Know-C19

A policy, health and implementation response to COVID-19

COVID-19 Mathematical Modelling of resurgence risk: | 26 Sept 2020

Estimating risks associated with early reopening in Victoria

Following the introduction of Stage 4 restrictions in Melbourne, daily new detected cases of COVID-19 have been declining. Accordingly, a roadmap detailing possible sequences of policy relaxations has been proposed to return to a "COVID normal", together with criteria for triggering each step. Due to the high social and economic impact of the restrictions currently in place, it is important that restrictions are relaxed as quickly as possible. However, relaxing too quickly increases the risk of a resurgence in infections, which may then require a reintroduction of restrictions to contain.

The Burnet Institute and the Institute for Disease Modelling in the USA have developed an individual-based COVID-19 model (*Covasim*), which we have previously used to assess the impact and risk associated with relaxing various physical distancing policies in Victoria at the end of the first wave. A key finding of that work was that relaxing restrictions too quickly could lead a considerable resurgence of COVID-19 in the community if there was failure to detect early clusters of infection.

In this study, we use *Covasim* to estimate the risk of Victoria experiencing a third COVID-19 epidemic wave if Stage 4 restrictions were eased on the 14th September 2020 or two weeks later on the 28th September. In both scenarios, restrictions were eased to a level of restrictions similar to Victoria in early June (pre-Stage 3), approximately the "final step" in the Victorian government roadmap or NSW in September. Specifically we modelled:

- Schools, childcare and workplaces reopen
- Cafes, restaurants, pubs, bars, entertainment venues, and places of worship all open with a 4sqm distancing rule
- Community sport and small social gatherings are allowed
- Test results take 24 hours to become available
- Contact tracing takes an additional 24 hours following test results, and includes use of the COVIDSafe app
- The number of tests per day is increased to maximum capacity observed in June upon easing
- Large events are banned and mandatory masks are maintained

While there are a wide range of options for incremental relaxation, in this study we sought to specifically examine the impact of timing, to examine the relationship between the degree of containment prior to relaxation and resurgence risk.

Key findings and recommendations

1) **Relaxing to the 'final step' on the 14th September would have posed an extremely high risk of epidemic resurgence**
   In 86% of the simulations where restrictions were eased on the 14th September, cases rose to over 100 new diagnoses per day within 4 weeks.
2) **Relaxing to the 'final step' on the 28th September has a high, but reduced risk of epidemic resurgence**
   In 41% of the simulations where restrictions were eased on the 28th September, cases rose to over 100 new diagnoses per day within 4 weeks.
3) **The use of epidemiological markers in the relaxation roadmap can considerably reduce risk**
   A major predictor of outbreak trajectory was the number of cases per day at the time of relaxation. For restrictions easing on the 28th September, among the simulations where the 14-day average daily diagnoses had reached <30 or <10 by this date, only 34% or 17% resulted in a resurgence within 4 weeks, respectively.
4) **Further work is required to assess the risks associated with a staged easing of restrictions**
   The scope of this analysis was to assess the feasibility of an early reopening of the Victorian economy, by simulating an immediate transition to the 'final step' of restrictions. In this study we did not model any intermediate relaxation steps, in particular those that are part of the Victorian roadmap, which may have lower risk and should be explored.

Authors: Romesh Abeysuriya, Dominic Delport, Margaret Hellard, Nick Scott

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For further information please contact:
Professor Margaret Hellard, Deputy Director, Burnet Institute. email: margaret.hellard@burnet.edu.au
Dr Romesh Abeysuriya, Senior Research Officer, Burnet Institute. email: romesh.abeysuriya@burnet.edu.au
Dr Nick Scott, Head, Modelling Working Group, Burnet Institute. email: nick.scott@burnet.edu.au

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Aim

This study aimed to estimate the risk of Victoria experiencing a third COVID-19 epidemic wave if Stage 4 restrictions were eased on the 14th September 2020, or two weeks later on the 28th September, **to assess the feasibility of an immediate return to a level of restrictions similar to NSW**.

Method

Model overview

We used an established agent-based microsimulation model, *Covasim* [1], developed by the Institute for Disease Modelling (USA) and previously adapted by the Burnet Institute to model the Victorian epidemic [2]. The model is available online [3] and reports are also available outlining its application to a number of other settings [4]. In brief, agents in the model are assigned an age (which affects their disease prognosis), a household, a school (for people age 5-18) or a workplace (for people aged 18-65), and participate in a number of daily community activities including attending restaurants, pubs, places of worship, community sport, and small social gatherings. Details of included contact types, network structures, transmission probabilities, and contact tracing capability (which vary by setting) are provided in the appendix at the end of this report.

