# Modelling to support COVID-19 preparedness and response in Australia


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Doherty Institute
THE UNIVERSITY OF MELBOURNE
The Royal Melbourne Hospital
A joint venture between The University of Melbourne and The Royal Melbourne Hospital

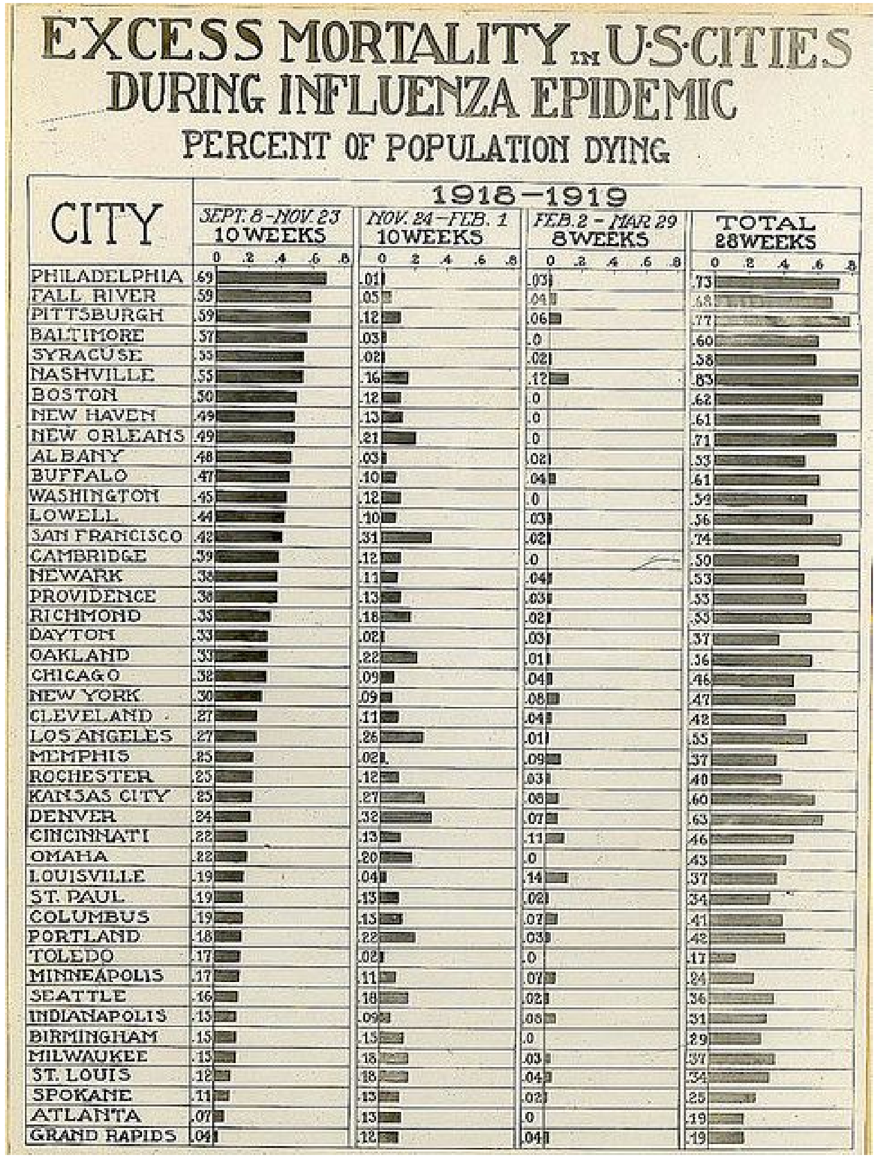
# Overview

- **Emerging infectious diseases and pandemics**
  - 1918-19 influenza
  - 2003 SARS
- **Early emergence and global spread of COVID-19**
- **Scenarios to inform preparedness and initial response**
- **Nowcasting and forecasting to inform social measures and health system requirements**

