]. Three other studies have investigated transmission during air travel. The results of these studies were variable with some suggesting super-spreading events and other suggesting more modest attack rates. This may reflect the substantial heterogeneity of transmission observed in other settings. However, none of these have used genomic sequencing to confirm transmission and criteria for potential contacts varied between studies, making them difficult to interpret [5-7]. In summary, there appears to be variation in rates of COVID-19 transmission between flights but few flights have been well studied. We are not aware of any empirical data on COVID-19 transmission risk at airports. Notably, genomic sequencing cannot distinguish whether transmission occurred during the flight or at airports. In some cases, travel exposure may also take place on shared transport between airport terminals or from the airport to hotels.

Given the considerable uncertainty around potential risk of acquisition of COVID-19 during travel we have considered the possibility that risk of transmission is low during travel (with the same rate of acquisition during travel as prior to travel within the country of origin), as well as considering the possibility that travel poses a considerable risk of COVID-19 acquisition (in this case, we assume that prevalence of COVID-19 doubles during travel).

We considered two assumptions regarding the likely timing of exposure prior to the commencement of quarantine.

- **Minimal travel risk:** In the first set, we assumed minimal risk of infection during travel. In that case, we assumed a uniform distribution for day of exposure within the 14 days prior to arrival - that is, people were equally likely to have been exposed on any of the 14 days prior to arrival. We refer to that set of assumptions as minimal travel risk.
- **Substantial travel risk:** In the second set of assumptions, we assumed that 50 per cent of those infected were exposed in the 2-14 days prior to travel, and the other 50 per cent were exposed within 24 hours of arrival (during travel). It is important to note that the level of risk during this period may be higher than the risk in days 2-14 prior to travel. We refer to that set of assumptions as substantial travel risk.

Assumptions regarding quarantine setting and transmission during quarantine

We generally assumed that the setting was managed quarantine given that is the current policy for quarantine of travellers. However, we did also investigate the risks associated with community-based quarantine (Part 5 of this report). For the setting of managed quarantine, a key assumption is that there was no risk to the community until individuals were released from quarantine. That is, the model estimates of risk do not include the risk of transmission from individuals in quarantine to managed quarantine staff. While this potential risk should be addressed, the reported number of transmissions from people in managed quarantine to staff has been very low. In addition, a new initiative has recently been introduced to monitor and improve infection prevention and control in hotel quarantine throughout Australia which may further reduce the probability of transmissions within this setting.

Initial estimation of risks of varying quarantine durations and test strategies

Estimations presented in this report are based on the assumptions in Table 9 and defined relationships between parent and children nodes. Given that they are not informed directly by empirical data, these initial outputs are considered prior probabilities. Four quarantine scenarios (7 days, 10 days, 14 days, and 21 days) and four testing and monitoring scenarios (none, symptom monitoring and testing on symptom onset only, symptom onset and test on arrival, symptom onset and tests on arrival and exit from quarantine) were considered for the purpose of this report. The testing scenarios were selected based on current practice in Australia.

CHAPTER 11
MODEL 2: TEST TIMING DURING QUARANTINE

MODEL 1	MODEL 2	MODEL 3
Jurisdication-specific, time-updated estimates for COVID-19 prevalence among arrivals.	Risk to the community from infected arrivals based on quarantine and testing strategies.	Cost-consequences of cost-effectiveness (economic) evaluation.

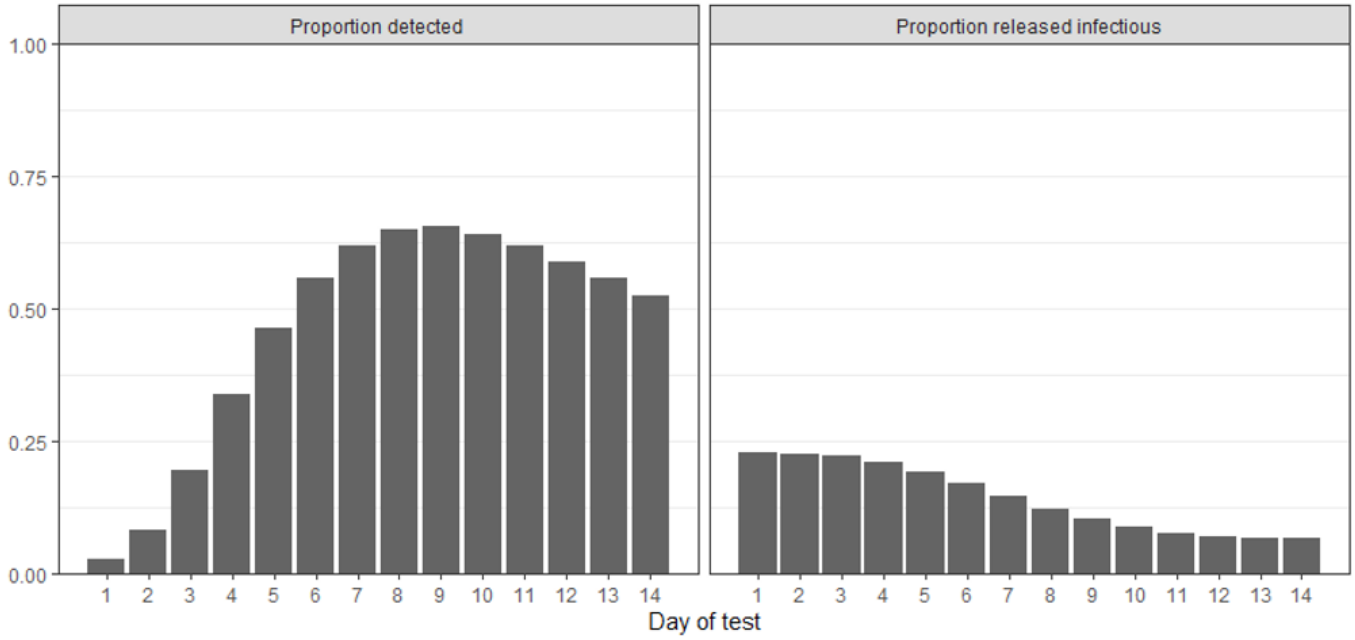
Testing and monitoring during quarantine

Current Australian quarantine recommendations for travellers include monitoring for symptoms with a test on symptom onset as well as two routine tests during quarantine at day three and three days before exit (that is, day eleven for the standard 14-day quarantine). We have called this standard testing. We also considered whether changing the timing of tests could reduce risks to the community.

The following figures show that for those infected during the 24 hours prior to arrival, the probability of detection peaks on the ninth day of quarantine. However, the probability of detecting cases that would otherwise be infectious after quarantine ends is always highest close to the end of quarantine. Therefore, the optimal test strategy for reducing the number of cases released infectious from quarantine is to test as close to the end of quarantine as possible, with two tests close to the end of quarantine more effective than one test.

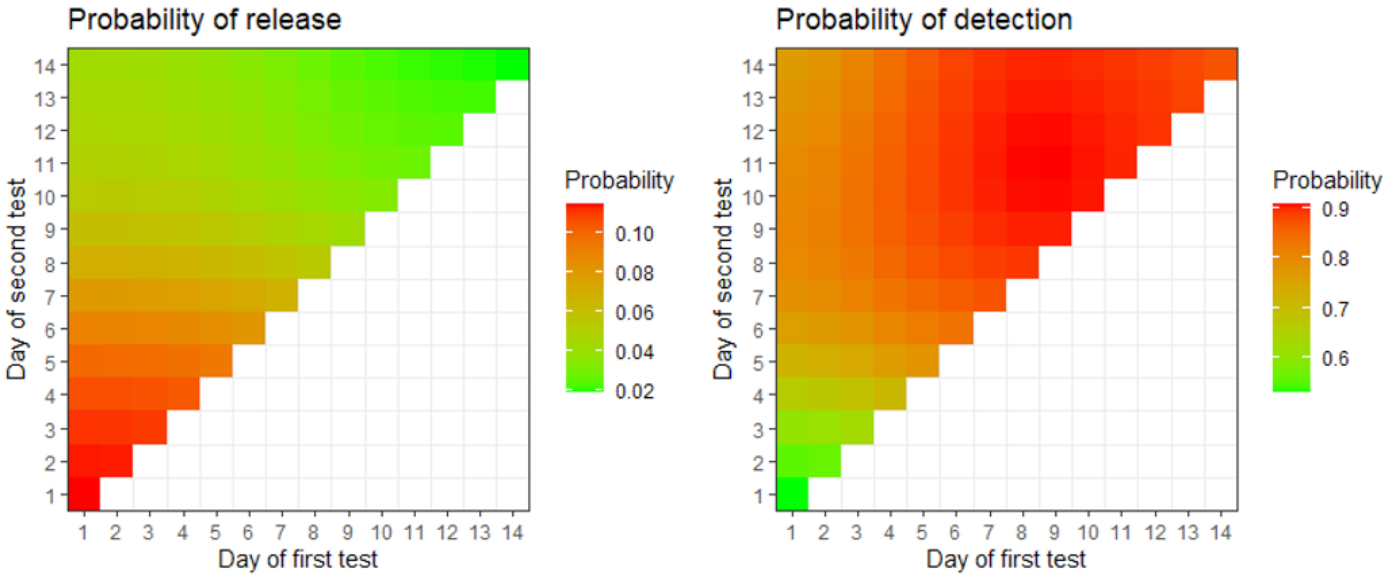
The following figure illustrates the probability of detection of cases, and the probability of release of an infectious case after a 14-day quarantine period based on the timing of a single test during quarantine.

Figure 15. Proportion detected and released from quarantine infectious by days of test among those infected on the day prior to entry in a 14-day quarantine.



The following figures illustrate the probability of release of an infectious case based on the timing of two tests.

Figure 16. Proportion detected and released from quarantine infectious using two routine tests by day of each test among those infected on the day prior to entry: 14-day quarantine.



Results are similar for shorter quarantine periods (graphs not shown). For every length of quarantine considered, the optimal testing time was one and two days before quarantine exit. We have called this enhanced testing. A comparison between the risk associated with standard testing and enhanced testing strategies are included in Part 3 of this report.

Testing pre-travel and on arrival

In addition to the standard testing and enhanced testing strategies we also considered pre-travel testing, either one day before departure or three days before departure, and for the no quarantine scenario we also considered testing on arrival (such as at the airport).

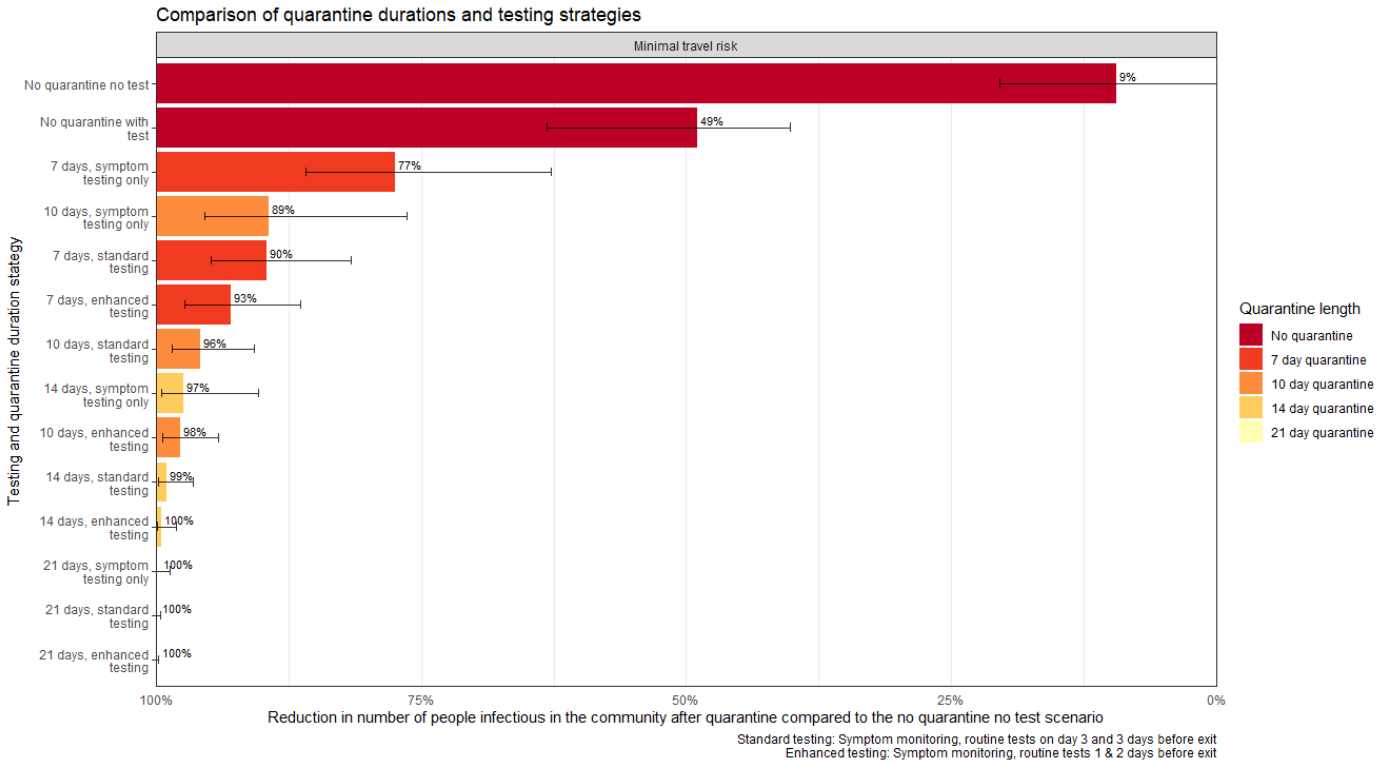
CHAPTER 12
MODEL 2: THE EFFECT OF QUARANTINE DURATION AND TESTING DURING QUARANTINE ON RISK TO THE COMMUNITY

MODEL 1	MODEL 2	MODEL 3
Jurisdication-specific, time-updated estimates for COVID-19 prevalence among arrivals.	Risk to the community from infected arrivals based on quarantine and testing strategies.	Cost-consequences of cost-effectiveness (economic) evaluation.

Effectiveness of quarantine for minimal travel risk

Assuming that risk during the journey to Australia is minimal, the status quo strategy would result in approximately 1 per cent of infected individuals being released from quarantine infectious. Compared to the status quo strategy (14-days quarantine, standard testing), we estimate that a do nothing strategy (no quarantine, no test) would result in approximately 90 times the number of people released into the community, and a routine PCR test on arrival will result in approximately 50 times the number of infectious people released into the community. In comparison, a 7-day quarantine with two routine tests and symptom monitoring would result in an increase by a factor of approximately 10 if a standard testing strategy was used (Figure 17). Potential additional benefits from pre-travel testing are discussed in chapter 13.

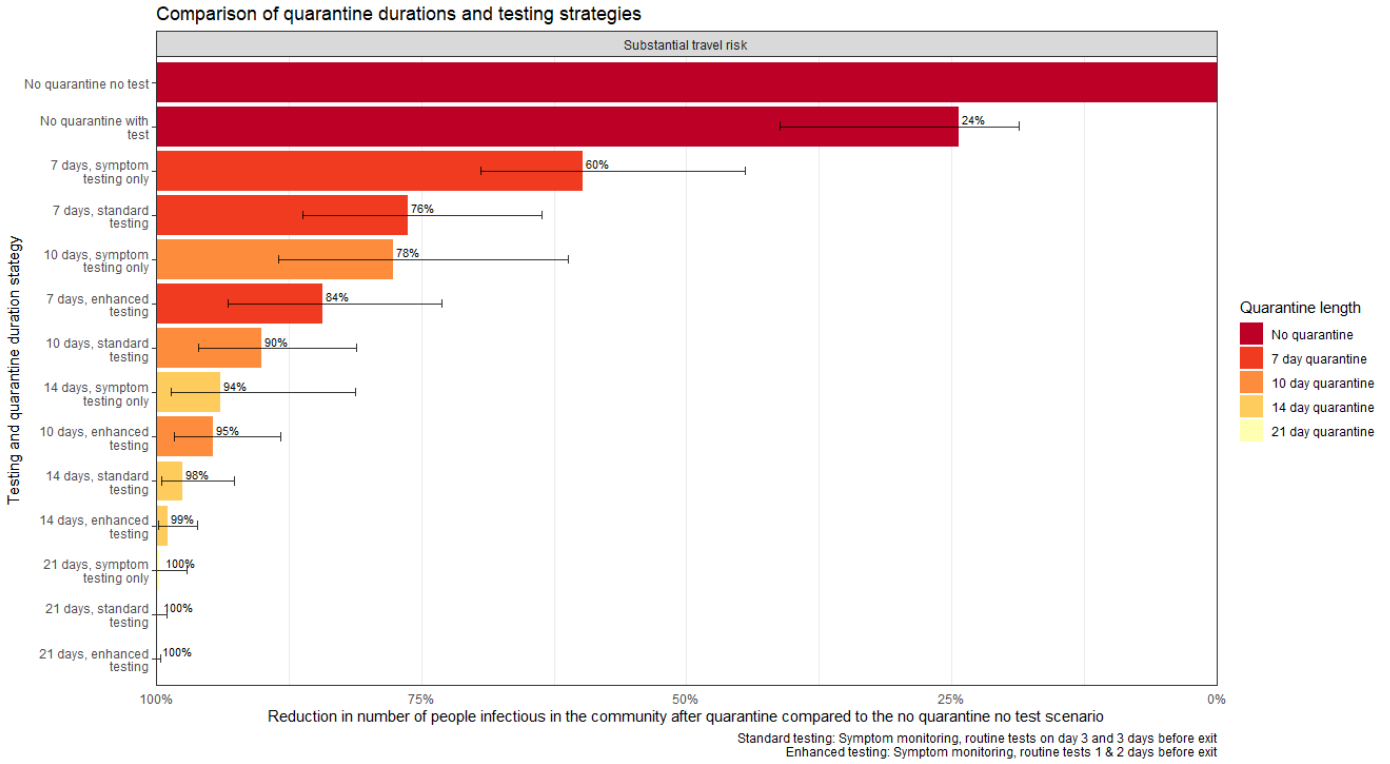
Figure 17. Number of infectious individuals released per infected arrival by quarantine and testing strategies: minimal travel risk



Effectiveness of quarantine for substantial travel risk

If we assume a substantial risk during the journey, the status quo strategy would result in approximately 2 per cent of infected individuals being released from quarantine infectious. In this case the relative increases in risk for the 'do nothing' and no quarantine but test on arrival are smaller (40 and 30 times the number of infectious people released into the community relative to the current strategy), due to the higher baseline risk from the status quo 14-day quarantine strategy. Under this assumption, the number of people released infectious into the community after 7 days of quarantine with standard testing is expected to increase by a factor of approximately 15 (Figure 18).

Figure 18. Number of infectious individuals released per infected arrival by quarantine and testing strategies: substantial travel risk.