Interventions

The model includes testing, contact tracing and quarantine of close contacts, isolation of confirmed cases, masks, physical distancing policies in venues (e.g. the 4 square metre rule), and policy restrictions to prevent or reduce transmission in different settings (e.g. closing schools or venues).

Calibration

The model was calibrated to data on daily new detected cases and hospitalisations from the COVID-19 outbreak in Victoria over the June-September period [5], and the associated policy changes and interventions that were implemented over that period (Table 1). Calibration and parameters associated with policy changes are provided in the appendix.

	Pre-stage 3 21 June (start of model)	Stage 3 Phased in from 2 July	Mandatory masks 23 July	Stage 4 5 August	Model scenarios Easing of restrictions on different dates
Schools	Open	Restrictions		Closed	Open
Workplaces	COVIDSafe plans	Restrictions		Heavier restrictions	COVIDSafe plans
Socialising	Limits on gathering sizes	No home visits		Curfew and outdoor limits	Limits on gathering sizes
Community sport	Going	Cancelled			Going
Pubs and bars	4 sq m rule	Closed			4 sq m rule
Cafes and restaurants	4 sq m rule	Take-away only			4 sq m rule
Places of worship	4 sq m rule	Closed			4 sq m rule
Childcare	Open			Closed	Open
Public parks	Open			Playgrounds closed	Open
Public transport	Demand reduced indirectly				🟩
Large events	Banned				🟥
Entertainment venues	Closed				🟥
Masks	No masks		Mandatory		🟨

Table 1: Policy changes included in the model simulations.

Scenarios

Two scenarios were run, one in which Stage 4 restrictions were eased on the 14th September, and another in which easing is delayed until 28th September. **For both scenarios, restrictions were directly eased to the same extent, corresponding to a similar policy setting as Victoria before Stage 3 restrictions were imposed in July or NSW as of 14th September 2020**, as shown in Table 1. Specifically, we modelled that when restrictions eased:

- Schools and childcare would open
- Return to work but maintain working from home where possible
- Outdoor gatherings of up to 200 people would be allowed
- Community sport and small social gatherings would be allowed
- Cafes, restaurants, pubs, bars, entertainment venues, and places of worship would open with a 4sqm distancing rule
- Mandatory mask policy would be maintained
- Large events would still not be permitted

Testing and contact tracing

From September onwards, testing and contact tracing in Victoria was assumed to be improved compared to at the start of the second wave. For all scenarios, from 14th September we assumed that any contacts who were identifiable would be notified exactly 24 hours after the test result was notified (based on estimated average performance; see the supplement for further details, and Table S1 for the percentage who are notifiable by transmission setting). We also assumed that the COVIDSafe app would be used for tracing, and that it had a coverage of 25%, based on approximately 6 million downloads nationally (although we note that this is an optimistic estimate since not all of these downloads represent unique users that currently have the app installed). For testing, we made the approximation that when restrictions eased the number of tests per day would increase to the maximum value observed throughout the June-September period. This was because although test numbers have dropped from this peak, we assumed that they would likely increase again if resurgence was observed (rather than remain at their current levels), and there is a reasonable chance that some form of occupational asymptomatic testing may be introduced in the near future. We also assumed that positive test results would be notified after exactly 24 hours [6].

Outcome measure

The model is stochastic, meaning that whether a resurgence occurs depends on randomly sampled factors such as whether any given interaction results in transmission or not, which differ each time the model is run. Therefore, we ran the model 2000 times and investigated the likelihood that a resurgence would occur. For this purpose, a resurgence was defined as reaching >100 new diagnoses per day. In most cases where resurgence occur, with the relaxed restrictions the outbreak grows rapidly. However, we note that in such cases it is likely that restrictions would be reimposed, so the projections for outbreak size in those cases would likely not be realized.

We also consider outcomes four-weeks after the easing of restrictions and not long-term predictions. This is because our calibration significantly constrains the model; we fit the model transmission parameters with the assumption that the observed second wave was the most likely outcome, which occurs in all simulations. In reality the second wave could have been an unlikely / unlucky outcome (or a lucky outcome compared to others), and we have not incorporated the probability of it occurring into our calibration. Therefore, our analysis is focussed on the risk of an immediate return to restrictions becoming necessary as a result of undiagnosed cases in the community effectively 'resuming' the second wave straight away (i.e. re-opening too early), rather than assessing how to sustain epidemic control over a longer period, which would additionally require an assessment of the dynamics and uncertainty of a new wave starting.