***Role of modelling to aid interpretation of incomplete/uncertain data***

***WHO modelling network activated 17 Jan 2020***

# 1918-19 pandemic influenza

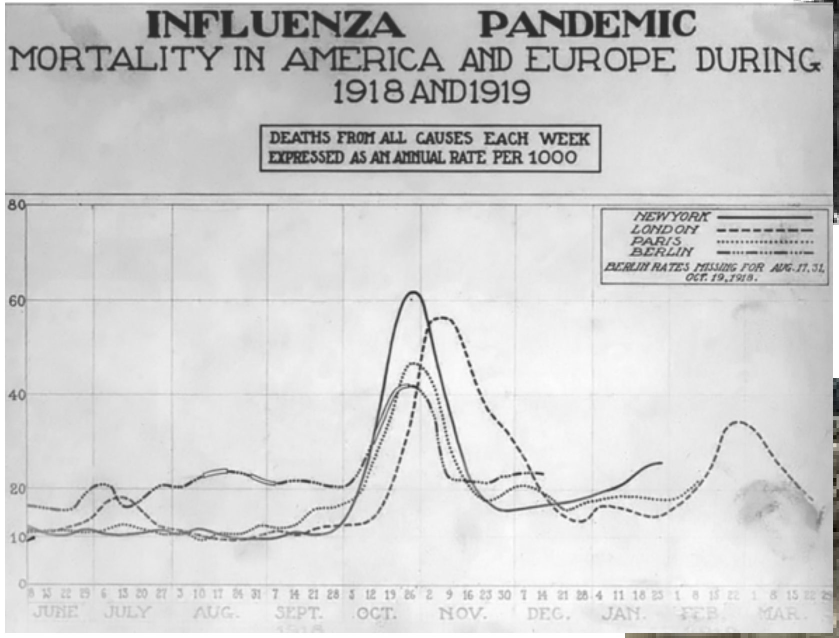


EXCESS MORTALITY IN U.S. CITIES DURING INFLUENZA EPIDEMIC

PERCENT OF POPULATION DYING

1918–1919

| CITY | SEPT. 8–NOV. 23 10 WEEKS | NOV. 24–FEB. 1 10 WEEKS | FEB. 2–MAR 29 8 WEEKS | TOTAL 28 WEEKS |
|---|---|---|---|---|
| PHILADELPHIA | .69 | .01 | .03 | .73 |
| FALL RIVER | .59 | .05 | .04 | .68 |
| PITTSBURGH | .59 | .12 | .06 | .77 |
| BALTIMORE | .57 | .03 | .0 | .60 |
| SYRACUSE | .55 | .02 | .02 | .58 |
| NASHVILLE | .55 | .16 | .12 | .83 |
| BOSTON | .50 | .12 | .0 | .62 |
| NEW HAVEN | .49 | .13 | .0 | .61 |
| NEW ORLEANS | .49 | .21 | .0 | .71 |
| ALBANY | .48 | .03 | .02 | .53 |
| BUFFALO | .47 | .10 | .04 | .61 |
| WASHINGTON | .45 | .12 | .0 | .59 |
| LOWELL | .44 | .10 | .03 | .56 |
| SAN FRANCISCO | .42 | .31 | .02 | .74 |
| CAMBRIDGE | .39 | .12 | .0 | .50 |
| NEWARK | .38 | .11 | .04 | .53 |
| PROVIDENCE | .38 | .13 | .03 | .53 |
| RICHMOND | .35 | .18 | .02 | .55 |
| DAYTON | .33 | .02 | .03 | .37 |
| OAKLAND | .33 | .22 | .01 | .56 |
| CHICAGO | .32 | .09 | .04 | .46 |
| NEW YORK | .30 | .09 | .08 | .47 |
| CLEVELAND | .27 | .11 | .04 | .42 |
| LOS ANGELES | .27 | .26 | .01 | .55 |
| MEMPHIS | .25 | .02 | .09 | .37 |
| ROCHESTER | .25 | .12 | .03 | .40 |
| KANSAS CITY | .25 | .27 | .08 | .60 |
| DENVER | .24 | .32 | .07 | .63 |
| CINCINNATI | .22 | .13 | .11 | .46 |
| OMAHA | .22 | .20 | .0 | .43 |
| LOUISVILLE | .19 | .04 | .14 | .37 |
| ST. PAUL | .19 | .13 | .02 | .34 |
| COLUMBUS | .19 | .15 | .07 | .41 |
| PORTLAND | .18 | .22 | .03 | .42 |
| TOLEDO | .17 | .02 | .0 | .17 |
| MINNEAPOLIS | .17 | .11 | .07 | .24 |
| SEATTLE | .16 | .18 | .02 | .36 |
| INDIANAPOLIS | .15 | .09 | .08 | .31 |
| BIRMINGHAM | .15 | .15 | .0 | .29 |
| MILWAUKEE | .13 | .18 | .03 | .37 |
| ST. LOUIS | .12 | .18 | .04 | .34 |
| SPOKANE | .11 | .13 | .02 | .25 |
| ATLANTA | .07 | .13 | .0 | .19 |
| GRAND RAPIDS | .04 | .12 | .04 | .19 |





# Influenza pandemics – mortality

DOI:10.1111/j.1750-2659.2009.00089.x
www.blackwellpublishing.com/influenza

Review

## Understanding influenza transmission, immunity and pandemic threats

**John D. Mathews, Joanne M. Chesson, James M. McCaw, Jodie McVernon**

Melbourne School of Population Health, The University of Melbourne, Melbourne, Australia
*Correspondence:* Dr Jodie McVernon, Vaccine and Immunization Research Group, Murdoch Childrens Research Institute and, Melbourne School of Population Health, The University of Melbourne, Level 5, 207 Bouverie Street, Carlton, Australia.
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*Accepted 28 May 2009. Published Online 12 June 2009.*

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## Understanding pandemic threa