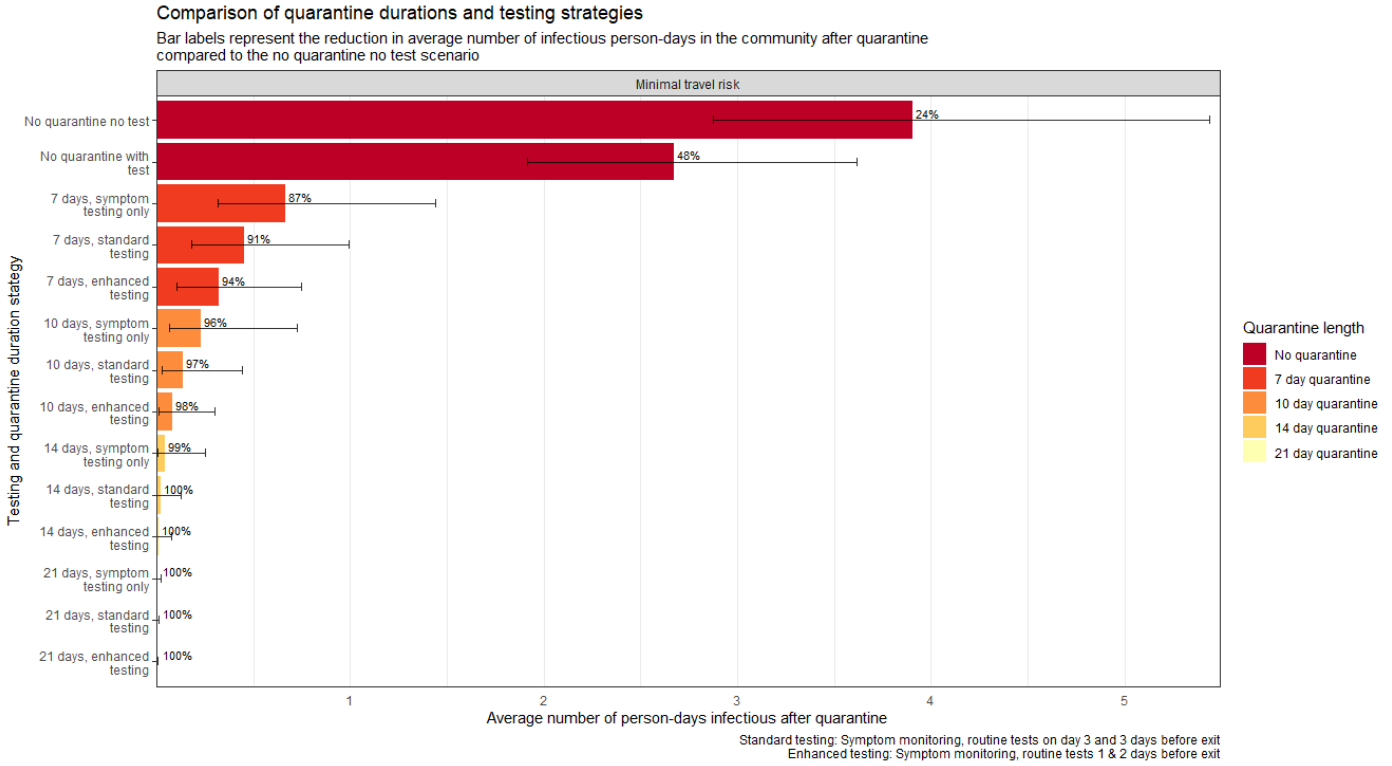
Testing Strategy

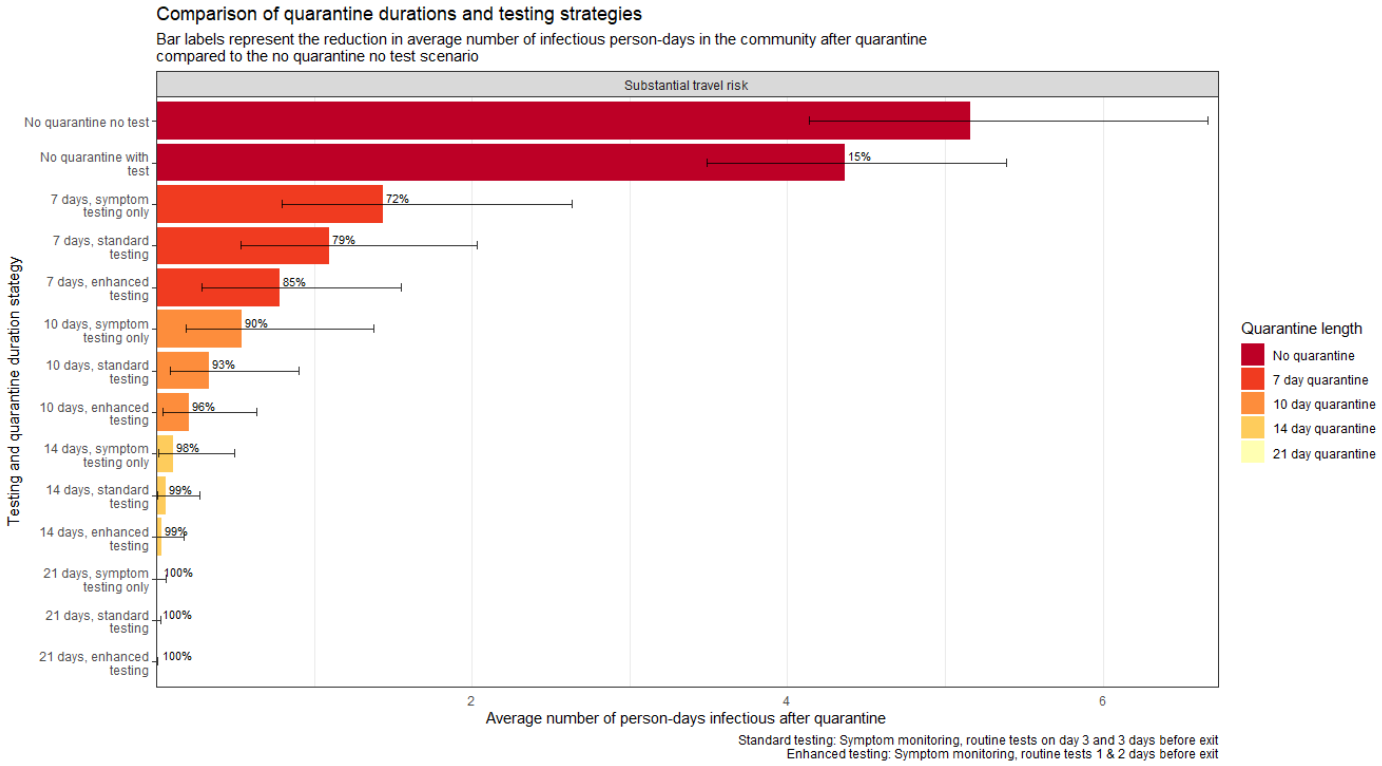
The duration of quarantine is more important than the testing strategy, but routine testing can also reduce COVID-related risk. We considered two routine testing strategies for each duration of quarantine. The standard strategy included routine tests on day three and three days prior to quarantine exit (e.g., for 14-day quarantine, this would be on day 3 and day 11 consistent with current Australian recommendations). The enhanced testing strategy included two tests, one and two days prior to quarantine exit (e.g., for 14-day quarantine this would be day 12 and day 13). The enhanced strategy reduced risk compared to standard testing for all quarantine durations, but the benefit in terms of the numbers of infectious individuals released are likely to be greater for shorter durations of quarantine. For example, for a 7-day quarantine, enhanced testing leads to an approximately one-third reduction in the number of cases with ongoing infection after quarantine compared to standard testing. While the equivalent policy change for a 14-day quarantine would be expected to lead to an approximately 50 per cent reduction in the number of cases released, because the baseline number released after 14-day quarantine with standard testing is much lower, in practice the testing strategy will be more important for the shorter quarantine (Figures 17 & 18).

Number of infectious days in the community

In addition to the number of people with ongoing infection after quarantine, we also considered the number of infectious person-days in the community. This considers not only how many people are released infectious, but also the number of days left in their infection at the time of release. This measure is likely to be a better indicator of the risk to the community than the number of people with ongoing infection because in the lengthier quarantine durations most of the infections that are not detected are nearing the end of their infectious period by the end of the quarantine period. For the status quo 14-day quarantine with standard testing, we expect approximately two infectious days in the community per 100 infected arrivals assuming minimal travel risk or six per 100 assuming substantial travel risk. When considering the number of infectious person-days in the community, a 'do nothing' strategy would lead to a >170 fold increase in the number of infectious days in the community compared to 14 days of quarantine with standard testing, assuming minimal travel risk (close to 90 fold increase assuming substantial travel risk). Testing on arrival would lead to an approximately 125 fold increase in the number of infectious days assuming minimal travel risk (75 fold increase if we assume substantial travel risk), and a 7-day quarantine would lead to close to >20 times increase in risk (similar if we assume substantial travel risk) (Figure 19). These substantial increases in risk with shorter or waived quarantine highlight the need for careful consideration of travel policies during the COVID-19 epidemic.

Figure 19. Number of infectious days in the community per infected arrival by quarantine and testing strategy



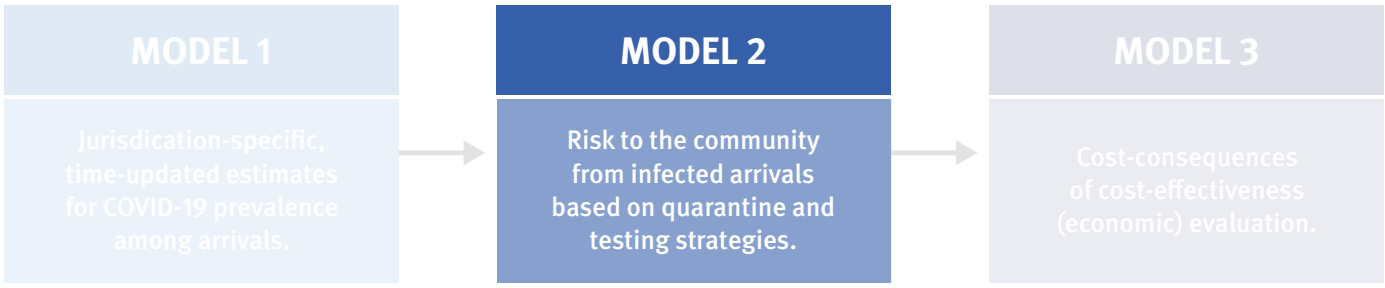


Notably, this work assumes that people are quarantined alone. It is likely that shorter quarantine durations in particular will be less effective for those quarantined in groups (such as couples and families) and different testing strategies are also likely to be required for family or group quarantine.

Key Points

- The 14-day quarantine is an effective public health tool for reducing risk of transmission of COVID-19.
- Shorter quarantine periods are less effective, even with the addition of routine tests.
- For individuals quarantined alone, enhanced testing (two routine tests one and two days before the end of quarantine) is more effective than standard testing for reducing transmission risk to the community.
- Further research is required to determine the optimal testing strategy for people quarantined in groups.

CHAPTER 13
MODEL 2: PRE-TRAVEL TESTING

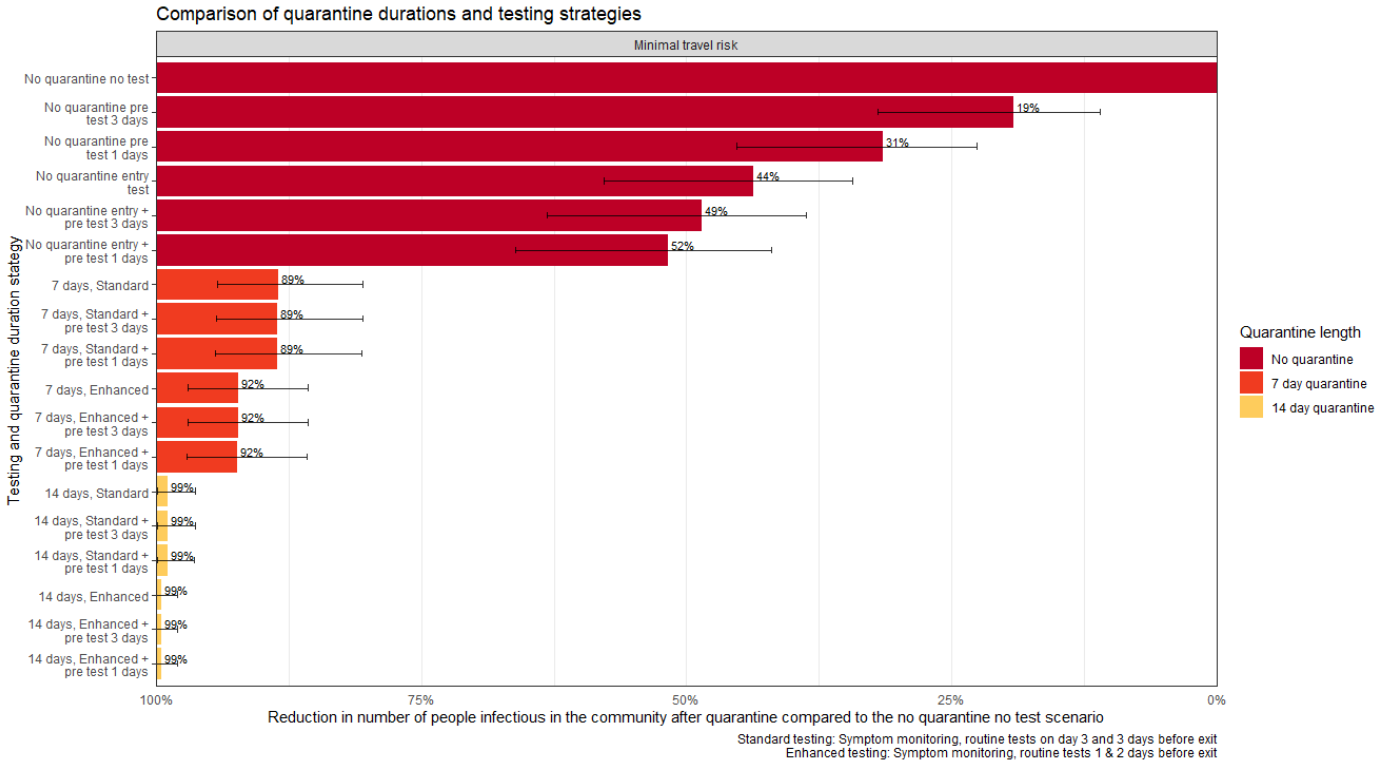


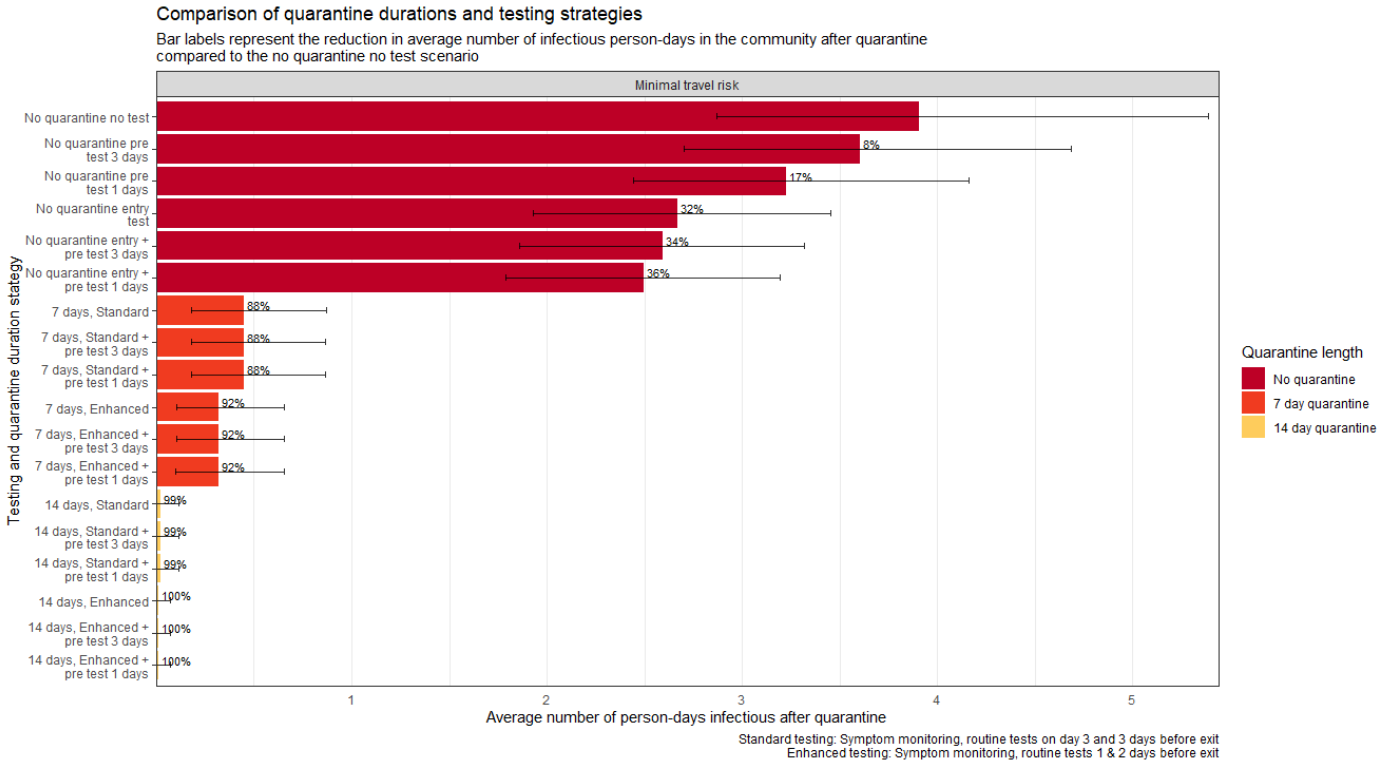
One strategy that has been proposed and has been used in several countries is PCR testing prior to travel. We considered two potential strategies for pre-testing, testing 3 days before travel or testing 1 day before travel. We considered the effect on the proportion of cases identified prior to release into the community and the average number of person-days infectious in the community.

The effect of pre-travel testing for minimal travel risk

Under the assumption of minimal travel risk, testing prior to travel only reduced risk to the community if there was no quarantine and even with no quarantine the effect is modest. As noted above, the status quo quarantine strategy is estimated to result in approximately one person released infectious per 100 infected arrivals, and approximately two days infectious in the community. Compared to the status quo strategy (14-day quarantine, standard testing), a routine PCR test on arrival is expected to lead to a 52-fold increase in the number of infectious cases entering the community and a 120-fold increase in the number of infectious days. In comparison, a test on arrival and a test three days prior to departure is expected to lead to a 47-fold increase in the number of infectious cases entering the community and an 110-fold increase in the number of infectious days. A test on arrival and a test one day prior to departure is expected to lead to a 44-fold increase in the number of infectious cases in the community, and a 110-fold increase in the average number of infectious days. There is minimal additional benefit of testing prior to departure if arrivals are quarantined for 7 or more days (Figure 20).