Results

Of the simulations where restrictions were eased on 14th September, 86% of the time cases rose to over 100 new diagnoses per day within 4 weeks (Figure 1). However, delaying by two weeks and easing restrictions on 28th September reduced the proportion of simulations resulting in outbreaks to 41%. **The high rate of resurgence in the model suggests that even with optimistic improvements to contact tracing and testing, it is likely that there were still too many active cases in the community on 14th September to be able to reopen without considerable risk of needing restrictions to be reintroduced.**

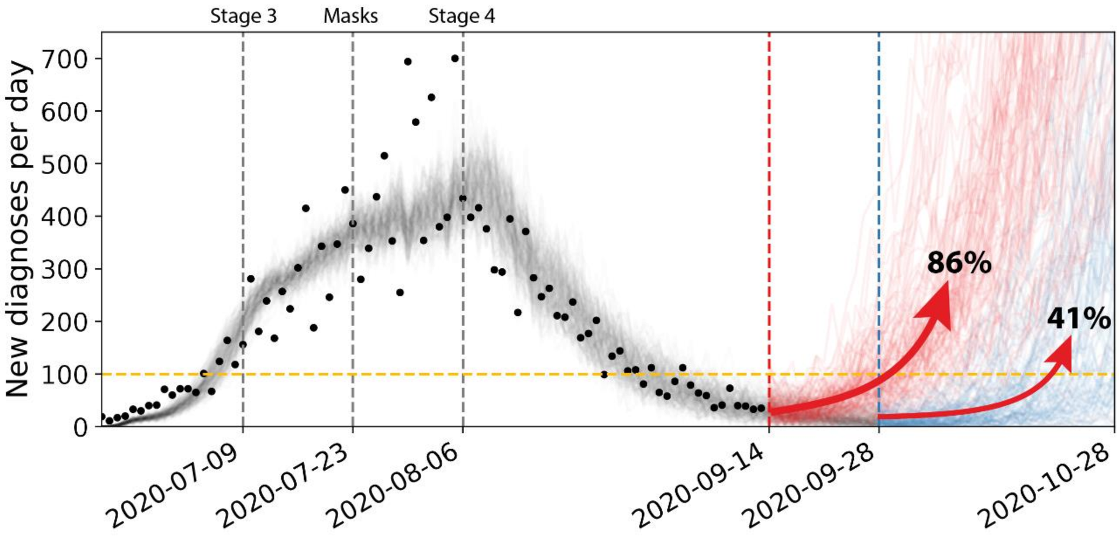


Figure 1: Model projections for daily new detected cases. Dashed vertical lines show dates of policy changes (Stage 3, mandatory masks, Stage 4, and easing dates); black dots show the data; grey lines show model projections throughout the calibration period; coloured lines show continued model projections for restrictions being eased on the 14th September (red), or delayed by two weeks (blue); 2000 simulations were run for each scenario, 100 of which are displayed here. The yellow dashed line shows the 100 new diagnoses per day threshold that was used to determine the risk of resurgence.

Although 41% of the simulations with a delayed relaxation date still showed a resurgence within 4 weeks, we note that compared to the scope of this analysis, the actual roadmap for reopening differs from the scenarios in Figure 1 in two key ways:

- We have assessed the feasibility of an immediate opening of the Victorian economy on 28th September, whereas the roadmap eases restrictions much more gradually.
- We have modelled the restrictions being eased on 28th September regardless of epidemiological indicators, whereas the roadmap incorporates case-based triggers, so that planned relaxations will only occur if the number of new cases each day is below a threshold.

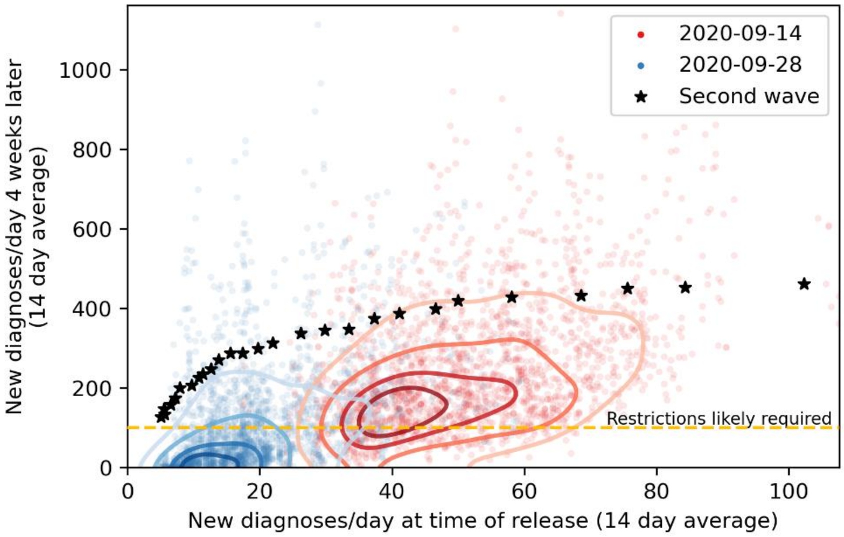
While assessing a gradual easing of restrictions was outside the scope of this work, to investigate the effect of adding a case-based trigger to the scenarios we ran a sub-analysis to assess the relationship between epidemic levels when restrictions were eased and the risk of resurgence. In our model, most of the simulation runs that led to a resurgence also had a relatively high number of cases on the easing date compared to the simulations that did not. We therefore examined the subset of simulations that had reached a 14-day average daily diagnoses on the release date of (a) less than 30, or (b) less than 10, and among these simulations examined the proportion that had a third epidemic wave. As shown in Table 2, the proportion of simulations exhibiting an outbreak was considerably lower when there were fewer cases per day being diagnosed at the time of easing. **These results emphasize the importance of the epidemiological trigger points in the Victorian roadmap for reopening – delaying relaxation of restrictions if case counts are higher than expected is likely to considerably reduce the risk of resurgence.** We note that these values are relatively noisy estimates because they are computed from only the subset of runs that met the trigger point – for example, on 28th September only around 300 runs had less than 10 cases per day.