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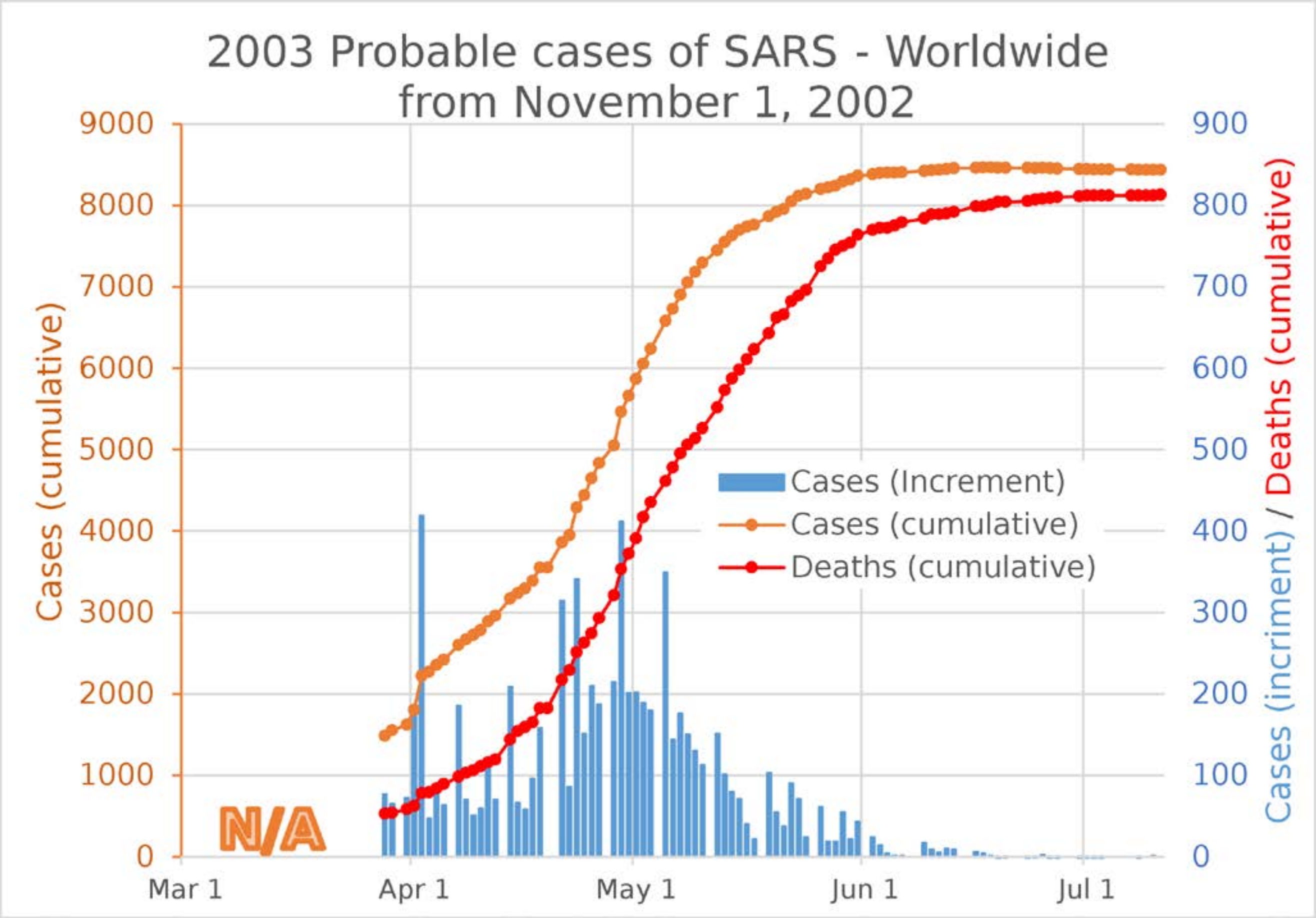
| Year | Population | Approximate deaths per 1000 population | Influenza A subtype |
|---|---|---|---|
| 1675 | London | 1 | Unknown |
| 1782 | London | 10 | Unknown |
| 1837 | London | 4·5 | Unknown |
| 1847 | London | 2·5 | Unknown |
| 1890 | UK | 1–2·5 | |
| 1918–1919 | Worldwide | 2–25 | H1N1 |
| | India | Up to 70 | |
| | Western Samoa | 200 | |
| | Alaska | Up to 600 | |
| | New Zealand – whites | 5·5 | |
| | New Zealand – Maori | 42 | |
| | New South Wales | 3 | |
| | Victoria | 2·4 | |
| 1957 | Worldwide | 0·7 | H2N2 |
| | Liverpool | 1 | |
| | USA | 0·35 | |
| 1968–1969 | Worldwide | 0·3 | H3N2 |
| | USA | 0·15 | |
| Seasonal influenza | Developed countries | 0·03–0·3 | H3N2, H1N1 |

# SARS 2003


BBC 2013 10 years on report




https://commons.wikimedia.org/wiki/User:Phoenix7777

Every patient infected with SARS showed symptoms

Symptoms arose first, and infectiousness rose slowly thereafter

# Emergence: Wuhan Huanan Seafood Market

## December 29, 2019

4 cases pneumonia of unknown aetiology

- Detected through syndromic surveillance implemented post-SARS
- All linked to the Huanan market
- Environmental samples positive, no animal source

## January 29, 2020

425 cases of pneumonia confirmed due to novel coronavirus

- 55% of those with onset before 1 Jan linked to Huanan market, only 8.6% thereafter
- Initial estimates of R0 considered differing proportion of spillover vs human-human spread
- Soon apparent that likely only one or very few crossover events, human transmitted infection

# 17/1 – Imperial College public report

- **16 January 2020 – 41 cases, including two deaths in Wuhan.**
- **3 confirmed cases in travellers (Thailand x 2, Japan)**

The two Chinese nationals identified in Thailand had visited Wuhan, but not the fish market

**Wuhan international airport has a catchment population of 19 million people, and approximately 3,300 people depart per day.**

**Assuming SARS/MERS characteristics:**

5-6 day incubation period (exposure to symptom onset)

4-5 day delay from symptom onset to detection (for these early severe cases, that was hospitalisation)

**Assume outbound travel is long enough to pick up cases, then:**

**Number of cases detected overseas, $X$, is binomial $Bin(p,N)$, with**

**$p$ = probability any one case will be detected overseas**

**$N$ = total number of cases (in Wuhan)**

**Therefore, $N$ is negative binomial, and we compute using MLE:**

**$N$ = 1,723 (427 - 4,471)**

**By 22/1, China had confirmed 440 cases, and based on 7 exported cases, $N$: 1,000 – 9,700.**

# Modelling for preparedness

DOI:10.1111/j.1750-2659.2007.00008.x
www.blackwellpublishing.com/influenza

Review

## Model answers or trivial pursuits? The role of mathematical models in influenza pandemic preparedness planning

**J McVernon, CT McCaw, JD Mathews**

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*Accepted 13 February 2007.*

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PLOS | NEGLECTED TROPICAL DISEASES

RESEARCH ARTICLE

## Model-Informed Risk Assessment and Decision Making for an Emerging Infectious Disease in the Asia-Pacific Region

**Robert Moss[1], Roslyn I. Hickson[2], Jodie McVernon[1,3], James M. McCaw[1,3,4], Krishna Hort[5], Jim Black[5], John R. Madden[6], Nhi H. Tran[6], Emma S. McBryde[7,8], Nicholas Geard[1]***