Figure 20. Number of infectious individuals released and number of infectious days in the community per infected arrival by quarantine and testing strategies, including pre-travel testing: minimal travel risk

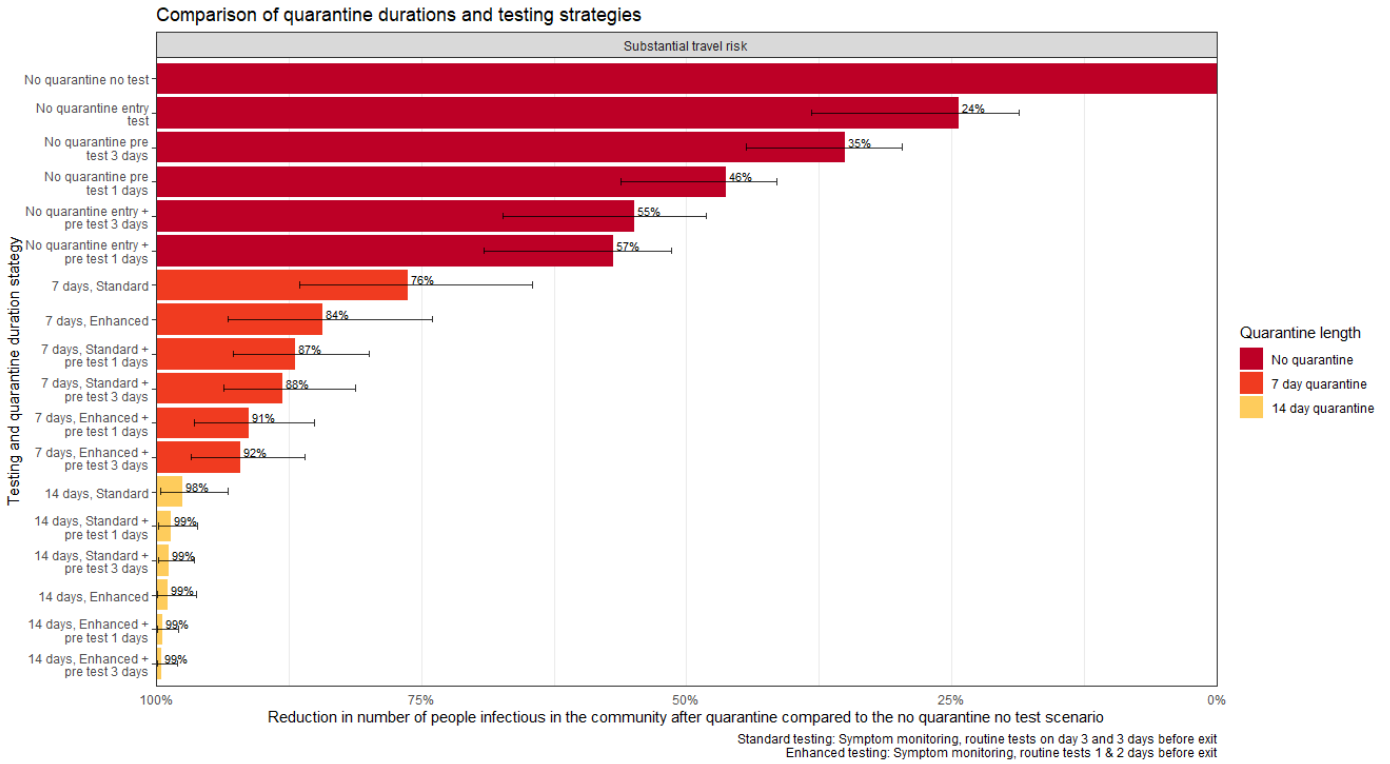


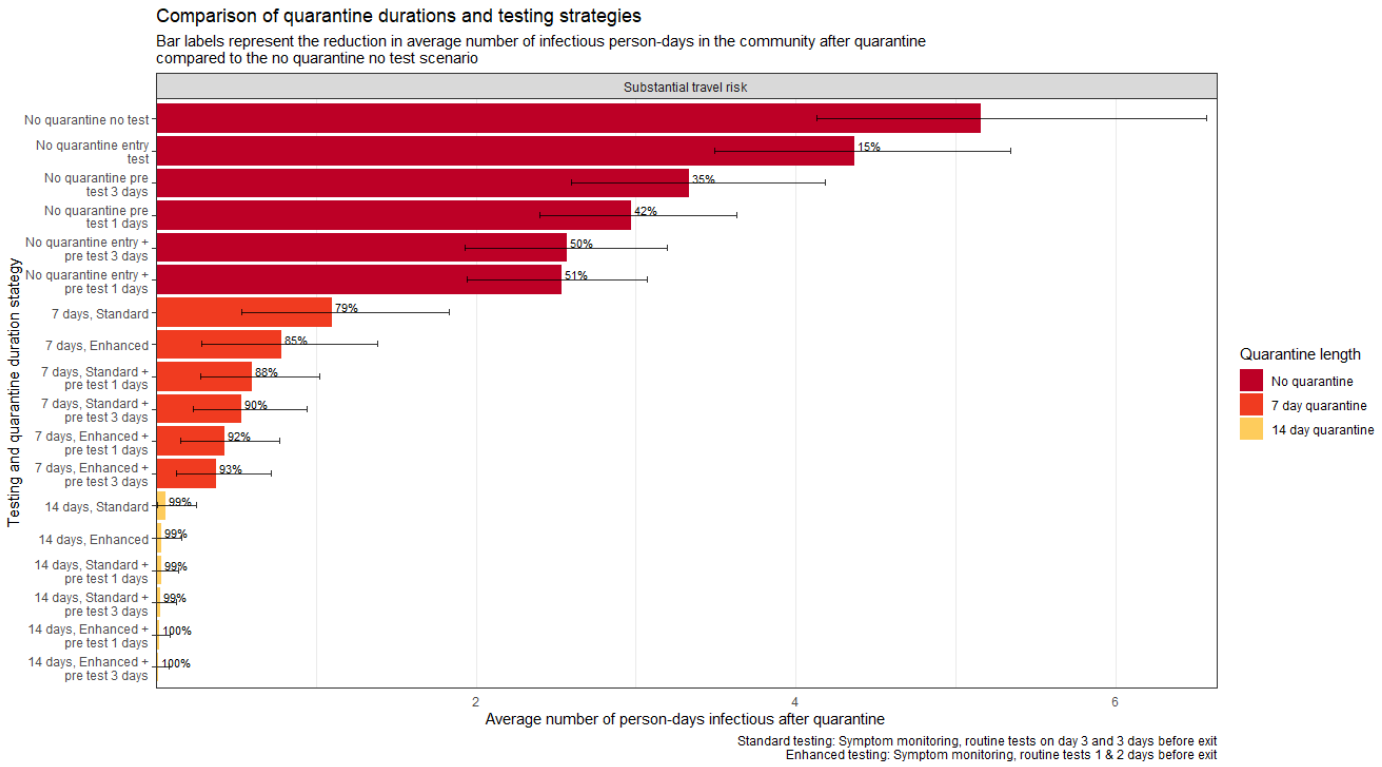


The effectiveness of pre-travel testing for substantial travel risk

In contrast to the minimal benefits of pre-travel testing under the assumption of minimal travel risk, if there is substantial travel risk testing prior to travel becomes more important. This is because it reduces the number of infectious people travelling and therefore averts some of the travel-related infections. As noted above, the status quo quarantine strategy is estimated to result in approximately two people released infectious per 100 infected arrivals, and approximately six days infectious in the community. Compared to the status quo (14 day quarantine), no quarantine with testing at entry increases the number of infectious people released 31-fold and the number of infectious days in the community 74-fold. In contrast, a pre-travel test one or three days before departure and a test at entry increases the risk 18-fold and the number of infectious days approximately 44-fold. Pre-travel testing remains important even with quarantine if we assume substantial travel risk. The 7-day quarantine with an enhanced testing strategy and a pre-travel test increases the number of infectious cases in the community approximately 3-fold (approximately 7-fold increase in infectious days in the community). Although the effect is less obvious with a lengthy quarantine, the addition of pre-travel testing to the standard Australian testing strategy reduces the number of infectious cases in the community from 2 per cent of the cases entering to 1 per cent of the cases entering (reduction in infectious days to 1 per cent as well, Figure 21).

Figure 21. Number of infectious individuals released and number of infectious days in the community per infected arrival by quarantine and testing strategies, including pre-travel testing: substantial travel risk

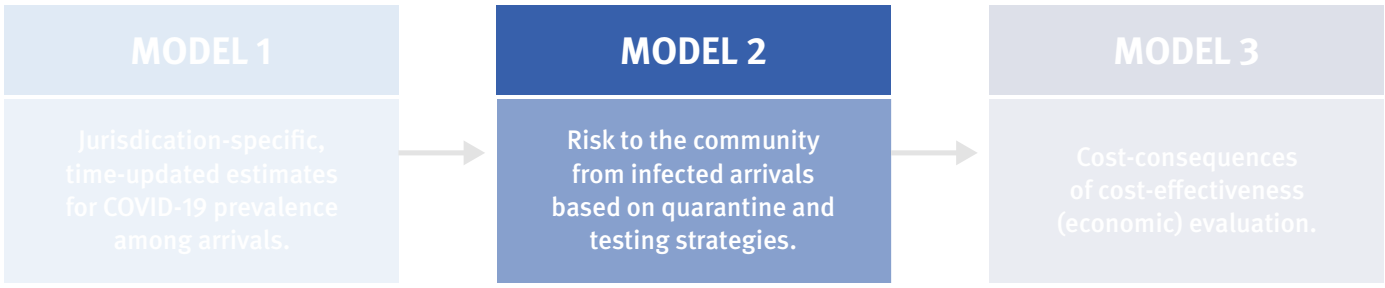




Key Points

- Pre-travel testing is beneficial if there is substantial travel risk because it reduces the number of transmissions during travel.
- It is unlikely to provide benefit if there is minimal risk of transmission during travel. However, given the level of risk during air travel is not well understood and risks during travel are difficult to control, a precautionary principle would support pre-travel testing.
- Notably, for this to work, it must be a requirement for all people travelling.
- Testing one day before departure is a little more effective than testing three days before departure but may not be realistic.
- Further modelling is required to investigate the potential use of rapid antigen testing prior to travel and on arrival.
- A combination of pre-travel testing plus 14-day quarantine reduces risk more effectively than other approaches.

CHAPTER 14
MODEL 2: QUARANTINE SETTING



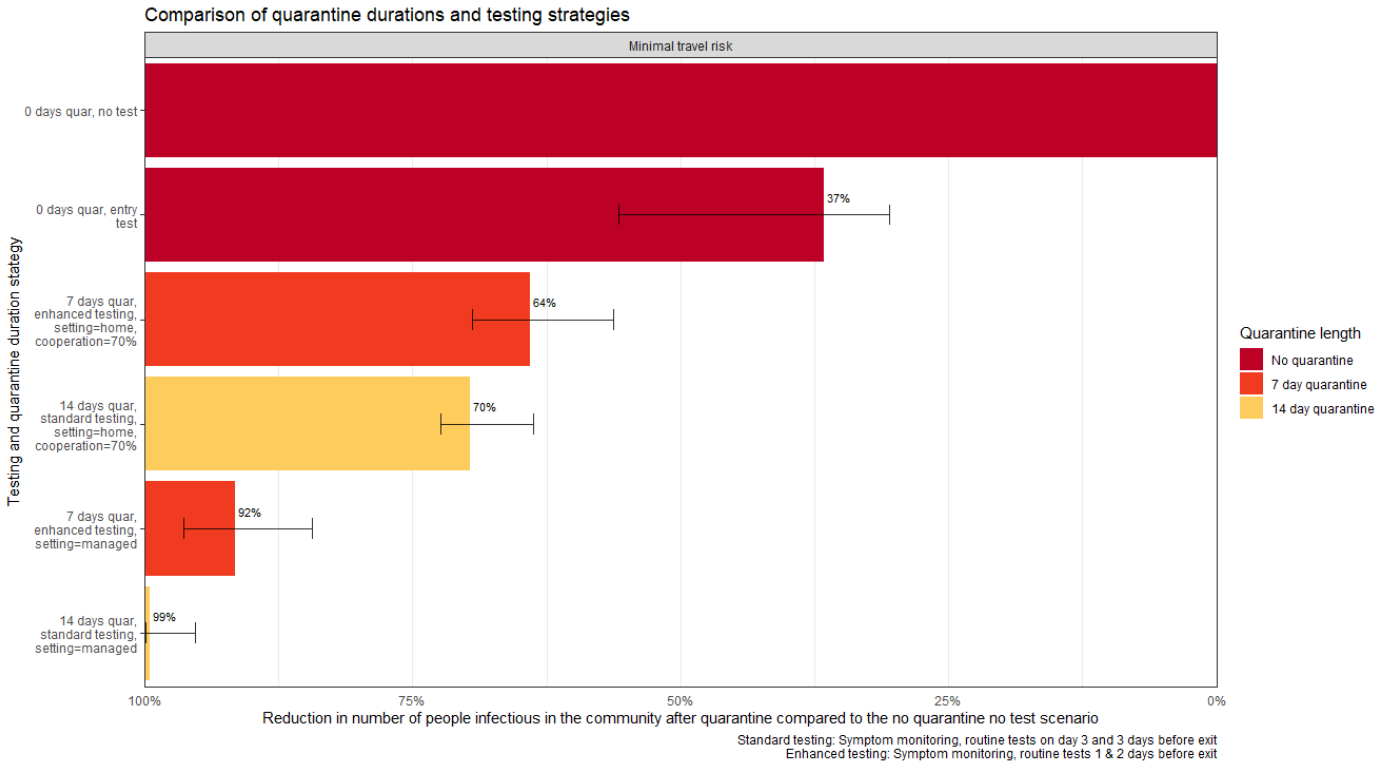
Most of the work in this report assumes that the quarantine setting is managed quarantine. A key assumption is that there was no risk to the community until individuals were released from quarantine. That is, the model estimates of risk do not include the risk of transmission from individuals in quarantine to managed quarantine staff. While this potential risk should be considered, the reported number of transmissions from people in managed quarantine to staff has been very low. While most of this report pertains to managed quarantine settings, we also investigated the potential effectiveness of home-based quarantine. For this analysis, we assumed that 70 per cent of people quarantined cooperated with quarantine rules. We assumed that those not cooperating with quarantine would also not cooperate with isolation if they tested positive. This approach is likely to be reasonable for estimating the number of people infectious in the community because those that test positive and do not cooperate prior to receiving their test results are very likely to be infectious before receiving those results. This is because detectability of the virus is unlikely until around the time than infectiousness develops and there is a lag between the swab being taken and results becoming available. However, that may overestimate the number of infectious days in the community for home quarantine if those not cooperating with quarantine rules (a) present for testing, (b) isolate effectively between being tested and receiving their result, and/or (c) isolate effectively after testing positive. Given that is the case, we have only included the graphs on the number of people infectious in the community. For these scenarios, we assumed standard testing in 14-day quarantine and enhanced testing in 7-day quarantine.

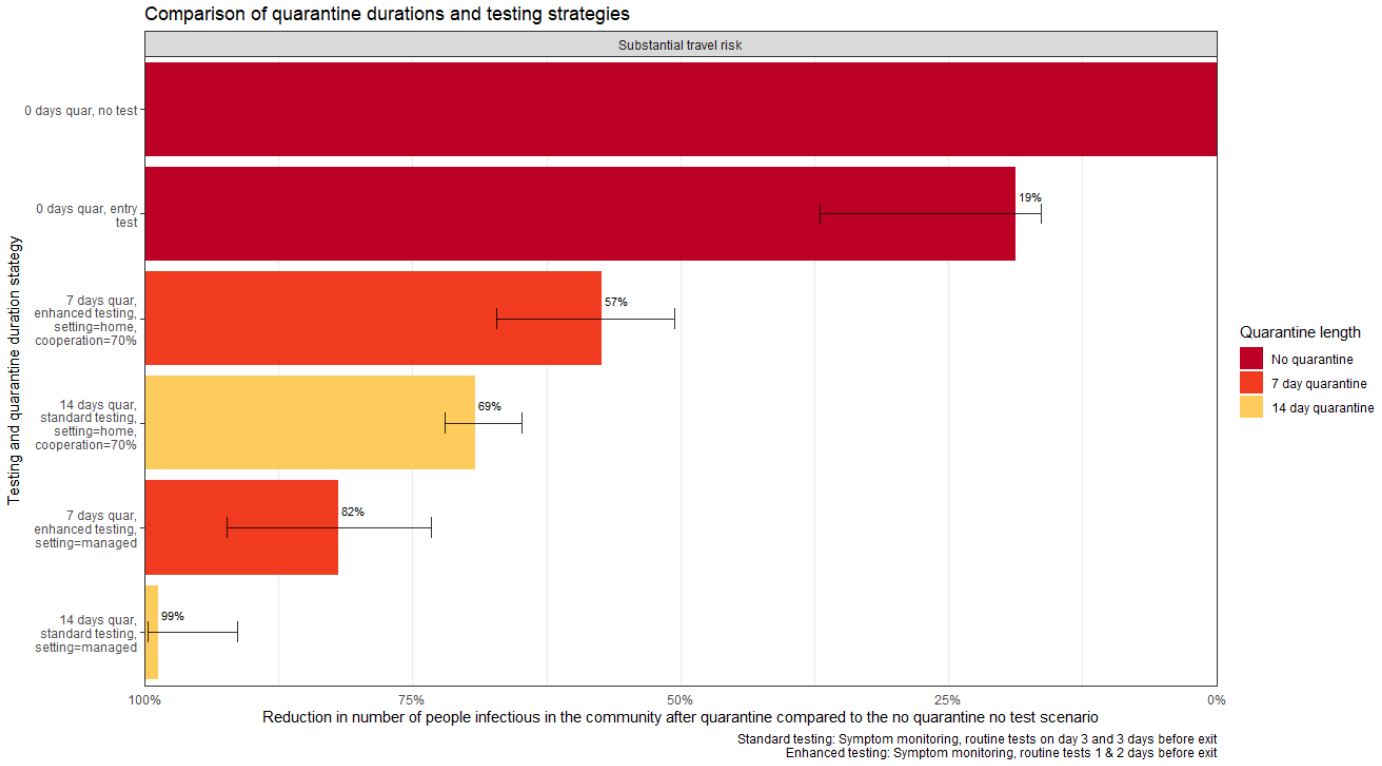
As shown, assuming 70 per cent cooperation with quarantine rules, we expect an approximately 59-fold increase in numbers of infectious people entering the community relative to the standard approach (14 days managed quarantine, standard testing) with 14-day home-based quarantine assuming minimal travel risk (24-fold increase assuming substantial travel risk). This is considerably higher than the increase in risk for 7 days of managed quarantine with enhanced testing (17-fold under the assumption of minimal travel risk and 14-fold under the assumption of considerable travel risk). (Figure 22).

Notably, this is based on the assumption that those not cooperating will not cooperate throughout the quarantine period. However, realistically cooperation may vary with the number of days in quarantine. Behavioural research could provide more insight into behaviour in home-based quarantine, including the proportion cooperating throughout and among those not cooperating whether this varies over time, as well as the influence of testing.

Electronic monitoring at home has been suggested as an alternative to managed quarantine. However, the effect on cooperation is not currently known. For example, the proportion of people quarantining at home with electronic monitoring having visitors to the home is unknown.

Figure 22. Number of infectious individuals released in the community per infected arrival by quarantine duration and quarantine setting

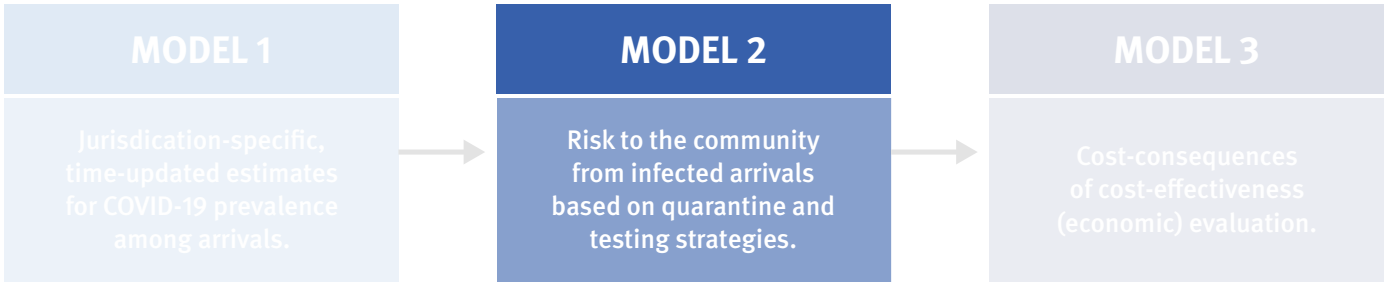




Key Points

- Assuming moderate levels of cooperation with quarantine directives, home-based quarantine is likely to result in considerably more infectious arrivals in the community compared to managed quarantine.
- Even short periods of managed quarantine (7 days) may be more effective than 14 days of home-based quarantine under the assumption of moderate cooperation.
- Behavioural research is required to better understand patterns of cooperation during home-based quarantine and potential interventions to increase cooperation such as electronic monitoring.