	Percentage with resurgence	Percentage with resurgence if <30 cases/day at release	Percentage with resurgence if <10 cases/day at release
14th September	86%	64%	No simulations achieved this outcome
28th September	41%	34%	17%

Table 2: Proportion of simulations resulting in resurgence, with and without an additional requirement that the 14-day average diagnosed cases is less than 30 or less than 10 on the scheduled easing date.

To further examine the relationship between the number of cases at the date of relaxation and epidemic trajectory, for each simulation we compared the 14-day average new cases per day on the release date to the 14-day average new cases per day four weeks later, as shown in Figure 2.

Figure 2: Relationship between 14-day average daily diagnoses at the time restrictions are eased and the projected 14-day average after four weeks. Each coloured dot represents a single model simulation, for restrictions being eased on the 14th September (red), or delayed by two weeks (blue). Black stars represent what was actually observed at the start of the second epidemic wave. The contours reflect the density of the dots, to more clearly contrast the distributions of outcomes for the two scenarios.



The rate of new cases at the time of release is significantly correlated with the size of the epidemic 4 weeks later, again highlighting the importance of case-based triggers for easing restrictions. Importantly, we can compare the growth rate of projected resurgence in the model with the actual growth of the second wave. The black stars in Figure 2 show the actual diagnosed cases per day (averaged over the previous 14 days) in the second wave, starting from 14th June. Although many outbreaks in the model reach hundreds of new diagnoses per day within two weeks, the growth rates projected in the model are typically lower than were actually experienced in the second wave. Even though the restrictions in our projections are more relaxed than the Stage 3+ restrictions throughout most of the second wave, the improvements in testing and contact tracing being modelled appear to compensate for some of this additional risk. Further work is required to explore this.

Conclusions and recommendations

Overall, our results suggest that Victoria would not have been able to safely return to NSW-level restrictions on 14th September, and there would be a high risk associated with lifting all restrictions at once on the 28th September.

1) **Relaxing to the 'final step' on the 14th September would have posed an extremely high risk of epidemic resurgence**
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3) **The use of epidemiological markers in the relaxation roadmap can considerably reduce risk**.
   A major predictor of outbreak trajectory was the number of cases per day at the time of relaxation. For restrictions easing on the 28th September, among the simulations where the 14-day average daily diagnoses had reached <30 or <10 by this date, only 34% or 17% resulted in a resurgence within 4 weeks, respectively.
4) **Further work is required to assess the risks associated with a staged easing of restrictions.**
   The scope of this analysis was to assess the feasibility of an early reopening of the Victorian economy, by simulating an immediate transition to the 'final step' of restrictions. In particular, we did not model the intermediate relaxation steps that are part of the Victorian roadmap in this study, which may have lower risk.

Limitations

The findings presented are derived from an individual-based model, which is an imperfect representation of the real world.