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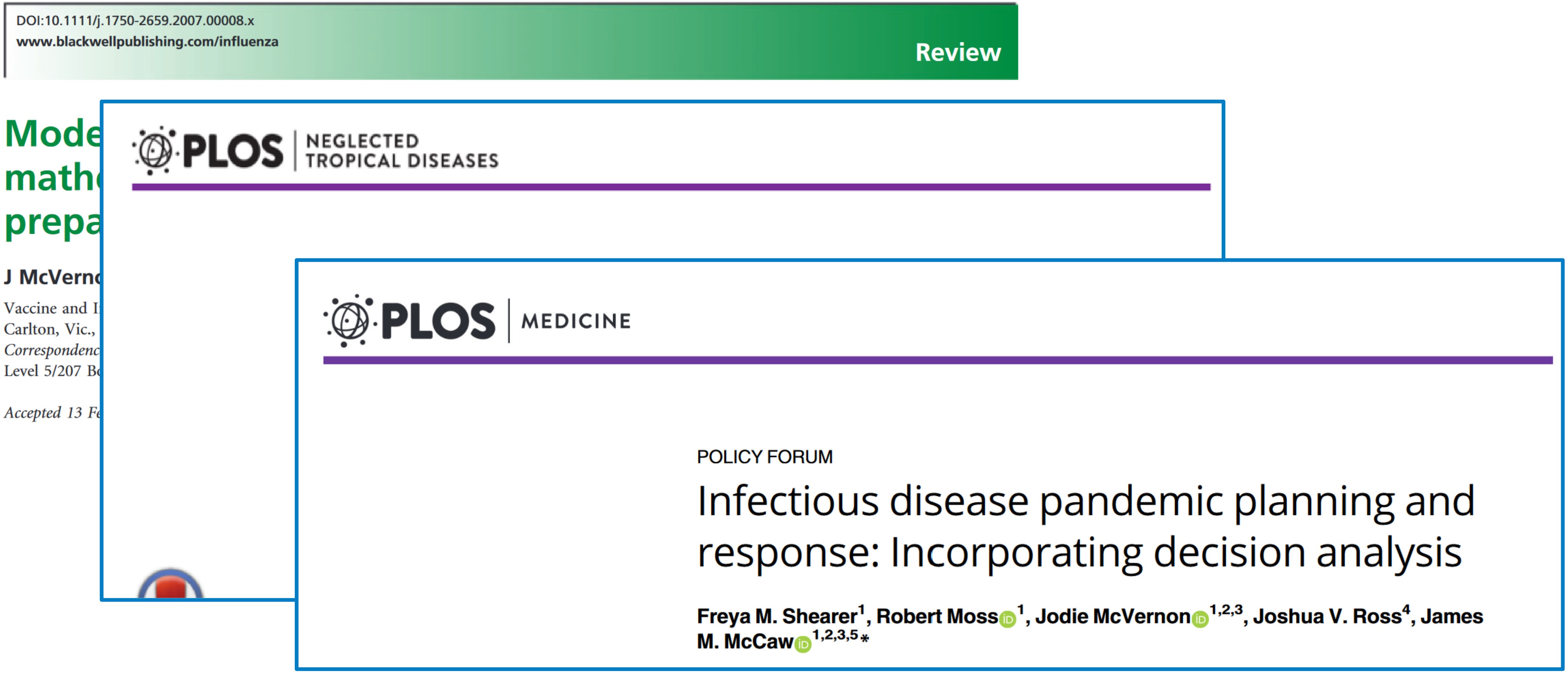
# Modelling for preparedness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*Accepted 13 F*