CHAPTER 15
MODEL 2: DEVELOPMENT OF A RISK-BASED STRATEGY FOR QUARANTINE FOR INTERNATIONAL TRAVEL



While a 14-day quarantine period is always relatively more effective than shorter duration quarantine, we considered whether a shorter duration quarantine might be appropriate for a situation where the probability of infection at arrival is relatively low due to lower rate of infection at the country or state of origin. We considered five potential classifications of risk (Table 11), and countries were assigned to risk categories based on the estimated prevalence of COVID-19 in travellers from that country on 7 October 2020. Prevalence was estimated by correcting for under-ascertainment, asymptomatic infection, and to account for selection bias and potential risk during travel. The method is described in Part 2 above.

Table 11. Recommended quarantine and testing strategies by risk classfication

Risk Classification	Estimated Prevalence Thresholds[a]	Testing Criteria	Examples of Countries meetings these criteria[b]	Quarantine / Testing Recommendation
Very Low	‹ 0.01%	Public testing data ≥ 50 tests per case	New Zealand, Thailand	Pre-travel testing No quarantine Test on arrival
Low	0.01 - 0.05%	Public testing data ≥ 50 tests per case	Cuba, Singapore, South Korea, Sri Lanka, Togo	Pre-travel testing 7-day quarantine for individuals quarantining alone Enhanced testing in quarantine
Moderate	0.05 - 0.1%	Public testing data ≥ 50 tests per case	Uruguay	Pre-travel testing 8-day quarantine for individuals quarantining alone Enhanced testing in quarantine
High	0.1 - 0.5%	Public testing data ≥ 50 tests per case	Estonia, Malaysia, Norway	Pre-travel testing 14-day quarantine Enhanced testing in quarantine
Very High	› 0.5%	No criteria	Denmark, Germany, India, Pakistan, UK, USA, UAE	Pre-travel testing 14-day quarantine Enhanced testing in quarantine

Table Notes. b. Prevalence estimated for 7 October 2020, adjusted for under-ascertainment, and observed high prevalence of COVID-19 in travellers using the approach described in Part 2 of this report. b. These countries meet the prevalence thresholds and published data on negative tests, and have undertaken at least 50 tests per case, suggesting adequate testing.

For each risk classification, we considered the number of infectious cases released into the community and the number of infectious person-days per 10,000 arrivals based on a range of shorter quarantine durations with enhanced testing strategy. Quarantine and testing strategies were selected to ensure that the expected risk was similar or lower than we estimated for returning residents (approximately 1 per cent risk of infection) based on a 14-day quarantine period with standard testing. Enhanced testing was recommended in each case based on the relative advantage compared to standard testing. Pre-travel testing was recommended for each scenario in the context of air or other mass transit due to unclear levels of risk, expected heterogeneity of risk, and difficulty controlling risk during travel.

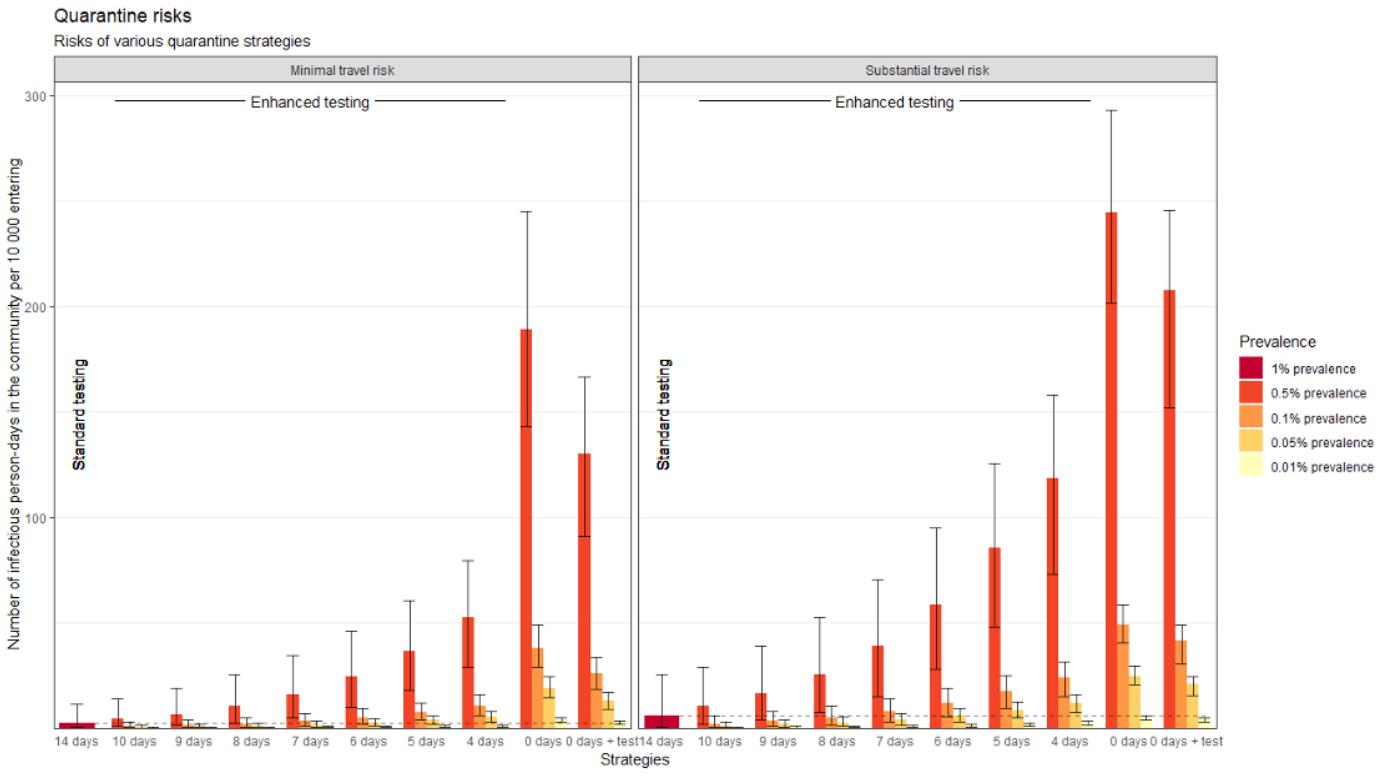
Some countries broadly considered low-risk are not included in Table 11 above. Table 12 discusses some of these examples.

Table 12. Countries widely considered low-risk but not classified as such by our model

Countries	Criteria	Implications
China **Vietnam**	Meet estimated prevalence criteria for **very low-risk** Do not publish testing data	Testing data provide confidence that case and mortality data are sufficiently accurate to provide confidence in model-based prevalence estimates.
Vanuatu **Other Islands**	No publicly available case, mortality or testing data	We understand that credible data exists that is not public demonstrating no excess pneumonia presentations and no diagnosed cases. Given these are Islands and travel restrictions currently exist, it is likely these are very low-risk. However, the capacity to detect an outbreak should one occur may be low, which implies a higher risk than countries such as New Zealand or Thailand with similarly low case numbers but more capacity to detect cases in a timely manner if they were to occur.

Figure 23 illustrates the number of person-days in the community per 10,000 entrants for each of the prevalence cut-offs in table 11 or no quarantine (with and without a routine PCR test on arrival), and 4-10 days of quarantine with enhanced testing. These are compared to the expected number of infectious days in the community per 10,000 arrivals to Australia with an overall COVID-19 prevalence of 1 per cent, and current quarantine and testing strategies (14 day quarantine, standard testing).

Figure 23. Number of person-days in the community by infection prevalence and quarantine and testing strategy



This figure demonstrates that 8 days of quarantine with enhanced testing for arrivals from countries with 0.1 per cent probability of infection, 7 days of quarantine with enhanced testing for arrivals from countries with 0.05 per cent probability of infection, and no quarantine with a routine PCR test at entry are expected to result in equivalent risk to the community as 14-day quarantine with standard testing for 1 per cent probability of infection. Notably, this is for individuals quarantining alone and cannot be generalised to family or other groups quarantining together.

If these recommendations were followed, our model estimated that for the number of arrivals that entered Australia in May-June 2020 based on the countries of origin of arrivals in June 2020 (the most recent month with these data available), the overall expected numbers of cases among arrivals and number of person-days infectious in the community are summarised in Table 13. If the numbers of arrivals were to remain stable relative to May and June, we would expect the overall prevalence of COVID-19 in arrivals to increase. However, these increases would be due to increased prevalence in high- and very high-risk countries. The expected number of cases from countries classified as moderate- or lower-risk would be 0, and therefore relaxing the quarantine requirements for those countries would not result in an appreciable increase in risk as long as the volumes of arrivals remained stable. Implementing these policies would reduce the burden on the managed quarantine system, with the number of person-days of quarantine required being reduced by up to 49,000 person-days per month if all arrivals were quarantined alone.

Table 13. Expected number of cases and person-days infectious in the community based on current policy (14 day quarantine for all arrivals, standard testing) and recommended policy (waived or reduced quarantine for selected countries).

Risk Classification	Countries	May / June Arrivals	Expected cases per month among arrivals (October prevalence applied to May/June arrivals)	Expected infectious person-days in the community based on existing policy Minimal/Substantial travel risk	Expected infectious person-days in the community based on policy recommendations Minimal/Substantial travel risk
Very Low	New Zealand	5,687	0 (0-1)	0 (0-0) / 0 (0-0)	0 (0-1.6) / 0 (0-1.6)
	Thailand	898	0 (0-0)	0 (0-0) / 0 (0-0)	0 (0-0) / 0 (0-0)
Low	Cuba	0	0 (0-0)	0 (0-0) / 0 (0-0)	0 (0-0) / 0 (0-0)
	Singapore	1,124	0 (0-0)	0 (0-0) / 0 (0-0)	0 (0-0) / 0 (0-0)
	South Korea	340	0 (0-0)	0 (0-0) / 0 (0-0)	0 (0-0) / 0 (0-0)
	Sri Lanka	423	0 (0-0)	0 (0-0) / 0 (0-0)	0 (0-0) / 0 (0-0)
	Togo	0	0 (0-0)	0 (0-0) / 0 (0-0)	0 (0-0) / 0 (0-0)
Moderate	Uruguay	12	0 (0-0)	0 (0-0) / 0 (0-0)	0 (0-0) / 0 (0-0)
High / Very High	All other countries	36,878	348 (141-681)*	8.0 (0.2 - 77.0) / 31.7 (0.9 - 253.40)	4.5 (0.1 - 47.0) / 7.0 (0.1 - 66.5)

*Note: estimated prevalence for other countries increased substantially from June to October 2020 so if the number of arrivals per country was stable, we would expect more imported cases in October compared to May and June.

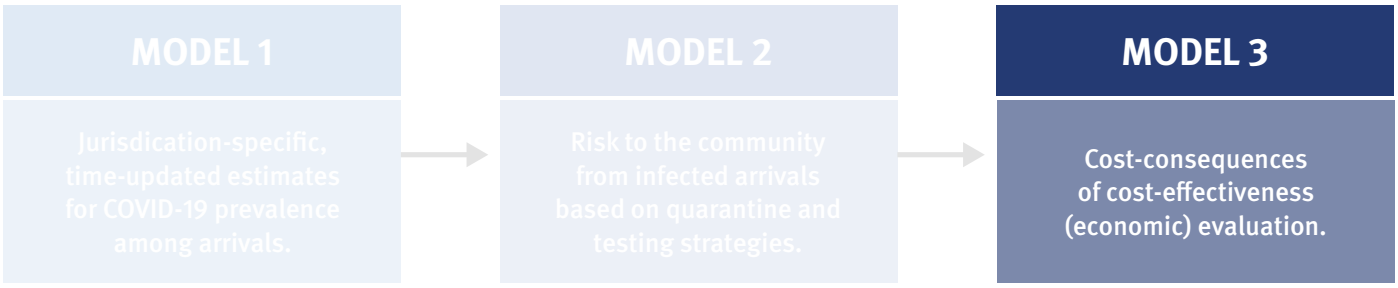
Notably, these estimates are based on travel volumes under a policy of border closure and 14-day managed quarantine for all arrivals. The number of people travelling per month is a key parameter determining the level of risk from travel. Reduced, and particularly waived, quarantine may lead to increased numbers of travellers. The numbers of arrivals to Australia in May and June 2020 were reduced by more than 99 per cent compared to the same time period the previous year. If the volume of travellers from low-risk countries were to substantially increase, this would lead to higher risk estimates. This is discussed further in the international tourism scenario in the economic evaluation part of this report.

These estimates and risk classifications can be updated regularly, providing timely information for policy. Notably, risk classifications can change rapidly. For example, over the past few weeks, the classification for Malaysia has changed from low-risk to high-risk due to increases in cases. While the ability to provide updated information is a strength of this approach, the rapidly changing situation may be challenging for policy and can be expected to continue to contribute to uncertainty for potential travellers.

Key Points

- Based on current travel volumes, waiving quarantine for very low-risk countries (currently New Zealand and Thailand) and reducing quarantine for low-risk and moderate-risk countries would not be expected to substantially increase COVID-19 risk to Australians from incoming travellers.
- Risk classifications rely on COVID-19 case and death data availability from countries. Some countries may need to be considered on an individual basis.
- Risk status within a country can change rapidly, with implications for policy.
- If travel volumes increase, this will lead to increases in the expected risk.

CHAPTER 16
MODEL 3: COST-CONSEQUENCES OF COST-EFFECTIVENESS EVALUATION



Brief methods

The economic component of this report aims to determine the costs, benefits and risk, of allowing travel with various quarantine and testing strategies for a number of different groups of travellers.

Evaluation will take the form of a cost-benefit analysis conducted from the Australian societal perspective, and risk estimates using the methods described in the previous sections of this report. The main costs to be considered will be the tangible costs of quarantine and the direct costs of each case of COVID-19 that occurs as a result of the quarantine scenario. Benefits will be based on the estimated GDP increment that results from each arrival under various of categories of migrant, visitor or returning resident.

Costs and benefits will be reported in 2020 Australian dollars (AUD$).

Cost of quarantine

The cost of quarantine is calculated for each scenario base on the selected quarantine strategy and the age of the arrival. Key determinants of direct quarantine costs include:

- Duration of quarantine
- Site of quarantine
- Number of tests
- Estimated productivity loss.

The direct cost of managed quarantine is estimated from publicly available figures for the cost of hotel quarantine in the state of Queensland: 50 per cent of adults are assumed to quarantine in a single room for $200 per night whilst 50 per cent are assumed to share a room for $132.50 per night each. Children are assumed to only quarantine in a room with a guardian for an incremental cost of $32.50 per night.

The direct cost of home quarantine is taken to be $0 per night.

The cost of each test performed is estimated at $85. This figure is taken from the Australian Medicare rebate offered for coronavirus PCR at the time of writing.

Productivity loss is calculated per day of quarantine. This is based on the average weekly wage stratified by age-group as reported by the Australian Bureau of Statistics (ABS). This calculation accounts for probability of employment at the time of quarantine and assumes that a proportion of employees would be able to work remotely from their quarantine site. Further details of these calculations are available in the appendix.

Cost of COVID-19 cases

For each infected individual, the average cost of the infection is estimated based on their age and sex. Key contributors to cost include:

- Probability of developing symptoms
- Cost of testing following onset of symptoms
- Productivity loss due to isolation
- Average use and cost of outpatient medical care
- Average use and cost for inpatient medical care
- Mortality rate and average cost of mortality.

For international travel, for involving cases that were already acquired overseas, we assume that travel to Australia does not affect the severity of the infection. As such, the costs that result from loss of productivity and life from a primary infection are predetermined and would not be influenced by the decision to permit entry to Australia.

On the other hand, the decision to allow an internationally-based cohort entry to Australia will transfer the cost of medical care of any primary cases contained within that cohort from an overseas medical system to the Australian medical system. As such, the costing equation for primary cases is centred on the average inpatient and outpatient medical costs for case management. Only symptomatic cases are assumed to accrue medical costs. All symptomatic cases are assumed to receive outpatient care with a cost of c_{GP}. Each case has an age- and sex-dependent probability of requiring inpatient admission which carries an age- and sex-dependent average cost. Furthermore, admitted cases have an age- and sex-dependent probability of being admitted to intensive care (ICU) with an age- and sex-dependent average cost. This gives the costing equation of a primary infection as:

$$c_{primary} = p_{Sx} \times (c_{GP} + p_{admit} \times (c_{admit} + p_{ICU} \times c_{ICU}))$$

Details on each of these parameters is provided in the appendix.

Determining benefit

Economic benefit for each traveller cohort was based on the estimated GDP contribution that would result from each arrival in that cohort. The table below demonstrates the range of the estimated benefit per arrival in each cohort. The methodology for these estimates is presented in the appendix.

The time-horizon used to calculate the benefit for each cohort is dependent on the presumed duration of stay in Australia following arrival:

- For tourists and unskilled workers, benefit is calculated for the duration of the visit
- For interstate FIFO workers, benefit is based on annual GDP contribution divided by annual number of interstate trips
- For students and skilled migrants, benefit is calculated using a presumed length-of-stay of 12 months
- For returning residents, benefit is calculated as the productivity gain that would result from lifting caps on returning Australian residents.

Table 14. Estimated benefit per arrival for six cohorts of travellers

Cohort	Lower-bound estimate per arrival per trip	Upper-bound estimate per arrival per trip
International Seasonal Farm Labour	AUD$81,600	AUD$127,000
Interstate FIFO Workers	AUD$23,400	AUD$41,300
International Tourist	AUD$1,630	AUD$4,880
International Students	AUD$406	AUD$701
Returning Residents	AUD$55,700	AUD$77,000
Skilled Migrants	AUD$105,000*	AUD$158,000

*Note that the ratio of total applicants (skilled migrants plus their dependents) to skilled migrants in the previous year was 1.94. The cost of entry of skilled migrants and the risk of entry of these migrants is increased by this factor in the analysis.

Quarantine strategies and risk-based entry criteria

For each cohort, costs, benefits and risks were calculated based on the following quarantine and entry criteria:

1. Open entry, standard quarantine: Allow entry to entire cohort, require 14-day quarantine, standard testing
2. Open entry, risk-based quarantine: Allow entry to entire cohort, use a risk-based quarantine and testing strategy, as recommended in Part 6 above. This involves tailoring the duration of quarantine based on the country of origin risk classification.
3. Moderate-risk entry, risk based quarantine: Allow entry to those countries with moderate or lower risk classification, use a risk-based quarantine and testing strategy, as recommended in Part 6 above. This involves tailoring the duration of quarantine based on the country of origin risk classification.
4. Very low-risk entry, no quarantine, with testing: Allow entry to those countries with very low-risk classification only, use a risk-based quarantine and testing strategy, as recommended in Part 6 above. For those with very low-risk, this involves no quarantine, testing three days prior to travel, testing on arrival
5. Low-risk entry, no quarantine, no testing: This strategy was tested for domestic travel only. Allow travel without quarantine or testing for low- or very low-risk.
6. Very low-risk entry, no quarantine, no testing: This strategy was tested for domestic travel only. Allow travel without quarantine or testing for very low-risk. No interstate travel for other risk classifications.

Determining risk

Risk was defined as the total number of expected infectious person-days in the community arising from allowing entry to the cohort. It was calculated using the quarantine model described in the sections above, taking into account the volume of arrivals, risk classifications of countries of origin, and age-distributions associated with each of the cohorts.

In each case other than returning residents, the volume of arrivals was assumed to be the same as in 2018 or 2019 depending on availability of data. For returning residents, the volume of travellers was based on data from DFAT.