- Model parameters are based on best-available data at the time of writing. However, studies are underway to obtain improved data to inform these parameters, including estimates of social mixing, contact networks, adherence to policies and quarantine advice, and disease characteristics (e.g. asymptomatic cases). Model projections should be updated as new epidemiological data and parameter estimates become available.
- It is not clear how testing and contact tracing will change in the future. For these projections, we have optimistically assumed that testing will increase and that contact tracing will occur in all settings exactly 24 hours after test results.
- We have calibrated the model to the second wave based on unvalidated assumptions about testing and contact tracing from the June-August period. For future projections, these parameters are based on publicly available information about Victoria's current testing and contact tracing performance. However, the likelihood of a resurgence will be impacted by the degree to which testing and contact tracing has been improved over time, which is unclear.
- Throughout this study we have reported the proportion of simulations in which resurgence occurred given the calibrated input parameters, as an approximation of the probability of resurgence given the input parameters we used. To estimate the overall probability requires sampling over input parameters based on their likelihood, which would require additional data and is computationally prohibitive.
- In this study, we used the number of tests as an input, and calibrated the proportion of those tests that would go to COVID-19 positive symptomatic people each day (i.e. positivity rate in the model), rather than explicitly setting the probability of an individual being tested based on their symptomatic status. In future work the model may be reparametrized to use the probability of being tested as an input, with the number of tests being an output.
- This model currently only attributes basic properties to individuals, specifically age, household structure and participation in different contact networks. The model does not account for any other demographic and health characteristics such as socioeconomic status, comorbidities (e.g. non-communicable diseases) and risk factors (e.g. smoking) and so cannot account for differences in transmission risks, testing, quarantine adherence or disease outcomes for different population subgroups.
- The model also does not include a geospatial component and so cannot capture geographic clustering of infections or concentration of interventions.
- We have assumed that there are no policy responses or significant behavioural changes in response to an emerging outbreak. As cases start to rise, if people voluntarily avoid interactions, or if there are campaigns to recommend actions without them being mandatory, the trajectory of the outbreak would be different.

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Appendix: Additional methodological details

The agent-based model *Covasim* models the spread of COVID-19 by simulating a collection of agents representing people. Each agent in the model is characterised by a set of demographic and disease properties:

- Demographics:
    - Age (one-year brackets)
    - Household size, and uniquely identified household members
    - Uniquely identified school contacts (for people aged 5-18)
    - Uniquely identified work contacts (for people aged 18-65)
    - Average number of daily community contacts (multiple settings / contact networks modelled, described below)
- Disease properties:
    - Infection status (susceptible, exposed, recovered or dead)
    - Whether they are infectious (no, yes)
    - Whether they are symptomatic (no, mild, severe, critical; with probability of being symptomatic increasing with age, and the probability of symptoms being more severe increasing with age)
    - Diagnostic status (untested vs tested)

Transmission is modelled to occur when a susceptible individual is in contact with an infectious individual through one of their contact networks. The probability of transmission per contact is calibrated to match the epidemic dynamics observed and is weighted according to whether the infectious individual has symptoms, and the type of contact (e.g. household contacts are more likely to result in transmission than community contacts). Transmission dynamics depend on the structure of these contact networks, which are randomly generated but statistically resemble the specific setting being modelled. The layers included are described below, and the model parameters values are provided for each layer that was included.

Household contact network: household size and age structure

The household contact network was set up by explicitly modelling households. The households size distribution for Australia [5]was scaled to the number required for the number of agents in the simulation. Each person in the model was uniquely allocated to a household. To assign ages, a single person was selected from each household as an index, whose age was randomly sampled from a subset of the Victorian adult population (which consisted of all adults 22 years and older, as well as a percentage of 18-21 year olds - 20%, 40%, 60%, and 80% of people aged 18, 19, 20 and 21, respectively - to ensure that at least one adult was in each household). The age of additional household members were then assigned according to Australian age-specific household contact estimates from Prem et al. [7], by drawing the age of the remaining members from a probability distribution based on the row corresponding to the age of the index member.

School and work contact networks

The school contact network was set up by explicitly modelling classrooms. Classroom sizes were drawn randomly from a Poisson distribution with mean 21 [8]. People in the model aged 5-18 years were assigned to classrooms with people their same age. Each classroom had one randomly selected adult (>21 years) assigned to it as a teacher. The result was that the school contact network was approximated as a collection of disjoint, completely connected clusters (i.e. classrooms).

Similarly, a work contact network was created as a collection of disjoint, completely connected clusters of people aged 18-65. The mean size of each cluster was equal to the estimated average number of daily work contacts.

Some workplaces are associated with a higher risk of infection, including healthcare settings, meat processing facilities, construction, warehousing and distribution, and are classified by the Department of Health and Human Services as high risk [9]. In the model, we classified 15% of workplaces as high risk, based on labour force data from the Australian Bureau of Statistics [10]. High risk workplaces were assigned a higher transmission probability, are less likely to be closed by restrictions (as many of these workplaces correspond to essential services), but also had faster contact tracing over the duration of the second wave.

Additional contact networks

An arbitrary number of additional networks can be added, but for this analysis we considered those most likely to be subject to policy change. Each network layer required inputs for: the proportion of the population who undertake these activities; the average number of contacts per day associated with these activities; the risk of transmission relative to a household contact (scaled to account for (in)frequency of some activities such as pubs/bars once per week); relevant age range; type of network structure (random, cluster [as per schools/workplaces]); and effectiveness of quarantine and contact tracing interventions.