PLOS | NEGLECTED TROPICAL DISEASES

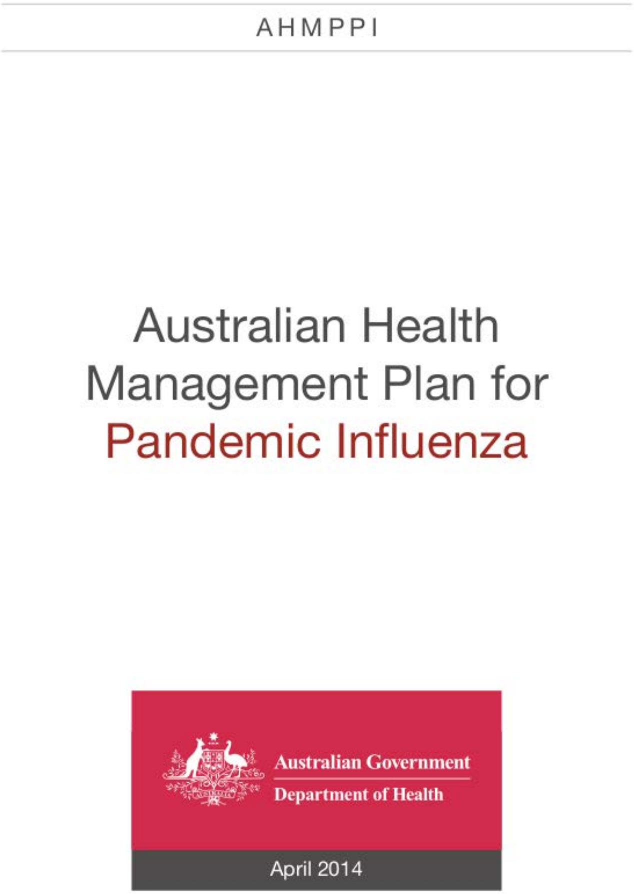
PLOS | MEDICINE

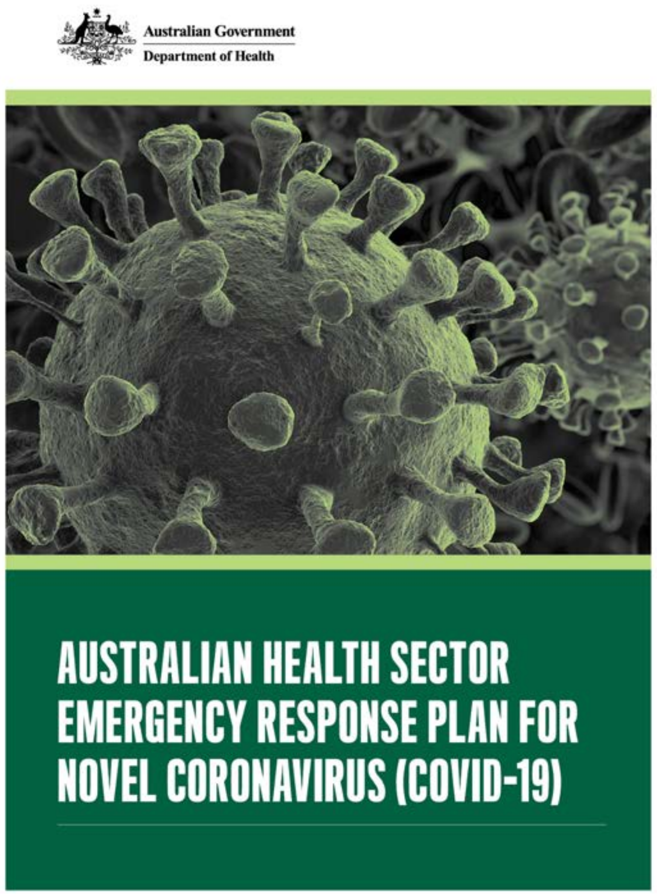
POLICY FORUM

Infectious disease pandemic planning and response: Incorporating decision analysis

**Freya M. Shearer[1], Robert Moss[1], Jodie McVernon[1,2,3], Joshua V. Ross[4], James M. McCaw[1,2,3,5]***

# Adaptable plans for response

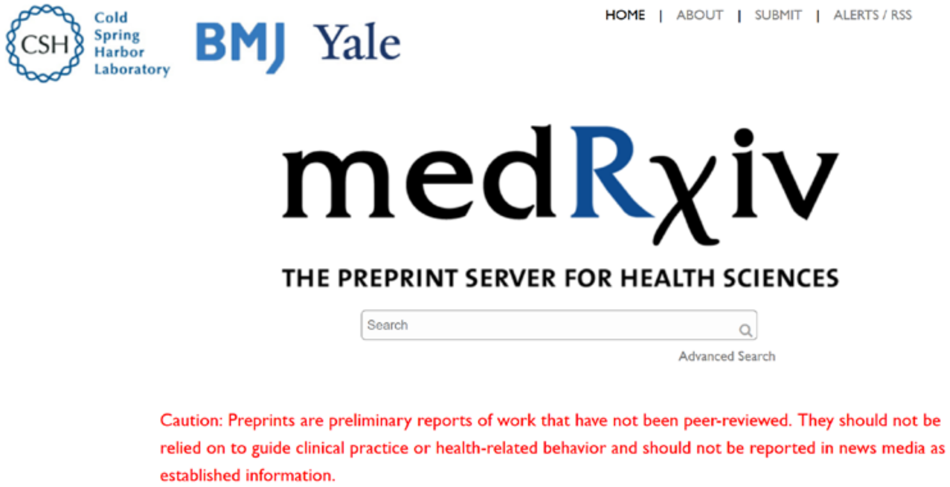


# Open Science – even pre-prints are too slow!

- **2009 – traditional “medical” style culture in publishing**

  Major groups released “fast” (weeks) big papers in top journals (e.g. Science)