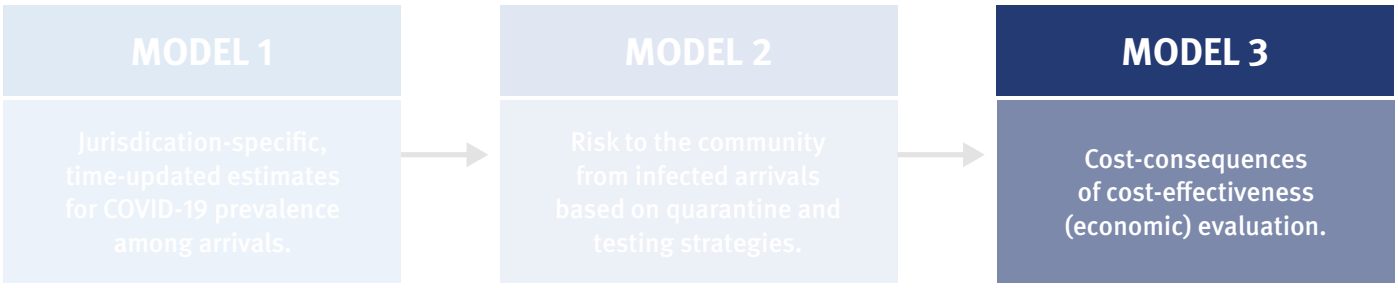
The proportions of each cohort expected to come from each country of origin were generally based on historical data from 2018 or 2019. For returning residents they were based on data from April to June 2020. Where data were not available for the entire cohort, data were based on a subset of the cohort. The risk classifications for each country of origin were calculated in two ways: (a) countries were classified based on the estimated prevalence (calculated as described in Part 2) and testing. Those without adequate testing were classified as being two risk levels higher than they would be based on estimated prevalence alone, and (b) countries were classified based on prevalence estimates alone. Countries that

were classified differently using the two approaches included China and Vietnam (moderate in (a) and very low-risk in (b)), and Japan (high-risk in (a) and low- risk in (b)). For some countries, prevalence estimates could not be calculated because of lack of case data or because the country had reported too few deaths to calculate the under-ascertainment multiplier. Those countries included Pacific Islands, Timor-Leste, and Taiwan. In risk classification (a), we categorised these as moderate-risk, and in risk classification (b), we categorised them as very low-risk. Given that prevalence could not be estimated for all countries we conservatively calculated the probability of infection using the upper-bound for prevalence for the risk category. Therefore, very low risk countries were assumed to have prevalence of 0.01 per cent, low-risk 0.05 per cent, moderate-risk 0.1 per cent, high-risk 0.5 per cent, and for very high-risk which does not have an upper bound we assumed 1.5 per cent. For some cohorts, the country of origin was only available for the most common countries with the remainder grouped in an 'other' category. Where country of origin was unknown, we assumed very high-risk.

For domestic travel, Australian states were also classified using two risk classification systems. In (a) prevalence estimates were calculated in the same way as for international travels including adjustment for under-ascertainment and for selection bias/traveller risk. In (b) prevalence estimates for adjusted for under-ascertainment but not selection/ bias/traveller risk.

Age distributions were based on either historical data for the entire cohort or for a subset of the cohort. Where there was no age-distribution data available (this was the case for domestic tourism, returning residents, and skilled migrants), we assume the age-distribution of the Australian population.

CHAPTER 17
MODEL 3: COST-CONSEQUENCES OF COST-EFFECTIVENESS EVALUATION



Strategies

Table 15. Risk-based quarantine strategy terminology

Term	Definition
Open entry	No criteria for entry
Moderate-risk entry	Only those from moderate or lower risk states or countries can enter
Low-risk entry	Only those from low or very low-risk states or countries can enter
Very low-risk entry	Only those from very low-risk states or countries can enter
Standard quarantine	14 days quarantine, standard testing
Risk-based quarantine	Quarantine and testing strategy depends on the risk classification of the state/ country of origin. See table below for specific details.
No quarantine with testing	No quarantine, pre-travel testing three days before departure and testing on arrival
No quarantine, no testing	No quarantine, no testing

Table 16. Country risk-classification (two schemas)

Estimated prevalence[a]	Adequate testing?[b]	Example countries	Risk classification scheme 1	Assumed prevalence (scheme 1)[c]	Risk classification scheme 2	Assumed prevalence (scheme 2)
‹0.01%	Yes	New Zealand, Thailand	Very Low	Estimated	Very Low	Estimated
‹0.01%	No	China, Vietnam, Rwanda, South Sudan	Moderate	Upper bound	Very Low	Estimated
0.01 - 0.05%	Yes	Singapore, Cuba, South Korea, Sri Lanka, Togo	Low	Estimated	Low	Estimated
0.01 - 0.05%	No	Pakistan, Yemen, Cameroon, Mali, Senegal, Haiti	High	Upper bound	Low	Estimated
0.05 - 0.1%	Yes	Uruguay	Moderate	Estimated	Moderate	Estimated
0.05 - 0.1%	No	Japan, Bangladesh, Algeria, Syria, Ethiopia	Very High	Upper bound	Moderate	Estimated
0.1 - 0.5%	Yes	Estonia, Malaysia, Norway	High	Estimated	High	Estimated
0.1 - 0.5%	No	Indonesia, Philippines, South Africa, Turkey	Very High	Upper bound	High	Estimated
›0.5%	Yes	Denmark, Finland, Germany, Greece, UAE	Very High	Estimated	Very High	Estimated
›0.5%	No	Brazil, USA, UK	Very High	Conservative	Very High	Estimated
Cannot estimate	N/A	Vanuatu, Taiwan, Cambodia, Fiji, Iceland, Papua New Guinea	Moderate	Upper bound	Very Low	Upper bound

Table Notes. b. Prevalence estimated for 13 October 2020, adjusted for under-ascertainment, and observed high prevalence of COVID-19 in travellers using the approach described in Part 2 of this report. b. Testing data is available, and countries have undertaken at least 50 tests per case. c. Upper bound is the upper bound of the prevalence for the risk classification bracket and conservative is 1.5% prevalence.

Table 17. Risk-based quarantine definition

Risk Classification	Quarantine and testing strategy
Very Low	No quarantine, pre-travel testing three days before departure and testing on arrival
Low	7 days quarantine, pre-travel testing three days before departure and enhanced testing during quarantine
Moderate	8 days quarantine, pre-travel testing three days before departure and enhanced testing during quarantine
High	14 days quarantine, pre-travel testing three days before departure and enhanced testing during quarantine
Very High	14 days quarantine, pre-travel testing three days before departure and enhanced testing during quarantine

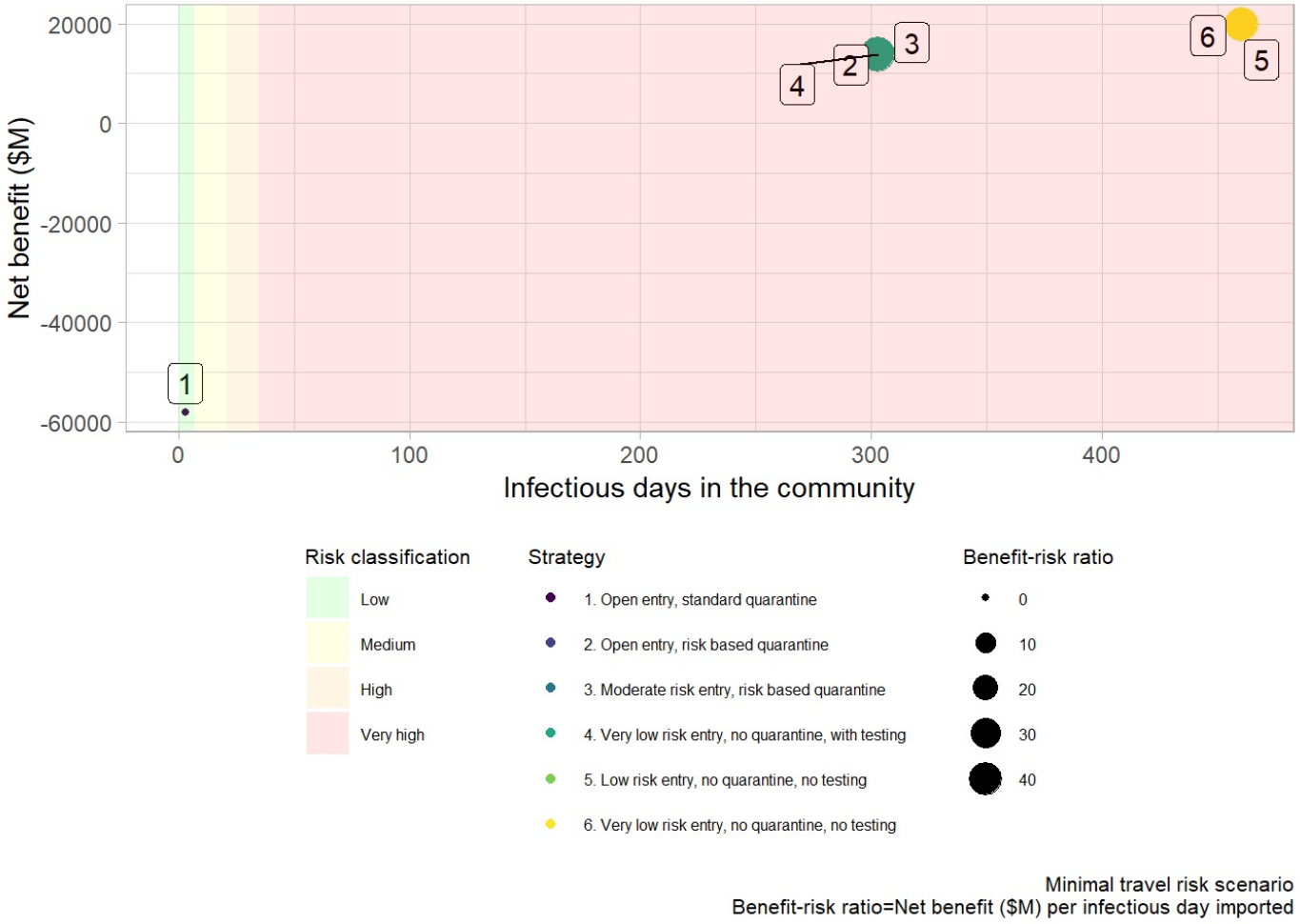
Table 18. Risk classifications for cohorts / strategies

Risk Classification	Number of infectious days in the community per jurisdiction per year
Low	‹ 1
Moderate	‹ 3
High	‹ 5
Very High	‹ 5

DOMESTIC TOURISM

	Arrivals	Costs		Benefits		Net benefit	Infectious days (total)		Infectious days (per 10 000 arrivals)	
Strategy	000s	Total $M	PP $	Total $M	PP $	$M	TR1	TR2	TR1	TR2
Open entry, standard quarantine	36000	78048	2168	19926	554	-58122	3	7	0.0008	0.002
Open entry, risk based quarantine	36000	6119	170	19926	554	13807	303	497	0.0842	0.138
Moderate risk entry, risk based quarantine	36000	6119	170	19926	554	13807	303	497	0.0842	0.138
Very low risk entry, no quarantine, with testing	36000	6119	170	19926	554	13807	303	497	0.0842	0.138
Low risk entry, no quarantine, no testing	36000	0	0	19926	554	19926	460	594	0.1278	0.165
Very low risk entry, no quarantine, no testing	36000	0	0	19926	554	19926	460	594	0.1278	0.165

Note:
M=million, PP=per person, TR1=minimal travel risk assumption, TR2=substantial travel risk assumption, **Not applicable

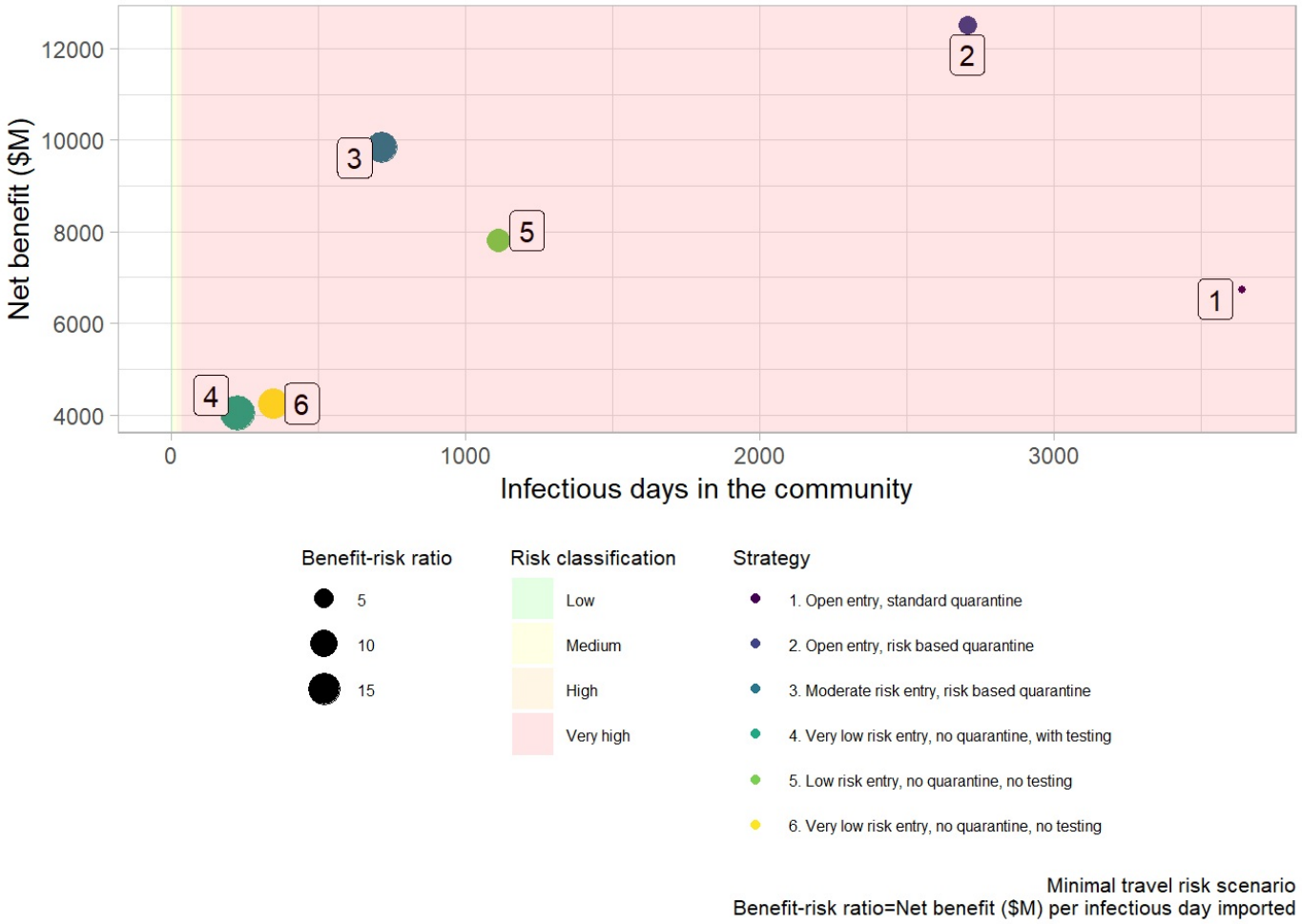


Minimal travel risk scenario
Benefit-risk ratio=Net benefit ($M) per infectious day imported

INTERNATIONAL TOURISM

Risk classification system (a)

	Arrivals	Costs		Benefits		Net benefit	Infectious days (total)		Infectious days (per 10 000 arrivals)	
Strategy	000s	Total $M	PP $	Total $M	PP $	$M	TR1	TR2	TR1	TR2
Open entry, standard quarantine	9300	23533	2530	30272	3255	6739	3640	9309	4	10
Open entry, risk based quarantine	9300	17757	1909	30272	3255	12514	2705	6704	3	7
Moderate risk entry, risk based quarantine	4435	4608	1039	14436	3255	9828	715	1572	2	4
Very low risk entry, no quarantine, with testing	1305	223	171	4248	3255	4025	227	373	2	3
Low risk entry, no quarantine, no testing	2397	0	0	7801	3255	7801	1114	1438	5	6
Very low risk entry, no quarantine, no testing	1305	0	0	4248	3255	4248	345	445	3	3

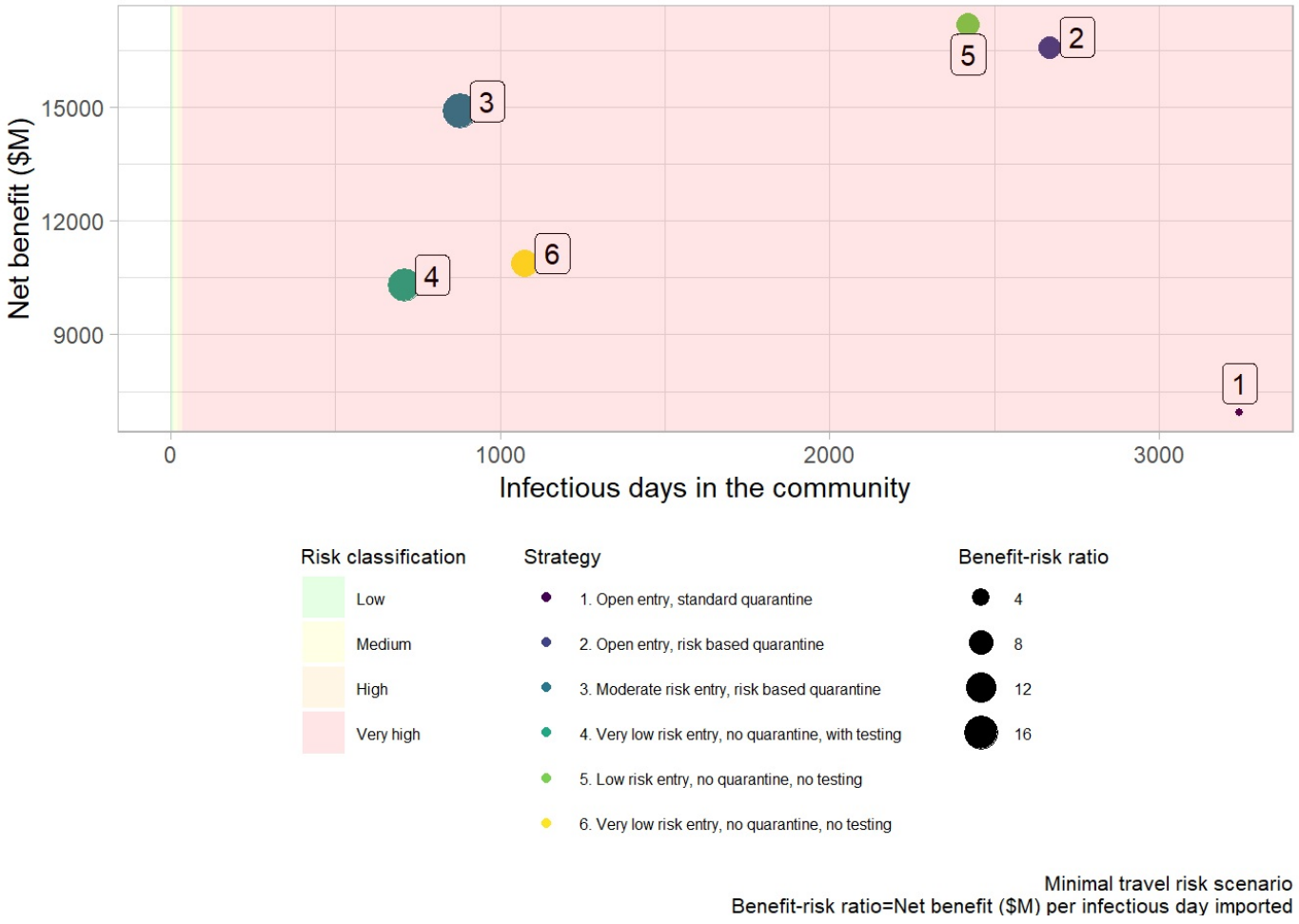


Minimal travel risk scenario
Benefit-risk ratio=Net benefit ($M) per infectious day imported

Risk classification system (b)