Parameter values for each contact network

Table S1 shows the parameters that define each contact network in the model. Unless otherwise noted, parameters are derived in [2] from a mix of published and grey literature and a Delphi parameter estimation process. The columns of Table S1 refer to:

- **Mean contacts:** The average number of contacts per person in each network. Each person in the model has their individual number of contacts draw at random from a Poisson distribution with these values as the mean. For the social network layer, a negative binomial distribution was used with dispersion parameter 2 to account for a longer tail to the distribution.
- **Transmission probability:** The transmission probability per contact is expressed relative to household contacts, and reflects the risk of transmission depending on behaviour. For example, a casual contact in a public park is less likely to result in a transmission event compared to a contact on public transport.
- **Quarantine effect:** If a person is quarantined, the transmission probability is reduced by this factor. For example, an individual on quarantine at home would likely not work or use public transport, but they may still maintain their household contacts.
- **Population proportion:** Each network will only include a subset of the population e.g. every person has a household, but not every person regularly uses public transport.
- **Lower age/upper age:** Each network will only include agents whose age is within this range.
- **Clustered:** Here, we refer to a clustered network as one that consists of small groups people who are all connected to each other (e.g. classrooms), and where contacts do not change over time. This is compared to non-clustered networks, where contacts are randomly allocated. Non-clustered networks can either remain constant over time (e.g. social network) or have new contacts sampled each day (e.g. public transport).
- **Contact tracing probability –** the probability that each contact can be notified in order to quarantine

Table S1: Parameters for each of the networks in the model.

Layer	Mean contacts	Transmission probability	Quarantine effect	Population proportion	Lower age	Upper age	Clustered	^Contact tracing probability
Household	4	1	1	1	0	110	Y	1.00
Aged care	12	0.600	0.2	0.07	65	110	Y	0.95
Schools	21	0.247	0.01	1	5	18	Y	0.95
Low risk work	5	0.282	0.1	1	18	65	Y	0.80
High risk work	5	0.847	0.1	1	18	65	Y	0.80
Church	20	0.043	0.01	0.11	0	110	Y	0.50
Community sport	30	0.071	0	0.34	4	30	Y	0.25[#]
Childcare	20	0.274	0.01	0.545	1	6	Y	0.95
Community	1	0.100	0.2	1	0	110	N	0.05
Social	6	0.124	0.5	1	15	110	N	0.50
Entertainment	25	0.008	0	0.3	15	110	N	0.25[#]
Cafes/Restaurants	19	0.043	0	0.6	18	110	N	0.25[#]
Pub/bar	30	0.057	0	0.4	18	110	N	0.25[#]
Transport	25	0.164	0.01	0.114	15	110	N	0.01
Public parks	10	0.028	0	0.6	0	110	N	0.01
Large events	50	0.007	0	0.2	0	110	N	0.10

^ Values are estimated or assumed by the authors. They do not represent data from, or the views of, the Victorian Department of Health and Human Services.

[#] Assumed to increase to 50% after 14th September, with QR scanning systems etc.

Testing and contact tracing

From 27th August onwards the Australian government has reported for each state the percentage of cases notifications within 24 hours of the test, and the percentage of close contacts notified within 48 hours of the positive test result [6]. Recent estimates (17th September) suggest that in Victoria 100% of cases are notified in 24 hours of testing, and 99% of close contacts were notified within 48 hours of the positive test. In reality, the notification time and contact tracing time will be distributions (with these estimates suggesting that 24 hours and 48 hours are the tail ends, respectively), however the model is parametised so that all tests and contact traces are completed at exactly the same time, and so single values are estimated as inputs.

To simulate Victoria's testing and contact tracing performance, we assumed some improvements over time, such that there were different inputs for the calibration period (June-14th September) and projection period (post-14th September). For the calibration period we assumed that test results took two days to be processed and the percentage of contacts traced were based on previous assumptions / unvalidated estimates [2], and for all forward projections, we assumed that all tests take exactly 24 hours and all contacts take exactly 24 hours to be traced (the model uses daily time steps so this was selected as more appropriate than the reported tail at 48 hours [6], or than assuming no delay).

Contact tracing was modelled by selecting individuals diagnosed each day, up to a maximum of 250 people each day representing an (unvalidated) estimate of contact tracing capacity in Victoria. For each person selected, their contacts were quarantined for 14 days with a network-specific probability of being detected (Table S1), reflecting differences in the level of difficult in identifying contacts in that network. The contact tracing capacity does not apply to household contacts, which are assumed to be directly notified by newly diagnosed individuals.