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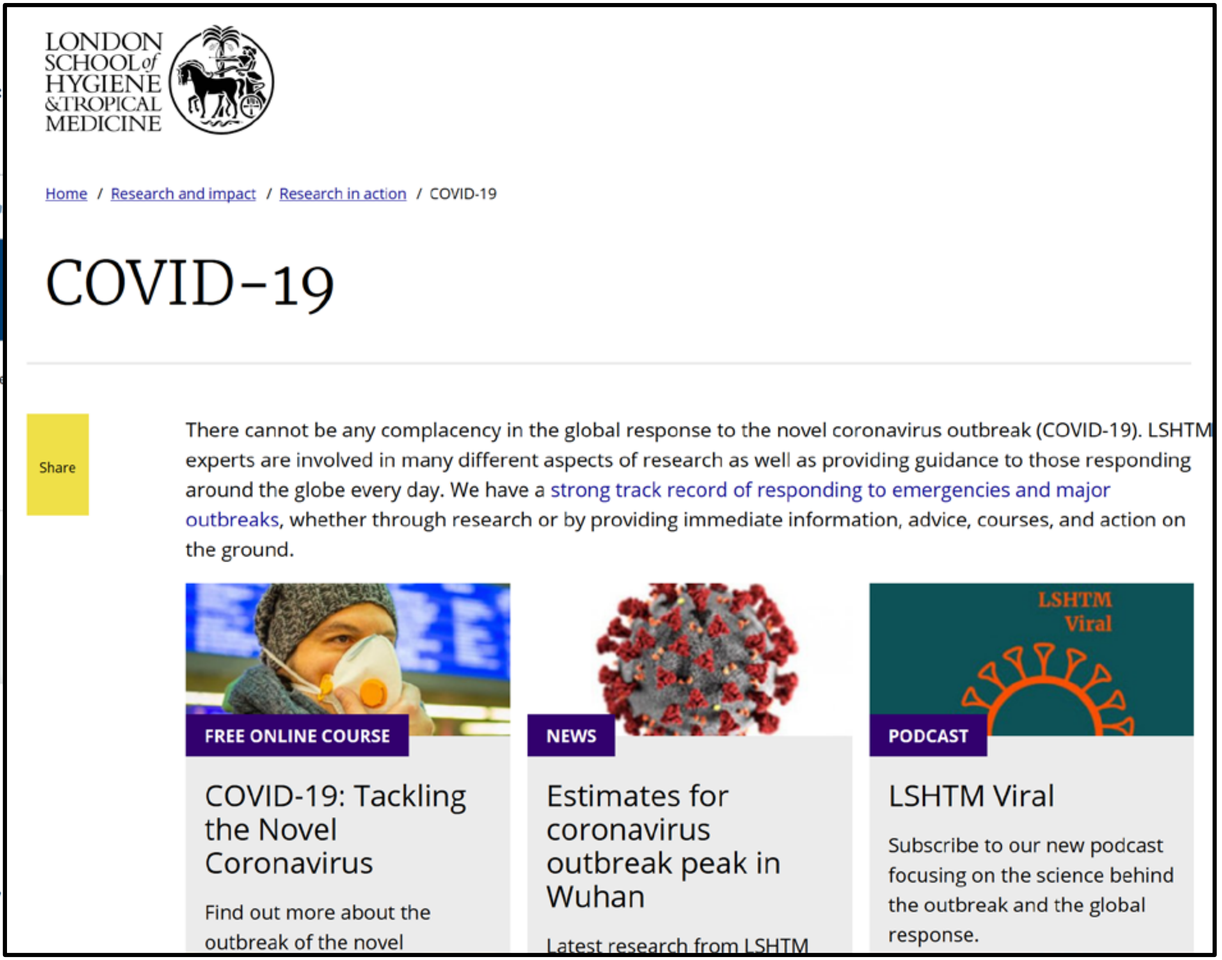
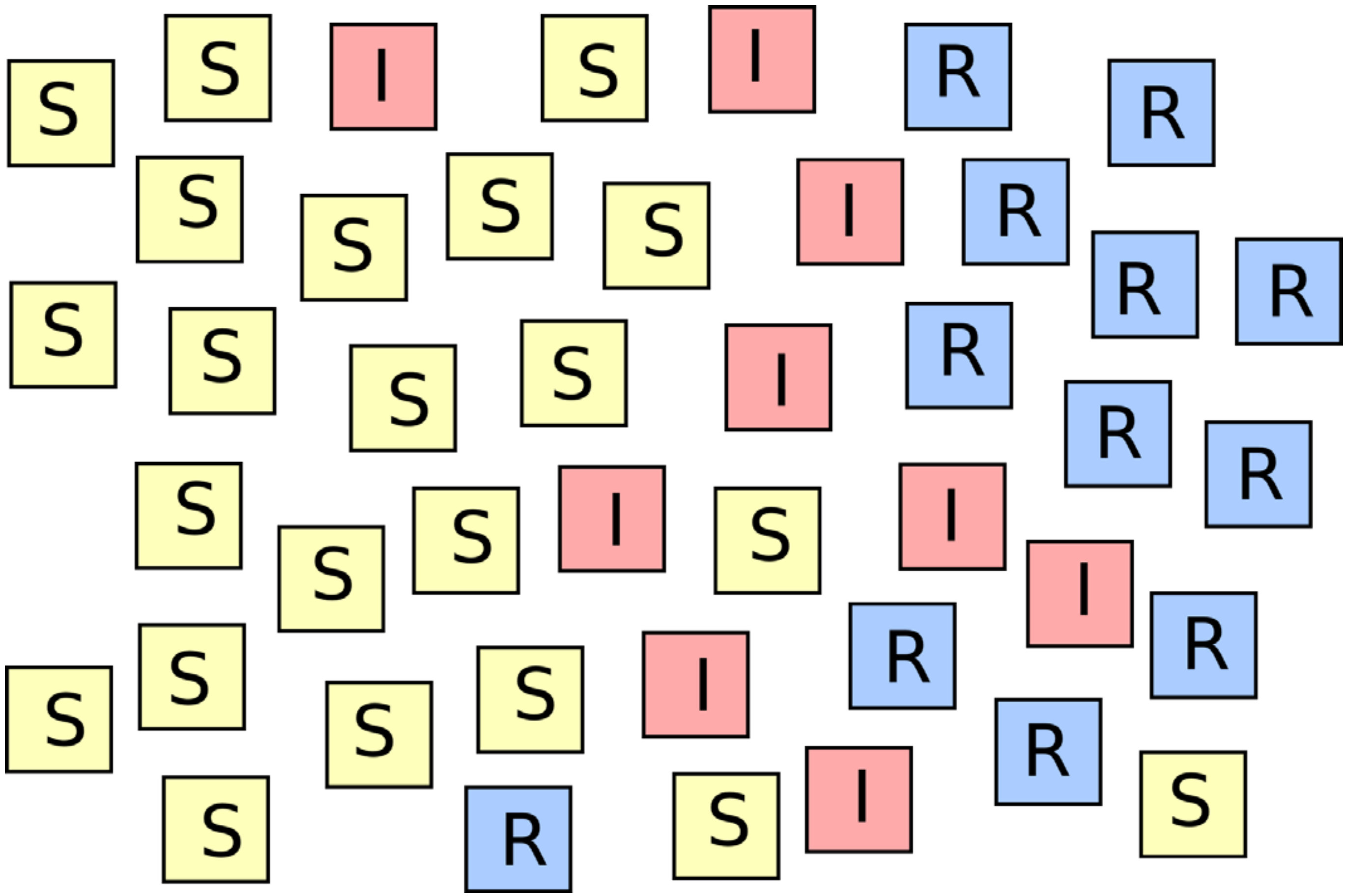