	Arrivals	Costs		Benefits		Net benefit	Infectious days (total)		Infectious days (per 10 000 arrivals)	
Strategy	000s	Total $M	PP $	Total $M	PP $	$M	TR1	TR2	TR1	TR2
Open entry, standard quarantine	9300	23335	2509	30272	3255	6936	3245	8298	3	9
Open entry, risk based quarantine	9300	13697	1473	30272	3255	16574	2667	6191	3	7
Moderate risk entry, risk based quarantine	5719	3727	652	18616	3255	14889	878	1577	2	3
Very low risk entry, no quarantine, with testing	3341	571	171	10874	3255	10303	709	1163	2	3
Low risk entry, no quarantine, no testing	5272	0	0	17159	3255	17159	2421	3126	5	6
Very low risk entry, no quarantine, no testing	3341	0	0	10874	3255	10874	1076	1390	3	4

Note:
M=million, PP=per person, TR1=minimal travel risk assumption, TR2=substantial travel risk assumption, **Not applicable

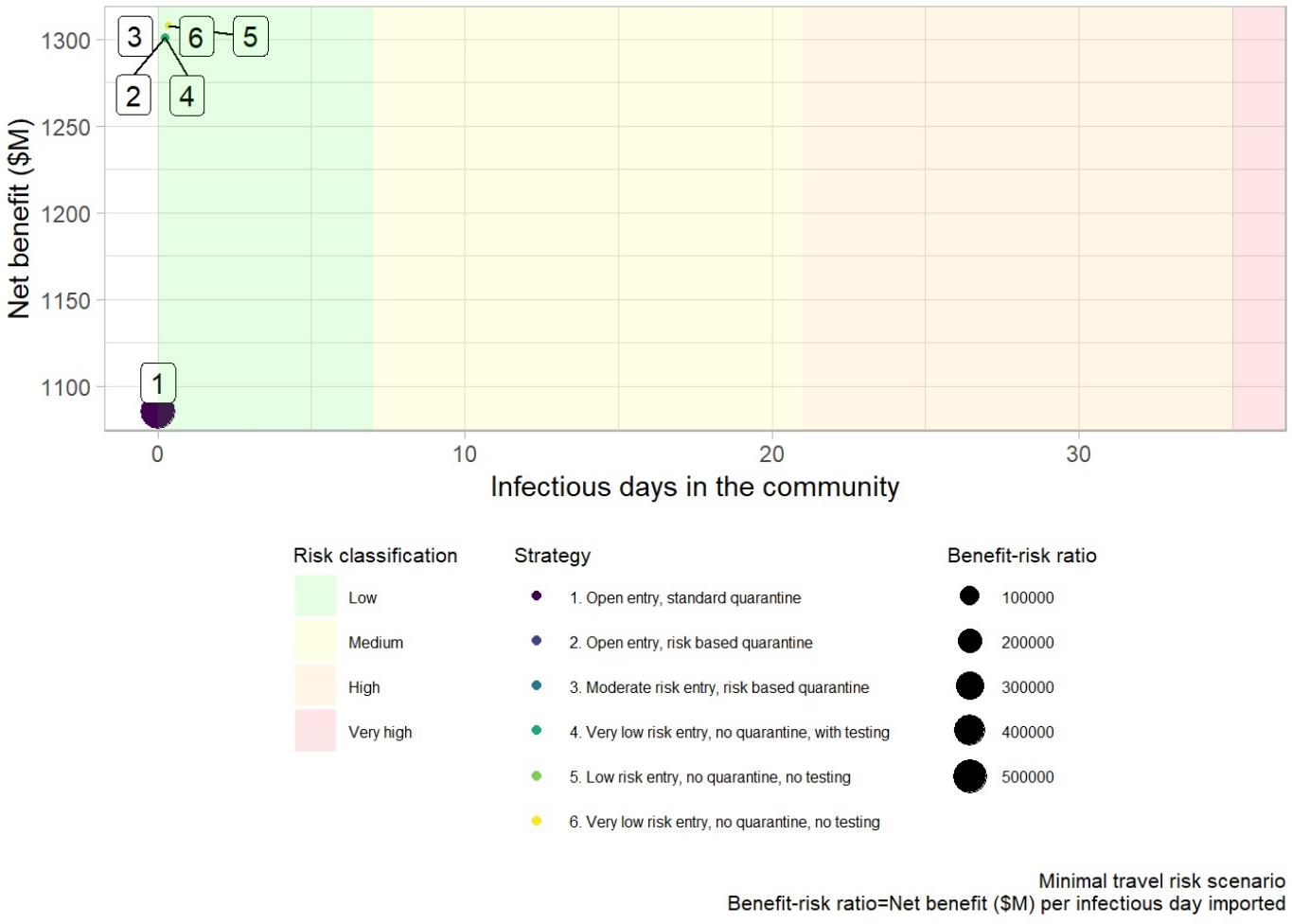


FIFO

	Arrivals	Costs		Benefits		Net benefit	Infectious days (total)		Infectious days (per 10 000 arrivals)	
Strategy	000s	Total $M	PP $	Total $M	PP $	$M	TR1	TR2	TR1	TR2
Open entry, standard quarantine	40	223	5506	1308	32350	1085	0.002	0.006	0.0005	0.001
Open entry, risk based quarantine	40	7	170	1308	32350	1301	0.242	0.398	0.0599	0.098
Moderate risk entry, risk based quarantine	40	7	170	1308	32350	1301	0.242	0.398	0.0599	0.098
Very low risk entry, no quarantine, with testing	40	7	170	1308	32350	1301	0.242	0.398	0.0599	0.098
Low risk entry, no quarantine, no testing	40	0	0	1308	32350	1308	0.368	0.475	0.0910	0.118
Very low risk entry, no quarantine, no testing	40	0	0	1308	32350	1308	0.368	0.475	0.0910	0.118

Note:

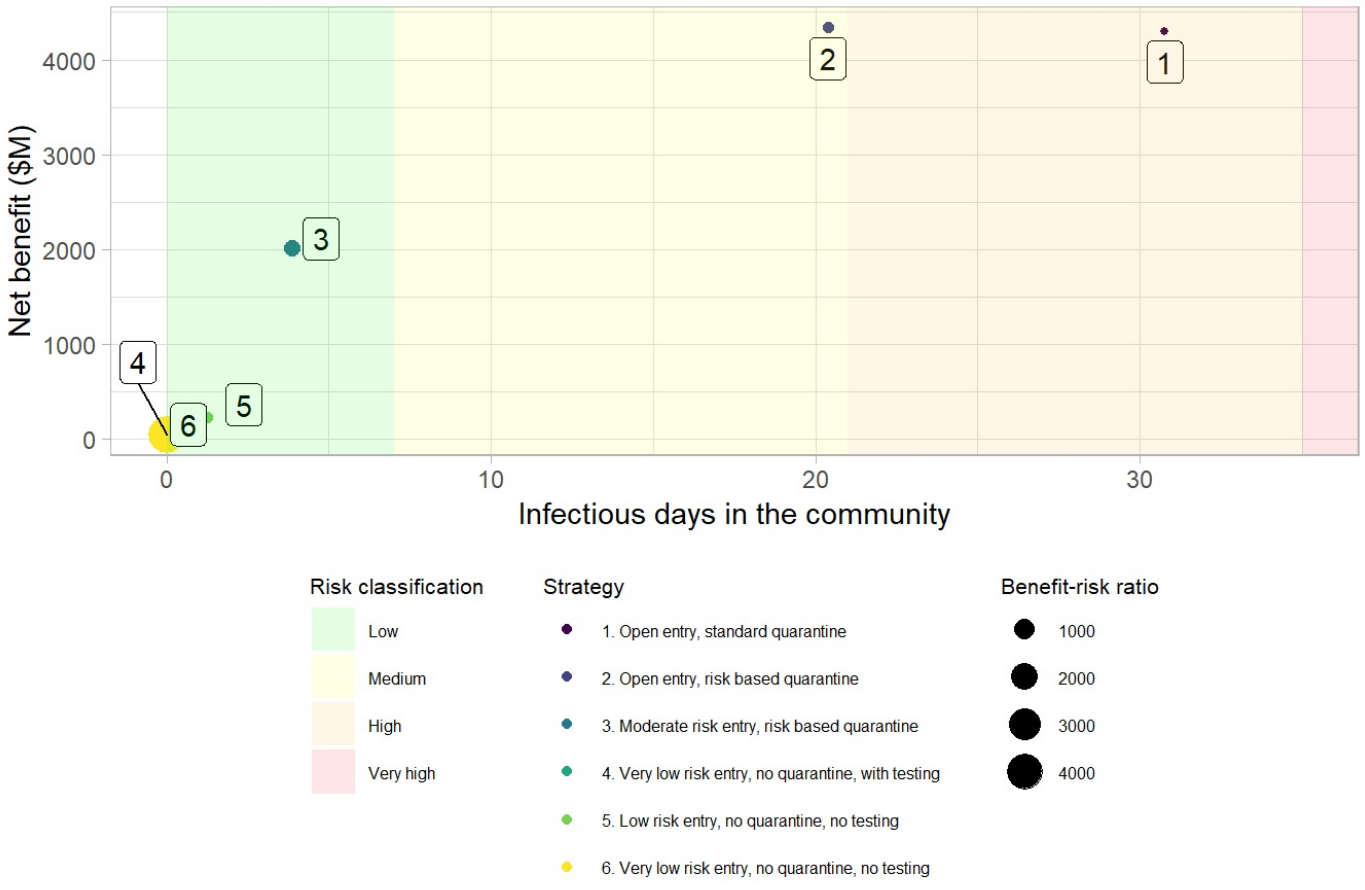
M=million, PP=per person, TR1=minimal travel risk assumption, TR2=substantial travel risk assumption, **Not applicable



AGRICULTURE

Risk classification system (a)

	Arrivals	Costs		Benefits		Net benefit	Infectious days (total)		Infectious days (per 10 000 arrivals)	
Strategy	000s	Total $M	PP $	Total $M	PP $	$M	TR1	TR2	TR1	TR2
Open entry, standard quarantine	43.2	202.39	4685	4506	104300	4304	30.77	78.54	7.1	18.2
Open entry, risk based quarantine	43.2	163.44	3783	4506	104300	4343	20.38	51.90	4.7	12.0
Moderate risk entry, risk based quarantine	19.8	53.13	2687	2062	104300	2009	3.89	9.51	2.0	4.8
Very low risk entry, no quarantine, with testing	0.4	0.07	170	44	104300	44	0.01	0.02	0.2	0.5
Low risk entry, no quarantine, no testing	2.2	0.00	0	234	104300	234	1.23	1.59	5.5	7.1
Very low risk entry, no quarantine, no testing	0.4	0.00	0	44	104300	44	0.01	0.02	0.2	0.5

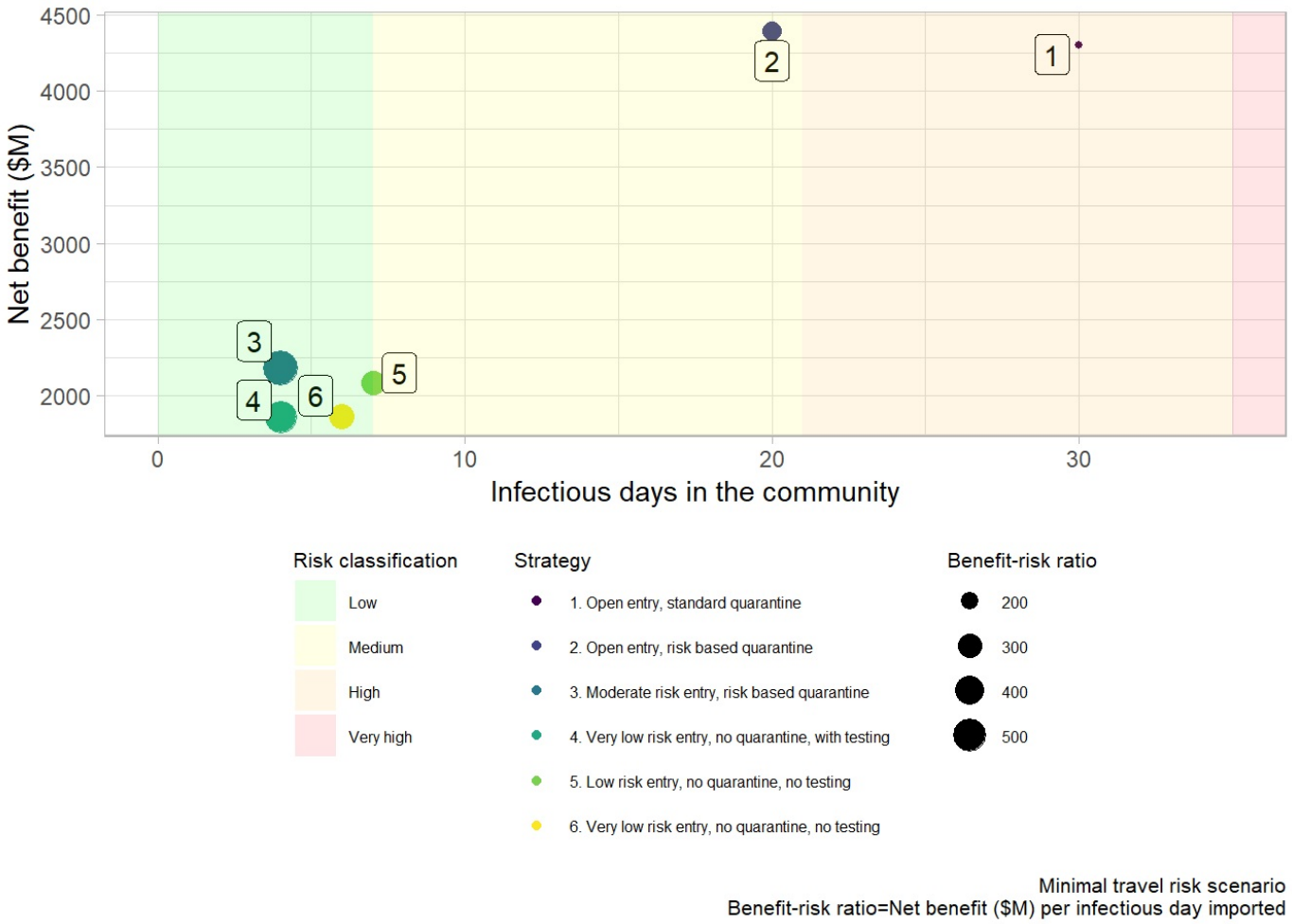


Minimal travel risk scenario
Benefit-risk ratio=Net benefit ($M) per infectious day imported

Risk classification system (b)

	Arrivals	Costs		Benefits		Net benefit	Infectious days (total)		Infectious days (per 10 000 arrivals)	
Strategy	000s	Total $M	PP $	Total $M	PP $	$M	TR1	TR2	TR1	TR2
Open entry, standard quarantine	43	202	4684	4506	104300	4304	30	76	7	18
Open entry, risk based quarantine	43	116	2677	4506	104300	4390	20	48	5	11
Moderate risk entry, risk based quarantine	21	11	526	2190	104300	2179	4	7	2	3
Very low risk entry, no quarantine, with testing	18	3	170	1863	104300	1860	4	6	2	3
Low risk entry, no quarantine, no testing	20	0	0	2088	104300	2088	7	9	3	4
Very low risk entry, no quarantine, no testing	18	0	0	1863	104300	1863	6	7	3	4

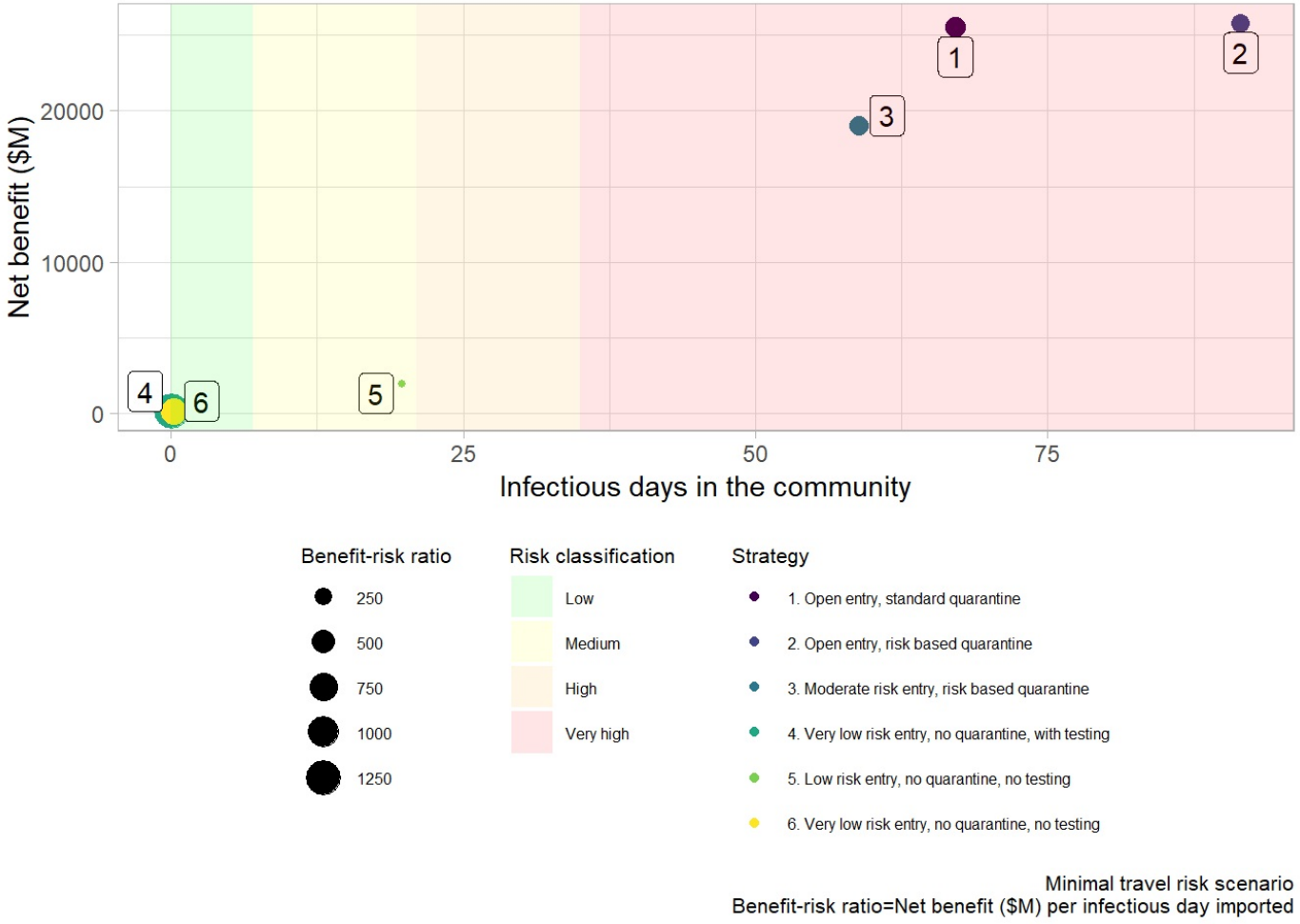
Note:
M=million, PP=per person, TR1=minimal travel risk assumption, TR2=substantial travel risk assumption, **Not applicable



INTERNATIONAL STUDENTS

Risk classification system (a)

	Arrivals	Costs		Benefits		Net benefit	Infectious days (total)		Infectious days (per 10 000 arrivals)	
Strategy	000s	Total $M	PP $	Total $M	PP $	$M	TR1	TR2	TR1	TR2
Open entry, standard quarantine	399	923.1	2316	26445	66350	25522	67.1	171.2	1.7	4
Open entry, risk based quarantine	399	659.1	1654	26445	66350	25786	91.5	227.4	2.3	6
Moderate risk entry, risk based quarantine	293	412.3	1409	19417	66350	19005	58.9	143.7	2.0	5
Very low risk entry, no quarantine, with testing	2	0.3	170	128	66350	128	0.1	0.2	0.5	1
Low risk entry, no quarantine, no testing	30	0.0	0	1985	66350	1985	19.8	25.5	6.6	9
Very low risk entry, no quarantine, no testing	2	0.0	0	128	66350	128	0.2	0.3	1.0	2