We also assumed 25% coverage of the *COVIDSafe* app with 24-hour tracing time.

Model calibration

The model was calibrated to the outbreak in Victoria over the June-September period, and the associated policy changes and interventions that were implemented over that period (Table 1). For the calibration shown in Figure S1, the model was initialised with a population of 100,000 agents, and parameters for the transmission risks per contact were varied such that when combined with inputs for the number of tests conducted over time and changes in contacts resulting from policy changes (e.g. community sports being cancelled and restaurants, cafes being take-away only when Stage 3 restrictions were introduced), the distribution of model outcomes was centred near the actual epidemic trajectory. Testing was modelled with a specified number of tests per day, distributed across symptomatic and asymptomatic people with an increased probability of testing symptomatic people that was fitted as part of calibration. The number of tests per day was based on the actual number of tests performed each day in Victoria, scaled to reflect the number of agents in the model and the extent to which the model oversamples hotspots in Melbourne – the latter scaling was estimated as part of calibration. Overall, the transmission probability per contact governs the rate of epidemic growth, and the testing parameters affect the proportion of cases that go undiagnosed. We assume that the proportion of undiagnosed cases is reflected in the number of diagnoses relative to the number of hospitalizations, as severe cases are assumed to present at hospital regardless of whether they have been tested or not. Thus, we used data on the number of hospitalizations to enable calibration of the testing parameters.

Due to the stochastic nature of the model, for the same input parameters and initializations, a wide range of outcomes may be observed. For the purpose of parameter estimation, it is generally sufficient to simply examine the distribution of outcomes. However, our projections for the relaxation scenarios are sensitive to the state of the epidemic at the date that policies are relaxed, as well as the choice for transmission probability per contact. For the projections, we require a set of initializations that represent realistic possible states of the epidemic as of 14th September. The likelihood of an outbreak in our projections is also likely to vary with the transmission risk per contact fitted in calibration. To ensure that we start with realistic initializations covering a range of transmission risk values, we generated 10000 proposed initializations with a range of transmission probabilities and different random seeds (i.e. initial active cases in the model when the simulations begin at 21st June). We then retained only those runs where the seed/transmission parameter combination produced a projection that sufficiently matched the data – we considered the model to be a suitable fit if it was within 10% of the cumulative diagnosed cases each day, after the first 30 days. Figure S1 shows examples of the simulation runs used in this study. We note that the variability permitted in the cumulative case counts (left panel) is dominated by how high the peak of the second wave is, and as the epidemic declines, the variability in new diagnoses per day by 14th September is somewhat smaller. Overall, approximately 200 of the 10000 proposed initializations were accepted. Many initializations are rejected because they diverge from the actual second wave early on, when case numbers are low and the outcomes of each individual case therefore have a significant impact on the trajectory of the outbreak.