# Infectious disease models



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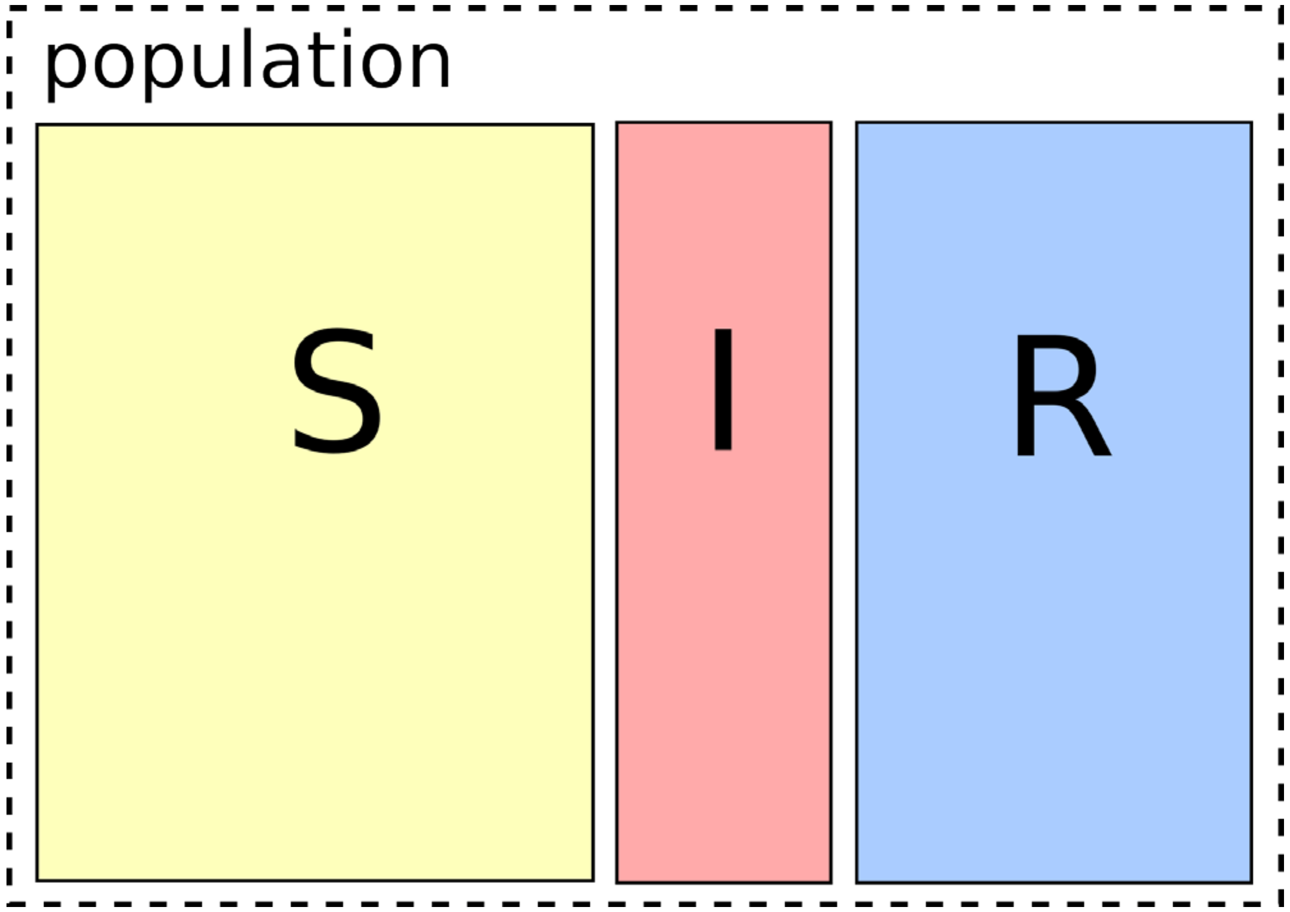
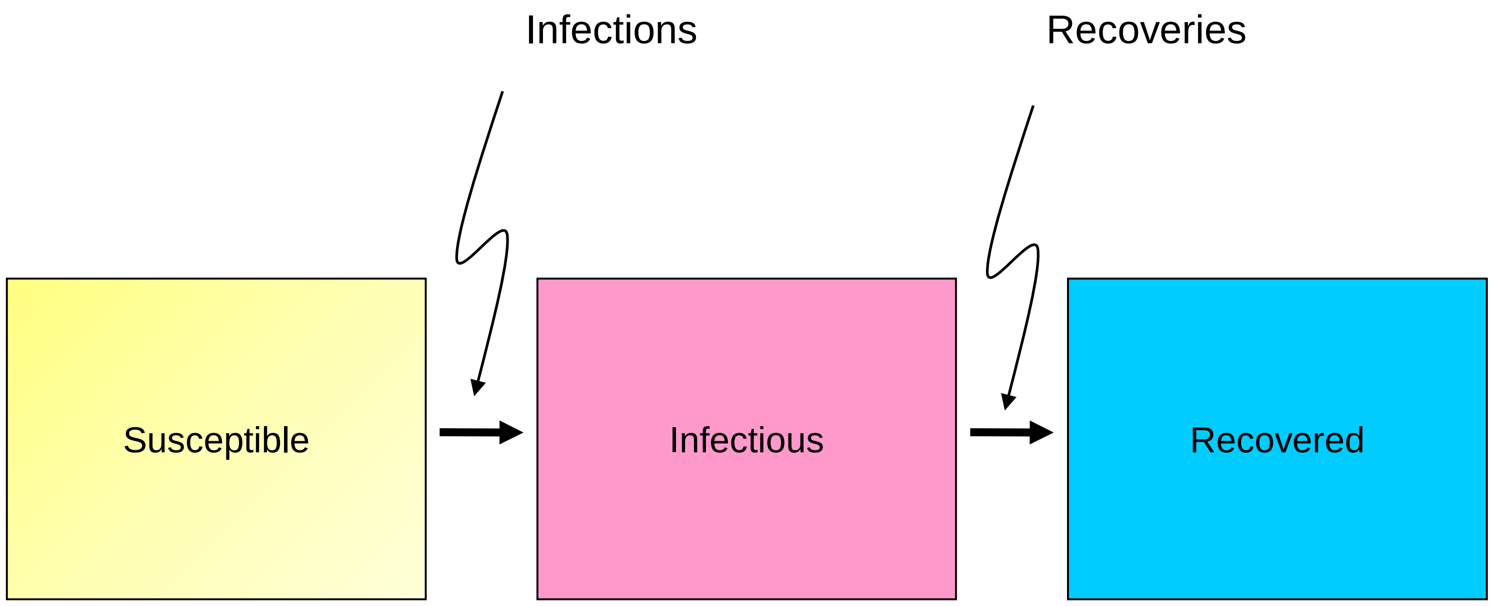