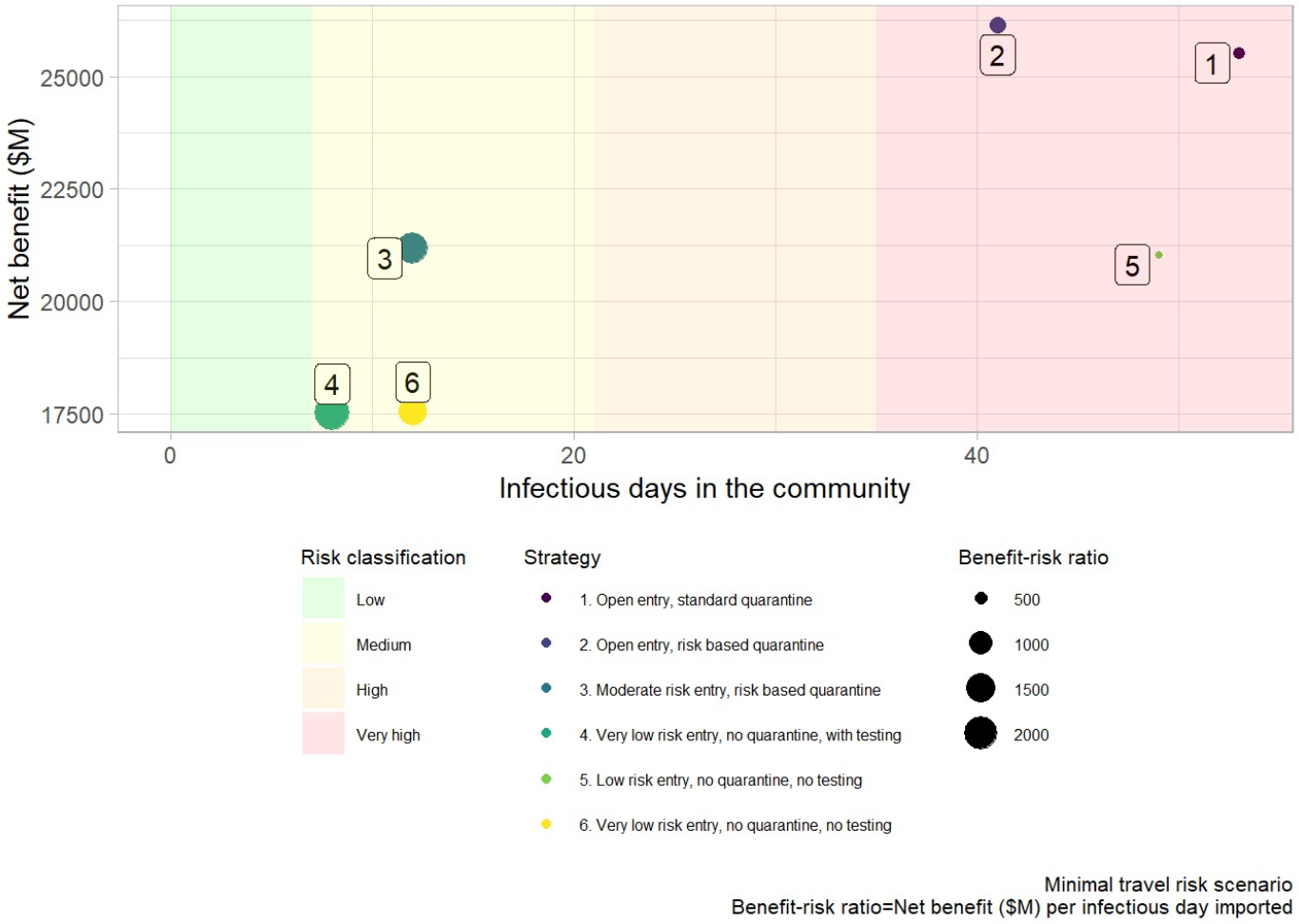


Minimal travel risk scenario
Benefit-risk ratio=Net benefit ($M) per infectious day imported

Risk classification system (b)

Strategy	Arrivals 000s	Costs Total $M	Costs PP $	Benefits Total $M	Benefits PP $	Net benefit $M	Infectious days (total) TR1	Infectious days (total) TR2	Infectious days (per 10 000 arrivals) TR1	Infectious days (per 10 000 arrivals) TR2
Open entry, standard quarantine	399	923	2315	26445	66350	25522	53	136	1.3	3.4
Open entry, risk based quarantine	399	299	750	26445	66350	26146	41	96	1.0	2.4
Moderate risk entry, risk based quarantine	321	118	368	21299	66350	21181	12	23	0.4	0.7
Very low risk entry, no quarantine, with testing	265	45	170	17559	66350	17514	8	13	0.3	0.5
Low risk entry, no quarantine, no testing	317	0	0	21029	66350	21029	49	63	1.5	2.0
Very low risk entry, no quarantine, no testing	265	0	0	17559	66350	17559	12	16	0.5	0.6

Note:
M=million, PP=per person, TR1=minimal travel risk assumption, TR2=substantial travel risk assumption, **Not applicable



Minimal travel risk scenario
Benefit-risk ratio=Net benefit ($M) per infectious day imported

RETURNING RESIDENTS

Risk classification system (a)

	Arrivals	Costs		Benefits		Net benefit	Infectious days (total)		Infectious days (per 10 000 arrivals)	
Strategy	000s	Total $M	PP $	Total $M	PP $	$M	TR1	TR2	TR1	TR2
Open entry, standard quarantine	29	106.7	3678	**	**	**	25.7	65.6	9	23
Open entry, risk based quarantine	29	97.8	3374	**	**	**	14.9	38.3	5	13
Moderate risk entry, risk based quarantine	5	7.2	1375	**	**	**	0.8	1.8	2	3
Very low risk entry, no quarantine, with testing	1	0.2	171	**	**	**	0.2	0.3	1	2
Low risk entry, no quarantine, no testing	3	0.0	0	**	**	**	1.4	1.8	5	7
Very low risk entry, no quarantine, no testing	1	0.0	0	**	**	**	0.2	0.3	1	2

Risk classification system (b)

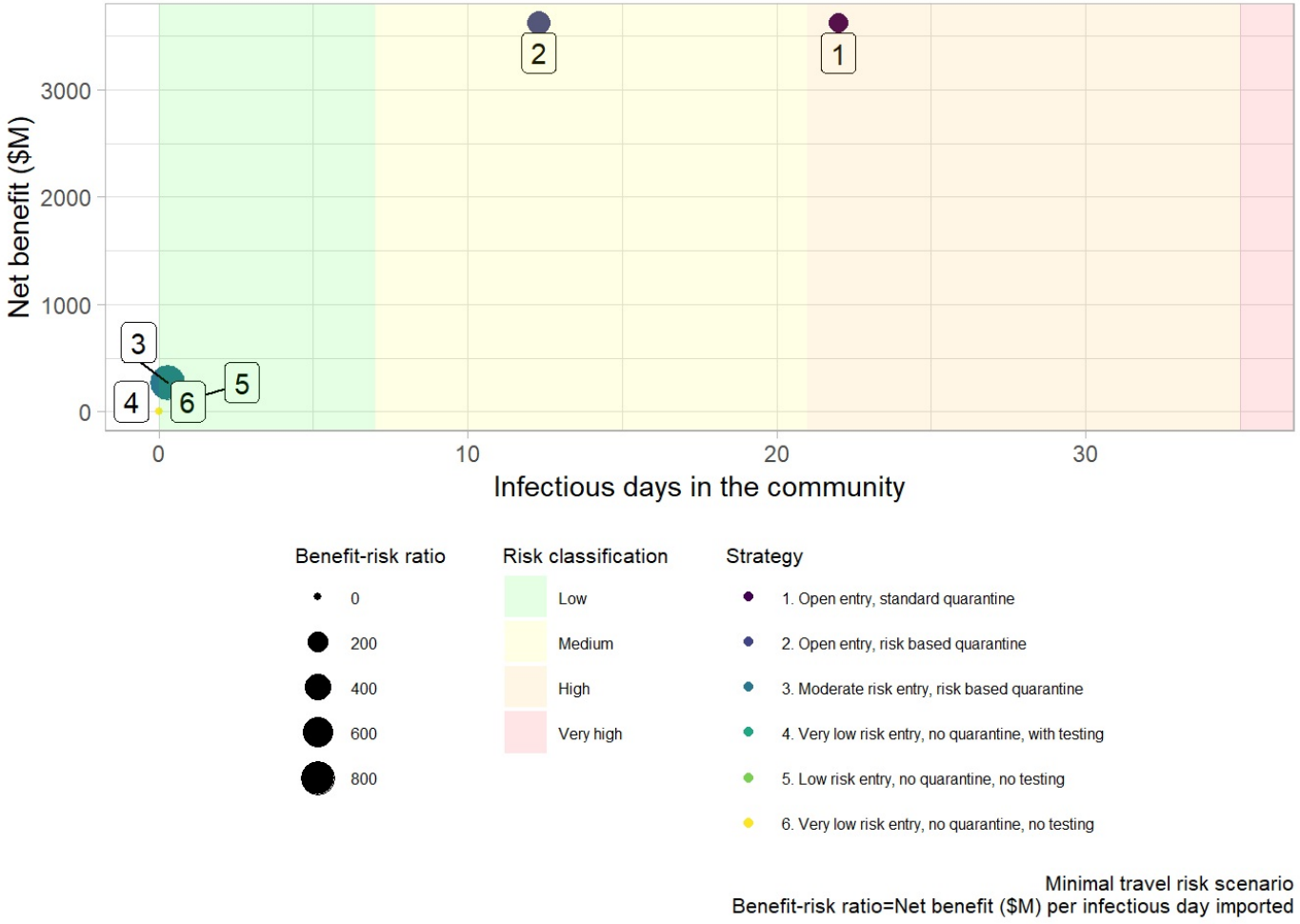
	Arrivals	Costs		Benefits		Net benefit	Infectious days (total)		Infectious days (per 10 000 arrivals)	
Strategy	000s	Total $M	PP $	Total $M	PP $	$M	TR1	TR2	TR1	TR2
Open entry, standard quarantine	29	105.8	3649	**	**	**	24.5	63	8	22
Open entry, risk based quarantine	29	89.6	3088	**	**	**	14.6	37	5	13
Moderate risk entry, risk based quarantine	8	7.1	924	**	**	**	1.1	2	1	3
Very low risk entry, no quarantine, with testing	4	0.7	171	**	**	**	0.7	1	2	3
Low risk entry, no quarantine, no testing	7	0.0	0	**	**	**	3.9	5	6	7
Very low risk entry, no quarantine, no testing	4	0.0	0	**	**	**	1.1	1	3	3

Note:
M=million, PP=per person, TR1=minimal travel risk assumption, TR2=substantial travel risk assumption, **Not applicable

SKILLED MIGRANTS

Risk classification system (a)

	Arrivals	Costs		Benefits		Net benefit	Infectious days (total)		Infectious days (per 10 000 arrivals)	
Strategy	000s	Total $M	PP $	Total $M	PP $	$M	TR1	TR2	TR1	TR2
Open entry, standard quarantine	28.4	118	4152	3735	131500	3617	22.0	56.1	8	20
Open entry, risk based quarantine	28.4	114	4025	3735	131500	3620	12.3	31.7	4	11
Moderate risk entry, risk based quarantine	2.0	5	2310	269	131500	264	0.3	0.8	1	4
Very low risk entry, no quarantine, with testing	0.0	0	**	0	131500	0	0.0	0.0	**	**
Low risk entry, no quarantine, no testing	0.9	0	0	123	131500	123	1.1	1.4	12	15
Very low risk entry, no quarantine, no testing	0.0	0	**	0	131500	0	0.0	0.0	**	**

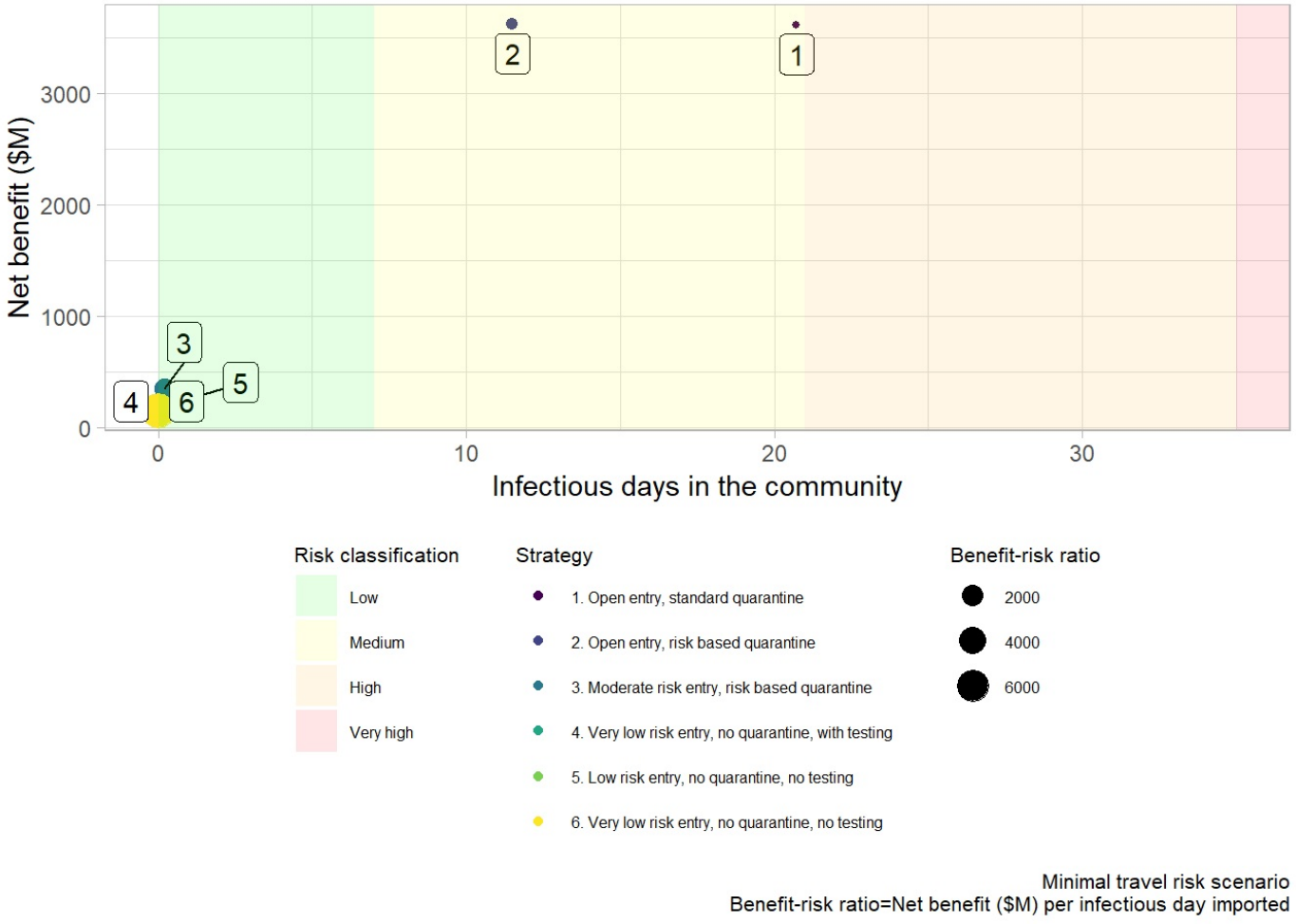


Minimal travel risk scenario
Benefit-risk ratio=Net benefit ($M) per infectious day imported

Risk classification system (b)

Strategy	Arrivals 000s	Costs Total $M	Costs PP $	Benefits Total $M	Benefits PP $	Net benefit $M	Infectious days (total) TR1	Infectious days (total) TR2	Infectious days (per 10 000 arrivals) TR1	Infectious days (per 10 000 arrivals) TR2
Open entry, standard quarantine	28	117.8	4147	3735	131500	3617	20.72	52.89	7.3	18.6
Open entry, risk based quarantine	28	110.5	3892	3735	131500	3624	11.50	29.56	4.0	10.4
Moderate risk entry, risk based quarantine	3	3.9	1421	359	131500	355	0.20	0.47	0.7	1.7
Very low risk entry, no quarantine, with testing	1	0.2	170	146	131500	146	0.02	0.02	0.2	0.2
Low risk entry, no quarantine, no testing	2	0.0	0	269	131500	269	1.14	1.48	5.6	7.2
Very low risk entry, no quarantine, no testing	1	0.0	0	146	131500	146	0.02	0.03	0.2	0.3

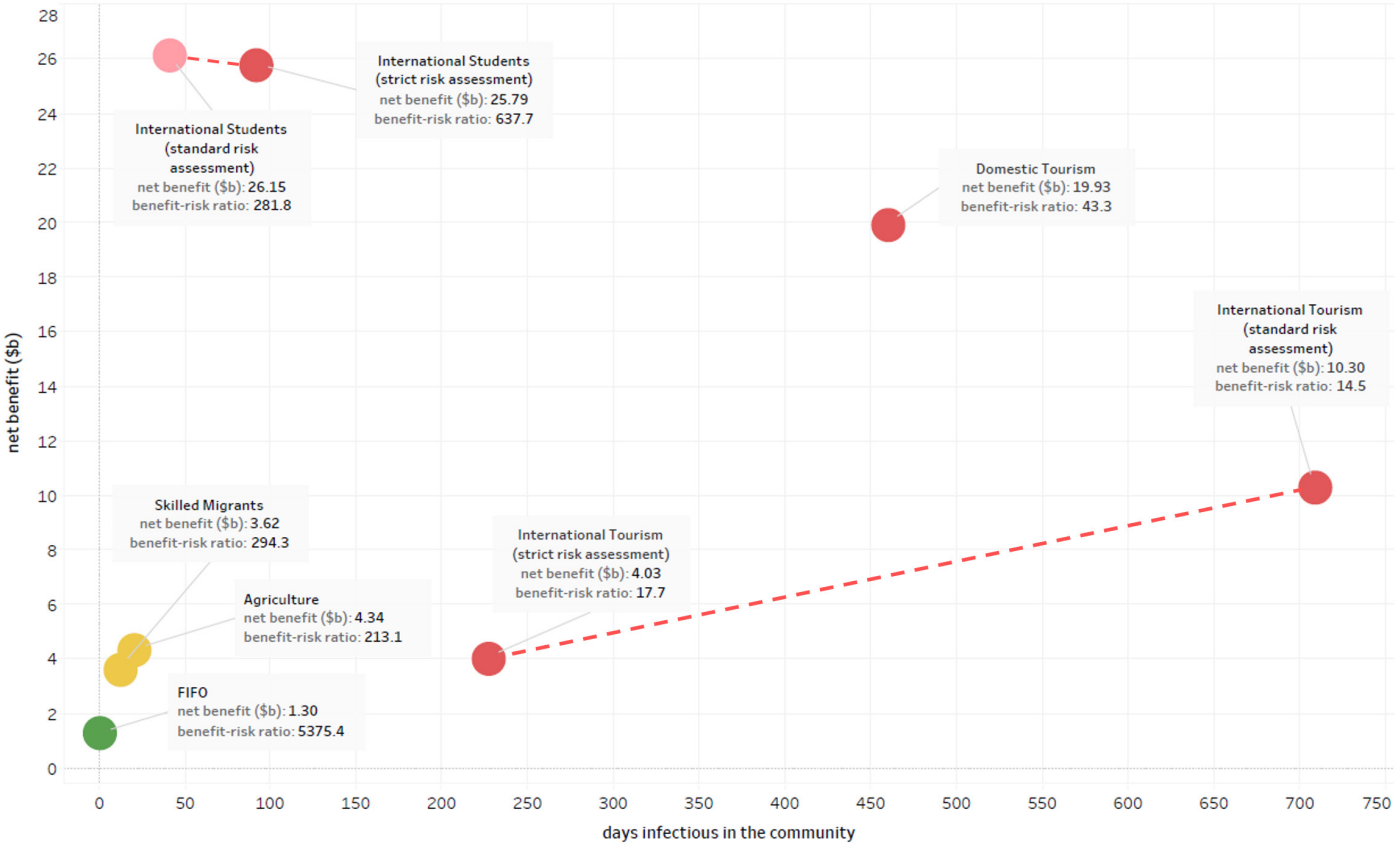
Note:
M=million, PP=per person, TR1=minimal travel risk assumption, TR2=substantial travel risk assumption, **Not applicable