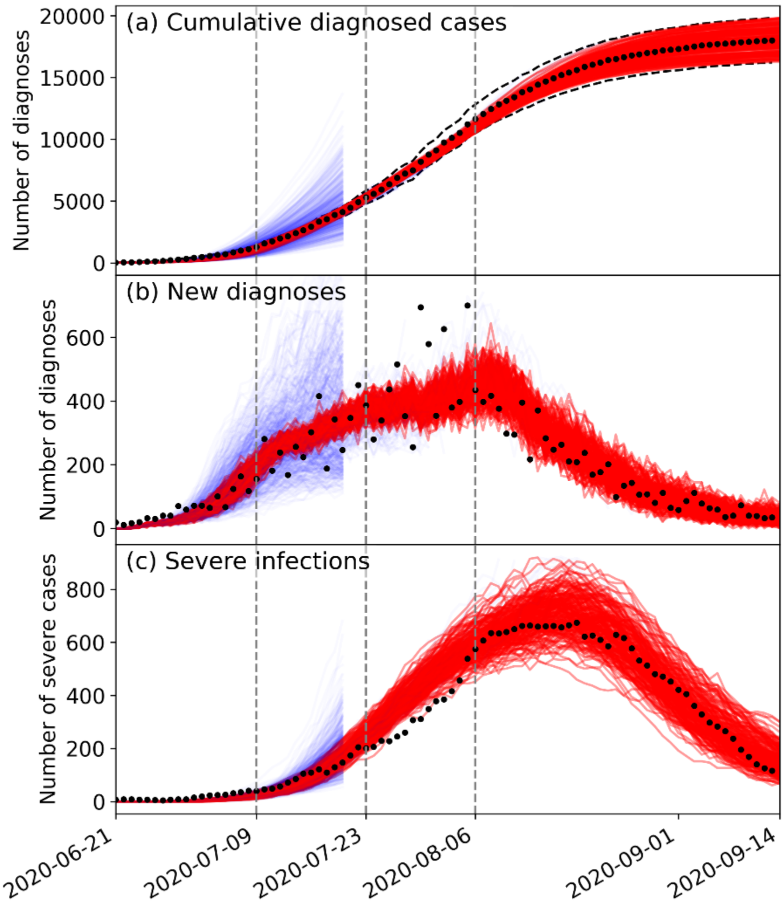

Figure S1: Model calibration to second wave in Victoria from June-September 2020. Vertical lines indicate when Stage 3 lockdowns took effect (9th July), masks were made mandatory (23rd July) and Stage 4 lockdowns took effect (6th Aug). Severe infections in the model represent infections requiring hospitalisation, and the corresponding data are for reported hospitalisations. Red lines indicate simulation runs that were maintained and used for the resurgence projections in this study; blue lines show a representative sample of simulations that were rejected.

Disease prognosis

Table S2: Age-specific susceptibility, disease progression and mortality risks**.**

	0-9	10-19	20-29	30-39	40-49	50-59	60-69	70-79	80+	Sources
Relative susceptibility	0.34	0.67	1.00	1.00	1.00	1.00	1.00	1.24	1.47	[11]
Prob[symptomatic]	0.50	0.55	0.60	0.65	0.70	0.75	0.80	0.85	0.90	[12]
Prob[severe]	0.00004	0.00040	0.01100	0.03400	0.04300	0.08200	0.11800	0.16600	0.18400	[13, 14].
Prob[critical]	0.0004	0.00011	0.0005	0.00123	0.00214	0.008	0.0275	0.06	0.10333	[14]
Prob[death]	0.00002	0.00006	0.00030	0.00080	0.00150	0.00600	0.02200	0.05100	0.09300	[13-15]

Policies

The effect of each policy is detailed below summarized from [2], showing the impact on the transmission probability per contact, and/or the number of contacts in the network. Policies that reduce the number of contacts in the network better preserve the clustering associated – for example, the 'Work from home' policy reduces the number of workplace contacts to model the same people working from home every day.

Community sports cancelled
- Household transmission increased by 10%
- Community sport transmission reduced by 100%

Small social gatherings banned
- Social gatherings contacts decreased by 25%

Mandatory masks[1]
- Work transmission reduced by 20%
- Additional community transmission reduced by 20%
- Church/places of worship transmission reduced by 20%
- Entertainment transmission reduced by 20%
- Cafes/restaurants transmission reduced by 20%
- Pubs/bars transmission reduced by 20%
- Public transport transmission reduced by 20%
- Public parks transmission reduced by 20%
- Large event transmission reduced by 20%
- Social gatherings transmission reduced by 20%
- Aged care transmission reduced by 20%

Outdoor gatherings limited to 2 people
- Additional community transmission reduced by 30%
- Entertainment transmission reduced by 100%
- Public transport transmission reduced by 50%
- Public parks transmission reduced by 50%
- Large event transmission reduced by 100%

Outdoor gatherings limited to 10 people
- Additional community transmission reduced by 20%
- Entertainment transmission reduced by 100%
- Public transport transmission reduced by 50%
- Public parks transmission reduced by 40%
- Large event transmission reduced by 100%

Outdoor gatherings limited to 200 people
- Public transport transmission reduced by 20%
- Large event transmission reduced by 100%

Work from home where possible
- Household transmission increased by 10%
- Work transmission reduced by 20%
- Additional community transmission reduced by 33%
- Public transport transmission reduced by 33%
- Work contacts decreased by 20%

Cafes/restaurants takeaway only
- Cafes/restaurants transmission reduced by 100%

Pubs/bars takeaway only
- Pubs/bars transmission reduced by 100%

Cafes/restaurants open with 4sqm physical distancing
- Household transmission increased by 5%
- Cafes/restaurants transmission reduced by 80%

Pubs/bars open with 4sqm physical distancing
- Household transmission increased by 5%
- Pubs/bars transmission reduced by 80%

Entertainment venues closed
- Entertainment transmission reduced by 100%

Schools closed
- School transmission reduced by 50%
- School contacts decreased by 90%

Churches and places of worship closed
- Church/places of worship transmission reduced by 100%

Churches and places of worship open with 4sqm physical distancing
- Church/places of worship transmission reduced by 60%

Large events cancelled
- Large event transmission reduced by 100%

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[1] A comprehensive meta-analysis [16] (conducted after two others [17,18]), covering 41 studies of mask effectiveness concluded that that masks are associated with a reduction in infection for mask-wearers by a third compared to control groups. For this analysis, we have used a 20% transmission reduction in specific community settings, based on a 30% individual-level efficacy and 75% compliance.