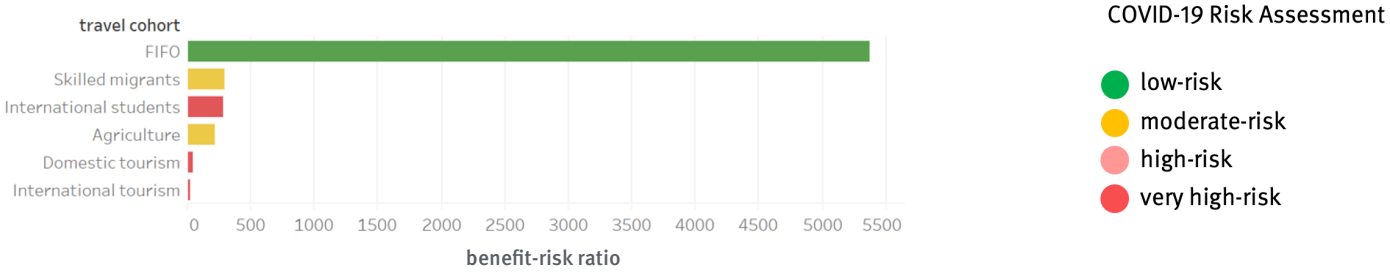
Minimal travel risk scenario
Benefit-risk ratio=Net benefit ($M) per infectious day imported

SUMMARY PLOT

Comparing risks and benefits from allowing entry to six cohorts



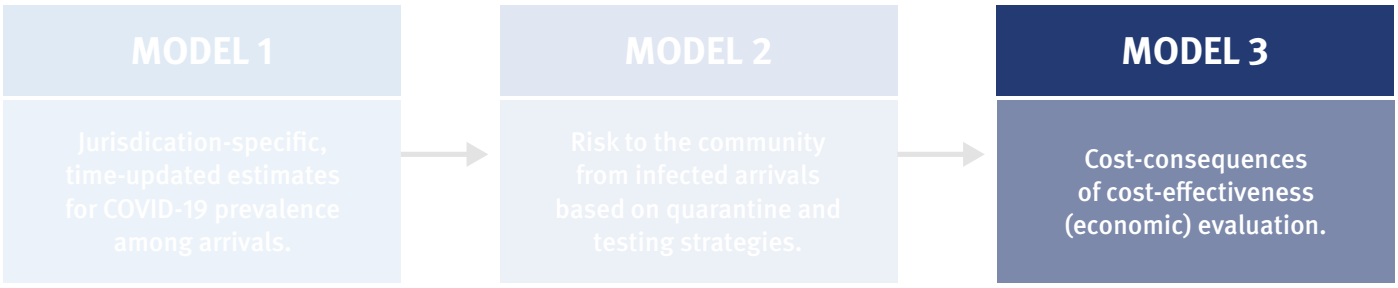
Benefit-risk ratio for travel cohorts



Explanatory Notes

- International student and international travel risks are calculated using two different sets of assumptions:
  - **Strict risk assessment:** includes higher data quality threshold to secure low- or very low-risk rating.
  - **Standard risk assessment:** based on estimates of prevalence alone.
- International tourism is limited to very low-risk jurisdictions (e.g. New Zealand) with pre-travel and on arrival testing.
- Domestic tourism assumes interstate travel with no testing between very low-risk states and territories.
- All other cohorts are subject to risk-based quarantine and testing.

CHAPTER 18
MODEL 3: COST-CONSEQUENCES OF COST-EFFECTIVENESS (ECONOMIC) MODEL DETAILED METHODS



Quarantine Cost Equation

The cost of quarantine c_q was calculated as:

$$c_q = t_q \times \left(\left(q_{setting} \times c_{hotel.age} \right) + \left(p_{employ} \times (1 - p_{home}) \times \frac{w_{age}}{7} \right) \right) + n_{test} \times c_{test}$$

Where:

- t_q is the parameter representing the number of days spent in quarantine.
- $q_{setting}$ is the parameter representing the quarantine setting. It takes the value of 0 for home quarantine and 1 for hotel quarantine.
- $c_{hotel.age}$ is an age-dependent variable representing the daily cost of hotel quarantine. The estimate is derived from advertised prices of hotel quarantine by the Queensland State Government (1). This estimate is taken from the flat rate of AUD$ 135 per day in addition to the following age-dependent daily cost for food:

Age	Daily Food Cost (AUD$)
18 years and over	$65
3 to 17 years	$32.50
0 to three years	$0

It was assumed that 50 per cent of adults would quarantine with another adult so that the average adult would pay 75 per cent of the room fee per day. Also assumed that no minor would quarantine without an accompanying guardian and so they do not accrue the cost of the room. This gives the following age-dependent daily cost for hotel quarantine:

Age	Daily Quarantine Cost (AUD$)
18 years and over	$166.25
3 to 17 years	$32.50
0 to three years	$0

- p_{employ} is a parameter representing the probability of an entrant being employed. The value that this parameter takes is dependent on the cohort being considered:
    - For returning residents, this takes the value of is taken from the participation rate less the unemployment rate in August 2020 as published by the Australian Bureau of Statistics (ABS) (2). This is 60.4% ($64.8 \times \frac{100 - 6.8}{100}$)
    - For tourists and international students, this parameter takes a value of 0
    - For local and international workers, this parameter takes a value of 1
- p_{home} is a constant representing the proportion of workers that can effectively work from home. It is estimated at 0.41 in Australia (3)
- w_{age} is an age-dependent variable of average weekly age in Australia, as calculated by the ABS (4). People at or over the retirement age of 65 years are assumed to earn no income from wages. It takes the following values:

Age range (years)	Average weekly earnings (AUD$)
0 - 17	$ 0
18 – 20	$ 383.7
21 – 45	$ 1 127.6
45 – 55	$ 1 503.7
55 – 64	$ 1 373.4
65 +	$ 0

- n_{test} is a parameter that takes the value of the number of coronavirus PCR tests that occur as part of the quarantine protocol
- c_{test} is the cost of each test. It is set at AUD$ 85 in line with the Medicare rebate for item number 69480 in Australia at the time of writing.

COVID-19 Case Cost Equation

The cost of a primary case of COVID-19 is given by the equation:

$$c_{primary} = p_{detect} \times (c_{GP} + p_{admit.age} \times (c_{admit.age} + p_{ICU.age} \times c_{ICU.age}))$$

Where:

- p_{detect} is a constant representing the proportion of coronavirus infections that are detected in Australia. This is estimated as 0.32 of all infections [London School of Hygiene and Tropical Medicine]
- c_{GP} is a constant representing the cost of a single telehealth appointment with a general practitioner. This is given the value AUD$ 45.55 in accordance with the item number 91809 as listed on the Australian Medicare Benefits Schedule at the time of writing
- $p_{admit.age}$ is an age- and sex-dependent variable representing the probability that a detected infection will require admission to hospital. This is calculated from publicly available epidemiological data for case and admission numbers in Australia as follows:
    - Case numbers by age-range were taken from the Australian Government Novel Coronavirus Health Alert on 5 October 2020 (5). The following value were employed in the calculation:

Age Range	Male Cases	Female Cases
0 – 9	717	634
10 – 19	1 172	1 127
20 – 29	2 929	3 208
30 – 39	2 366	2 312
40 – 49	1 714	1 706
50 – 59	1 540	1 658
60 – 69	1 142	1 168
70 – 79	829	732
80 – 89	487	773
90 +	231	553

For the purpose of further calculation, it is assumed that cases are attributed equally within each age group. For example, it is assumed that 20-year-old females accounted for 320.8 (3 208 / 10) cases, and 1-year-old males accounted for 143.4 (717 / 5) cases. The last interval was assumed to have a closed upper bound of 100 years in every case.

The sum of all cases is calculated as 26, 998.

- Data on cumulative hospitalisations by age-group were not available at the time of writing. According to the epidemiology reporting by the Australian Government Department of Health, the total rate of hospitalisations in Australia was estimated to be 13 per cent at the time of writing (6). This figure was combined with the above total case number to give an estimated total number of hospitalisations across all age groups of 3,509.74 at the time of writing.

- The number of cumulative hospitalisations by age-group was inferred through hospital surveillance statistics. The following data was taken from the report published for the period ending August 30, 2020 and represents a sample of data of COVID-19 admissions from selected hospital surveillance sites in Australia (6):

Age-group	Male Hospitalisation Numbers	Female Hospitalisation Numbers	Mean duration of hospitalisation
0 – 4	10	10	4.4
5 – 17	5	8	4.2
18 – 39	39	24	5.9
40 – 59	45	61	7.9
60 – 79	39	71	9.8
80 +	39	19	11.0

For each age and sex stratum, an incidence factor was calculated as the number of admissions from surveillance divided by the mean duration of admission. For example, the incidence factor for males aged 0 to 4 years old is 2.27 (10 / 4.4). An incidence fraction was then calculated for each age group as the incidence factor divided by the sum of all incidence factors. The incidence fraction was then multiplied by the estimated total number of hospitalisations to estimate the total number of hospitalisation attributable to each age and sex stratum.

- $C_{admit.age}$ represents an age-dependent variable for the cost of hospitalisation not including admission to ICU:
  - Cost was estimated using the data for the diagnosis related group (DRG) for *respiratory infection/inflammation* presented in the National Hospital Cost Data Collection report for the financial year of 2017/18 (7)
  - All costs were inflated to AUD$ 2020 using the general consumer price index (CPI) as presented by the ABS (8). June 2018 was taken as the baseline and costs were inflated by 1.1 per cent to reflect AUD$ 2020

DRG Code	Number of separations	Cost (AUD$2018)	Cost (AUD$2020)
RESPIR INFECTIN/INFLAMM, MAJC	39 794	9 224	9 325.46
RESPIR INFECTIN/INFLAMM, MINC	44 531	3 877	3 919.65

  - The reported number of separations for each of *respiratory infection/inflammation, minor complications* and *respiratory infection/inflammation, major complications* was used to estimate the percentage of COVID-19 hospital admissions that would attract the lower cost (52.8%) and the proportion that would attract the higher cost (47.2%)

- Duration of hospital stay was used as a proxy for severity of illness. The duration of stay for each age group was estimated to have a lognormal distribution with parameters drawn from hospital surveillance data (6):

Age-group	Mean duration	Lower quartile duration	Median duration	Upper quartile duration
0 – 4	4.4	0.5	2.0	6.5
5 – 17	4.2	0.5	4.0	6.5
18 – 39	5.9	1.0	4.0	8.0
40 – 59	7.9	2.0	4.0	10.0
60 – 79	9.8	4.0	7.0	13.0
80 +	11.0	7.0	11.0	13.0

The lognormal distribution for each age group was estimated with mu of log(median) and sigma of log((upper quartile – lower quartile) / 1.35 in line with the assumption of an underlying normal distribution of the log values. For the set of estimated hospital admissions for each age group, each admission was given a duration that was randomly sampled from the corresponding lognormal distribution. Admissions for all age groups were then pooled and attributed a cost based on duration, with the lower 52.8 per cent attracting the cost of *respiratory infection/inflammation, minor complications* and the upper 47.2 per cent attracting the cost of *respiratory infection/inflammation, major complications*. These admissions were then segmented back into the relevant age group. The estimated cost for each age group was then calculated as the mean estimated cost for each admission.

- $p_{ICU.age}$ is an age-dependent variable representing the proportion of cases that require an ICU admission. This was estimated analogously to $p_{admit.age}$ according to the following values:
  - The estimate for the total number of ICU admissions was estimated at 701.95. This was based on the estimated number of hospitalisations (3 509.74) together with the surveillance observation that 20 per cent of hospital admissions go on to be admitted to ICU (6)
  - This estimated number of ICU admissions was partitioned across age groups according to ICU admission statistics (6):

Age group	ICU Admissions	Mean duration (days)
0 – 4	1	52.0
5 – 17	3	10.3
18 – 39	38	9.5
40 – 59	114	15.7
60 – 79	137	17.3
80 +	5	12.6

  - $p_{ICU.age}$ was then calculated as the quotient of the estimated ICU admission numbers each age group over the sum of male and female case numbers for each age group

- $c_{ICU.age}$ is an age-dependent variable representing the cost for ICU admission. This was estimated analogously to $c_{admit.age}$ according to the following values:
    - Cost was estimated using the data for the diagnosis related group (DRG) for *ventilation >= 96 & < 336 hrs, intc* to represent ventilated patients and *septicaemia, majc* to represent non-ventilated patients (7)
    - All costs were inflated to AUD$ 2020 using the general consumer price index (CPI) as presented by the ABS (8). June 2018 was taken as the baseline and costs were inflated by 1.1 per cent to reflect AUD$ 2020

DRG Code	Number of separations	Cost (AUD$2018)	Cost (AUD$2020)
VENTILATION >= 96 & < 336 HRS, INTC	*	96 731	97 795.04
SEPTICAEMIA, MAJC	*	26 884	27 179.72

    - Rather than use the number of separations, the estimated proportion of ICU admissions that were ventilated was based on surveillance data that 40 per cent of those admitted to ICU in Australia are ventilated (9)
    - Duration of ICU stay was used as a proxy for severity of illness. The duration of stay for each age group was estimated to have a lognormal distribution with parameters drawn from ICU surveillance data (6):

Age-group	Mean duration	Lower quartile duration	Median duration	Upper quartile duration
0 – 4	52.0	52.0	52.0	52.0
5 – 17	10.3	1.0	5.0	25.0
18 – 39	9.5	5.0	6.0	11.0
40 – 59	15.7	8.0	11.0	20.0
60 – 79	17.3	10.0	23.9	33.0
80 +	12.6	11.0	13.0	15.0

    - Mean cost for admission per age group was then calculated as for $c_{admit.age}$, with the longest 40 per cent of admissions attracting the cost of the *ventilation* DRG and the remainder attracting the *septicaemia* DRG

Cohort Benefit Calculations

The economic benefit for each scenario is estimated for each arrival that is permitted into an Australian jurisdiction from another jurisdiction, be that interstate or overseas. Estimates are drawn from a range of data sources and aim to represent the direct contribution to GDP per arrival. Where a quarantine scenario relates to a particular industry, benefits are calculated in relation to that industry. Unless explicitly stated, downstream economic benefits are not considered.

Seasonal Farm Labour

A significant proportion of Australian agricultural labour is provided by foreign workers on temporary contracts. The agricultural sectors that rely most heavily on visa holders include:

- Vegetables (approximately 40.8% of workforce)
- Fruit and nuts (approximately 33.7% of workforce)
- Cotton (approximately 16.7% of workforce) (10).

It was assumed that blanket travel restrictions would exacerbate labour shortages for these key industries. For simplicity, it was also assumed that labour shortages would have a proportionate impact on gross value by sector. The gross value of each sector was drawn from ABS estimates from the 2018-19 financial year (11). As such, the value of seasonal labour for each sector was estimated:

- Fruit and nuts: approximately AUD$2.04 b (40.8% of $ 5 b total)
- Vegetables: approximately AUD$1.39 b (33.7% of $ 4 b total)
- Cotton: approximately AUD$0.167 b (16.7% of $ 1 b total)

This creates a total of approximately AUD$3.6 b of gross value that is dependent on seasonal labour in agriculture.

There were an estimated 44,121 seasonal labour roles in agriculture in the 2018-19 financial year (10):

- 31,000 backpackers
- 12,200 seasonal workers
- 912 workers on temporary skilled visas

The entry of each seasonal labourer was given an estimated lower-bound value of AUD$81.6 k.

The above estimate is based on the assumption that existing visa requirements will remain in place. For example, overseas visitors on Working Holiday Maker Visas subclass 417 and 462 are only required to work in regional Australia for 88 days to gain a 12-month extension on their visa. If the COVID-19 pandemic exerts an ongoing major disruption on international travel and exacerbates a baseline labour shortage in the Australian agricultural sector, it is likely that government policy and market forces will combine to increase the duration of employment of each individual seasonal worker. As such, the GPD contribution of each seasonal worker that passes through quarantine was given an estimated upper-bound of AUD$122.4 k, which is 50 per cent higher than the above baseline estimate.

Interstate FIFO Workers in the Mining Industry

Interstate workers were assumed to constitute 10 per cent of the mining workforce and were assumed to represent a skillset which could not be otherwise drawn from within the state. Mining was taken to represent 10 per cent of Australian GDP (12). Total Australian GDP was taken to be AUD$1.88 t for the 2019-20 financial year (13). Assuming that interstate mining workers made a proportional contribution to the total GDP of the mining sector, these workers were estimated to contribute AUD$18.8 b annually.

Total numbers of out-of-state mining workers was estimated to be 76 360. This was based on the most recently available estimates of 60 000 in Western Australia and 16 360 in Queensland (14) (15). From these figures, a top-down annual benefit for each interstate mining employee is estimate at AUD$246.2 k per year. Assuming six FIFO trips per year per worker, this figure was then divided by six to obtain to the benefit per quarantine.

A lower-bound estimate for annual benefit per worker was based on the current average wage in the mining industry of AUD$ 140.2 k (16).

Tourism

The total GDP contribution of tourism in Australia was taken to be AUD$60.8 b from the 2018-19 financial year (17). Twenty five per cent of this figure (AUD$ 15.2 b) was estimated to derive from international tourism based on historical data (18). The remaining 75 per cent (AUD$ 45.6 b) was attributed to domestic tourism, with 56 per cent of this figure (AUD$ 25.5 b) attributed to interstate tourism in line with the proportion of domestic tourism revenue attributed to interstate travel pre COVID-19 (17). The below table demonstrates the lower- and upper-bound estimates per entrant for both interstate and international tourists, based on per capita GDP contribution and per-capita gross expenditure respectively.

Category	Interstate	International
Annual Number of Trips	36.0 m	8.7 m (19)
Total Expenditure	*	$ 45.4 b (19)
Total GDP Contribution	$ 25.5 b	$ 15.2 b
Per-capita Expenditure	$ 1 173	$ 5 218
Per- capita GDP Contribution	$ 708.2	$ 1 747

International Students

There were 398 563 overseas enrolments in higher education in Australia in 2018 (20).

In 2017-18, international students contributed AUD$ 22.2 b to education export revenue. Assuming that education spending approximates value added, the baseline direct contribution to GDP is estimated to be approximately AUD$ 55.7 k per student per year. This will also be the cost per quarantine if it assumed that each student returns to their home country once per year.

International students also contribute to the Australian economy through household consumption. The Australian government estimates annual expenditure of AUD$ 21 041 per student (21). This figure is used to calculate the upper-bound of GDP contribution per student as AUD$ 76.7 k.

Skilled Migrants

Baseline economic benefit per entrant was estimated based on the average wage of skilled migrants in Australia during the 2019-20 financial year (AUD$ 105 k) (22). This annualised benefit assumes that each worker returns to their home country once per year.

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