# Infectious disease models




$dS/dt = -\beta IS/N$ $\quad$ $dI/dt = \beta IS/N - \gamma I$ $\quad$ $dR/dt = \gamma I$

$S(t=0) = N\text{-}1$ $\quad$ $I(t=0) = 1$ $\quad$ $R(t=0) = 0$

Reproduction number

$dI/dt = \gamma I(R_0\,(S/N) - 1)$

with

$R_0 = \beta/\gamma$

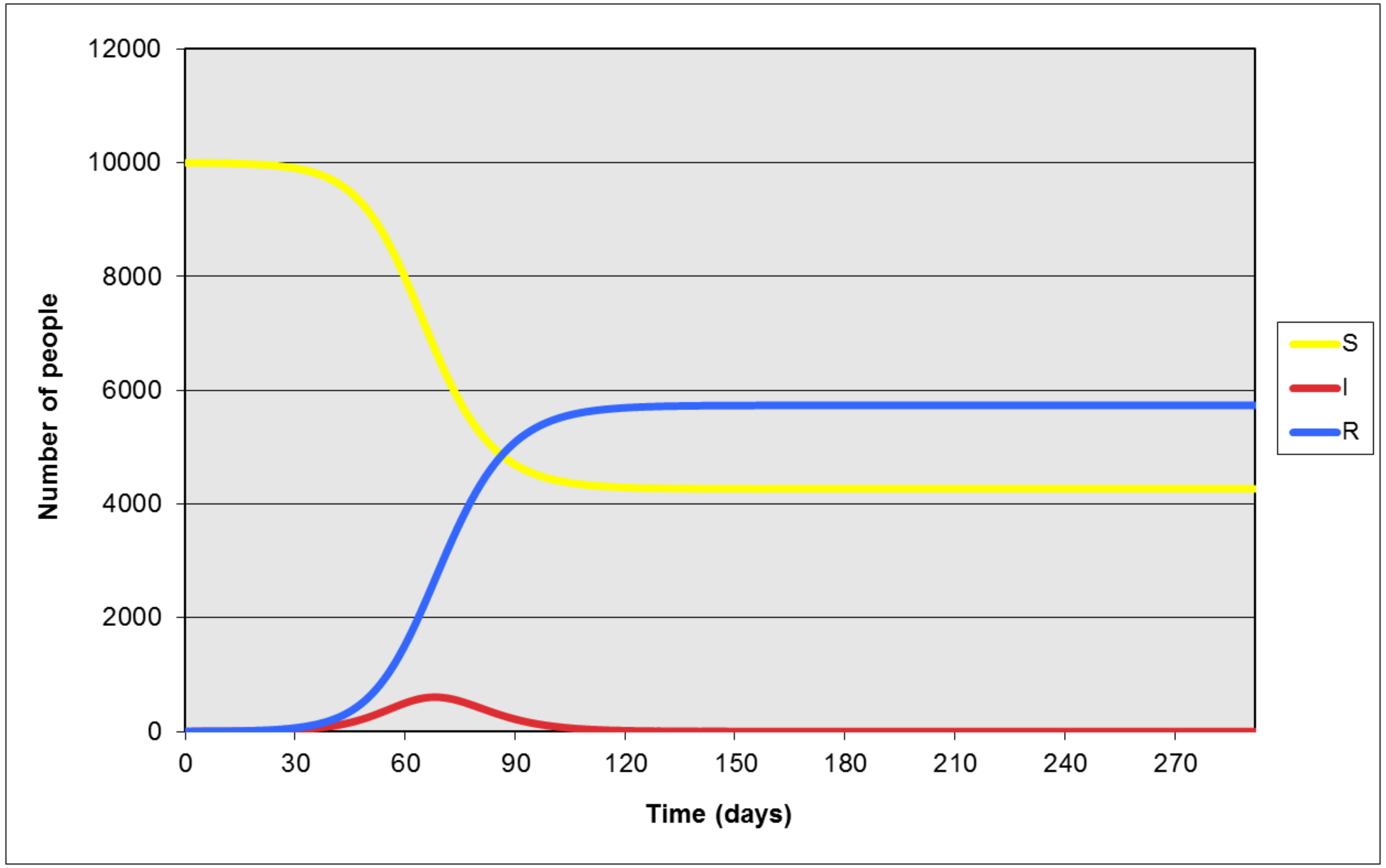
which defines the threshold condition for an epidemic (>1)

Through time, susceptibles are depleted.

Epidemic peaks at $S = 1/R_0$.

$R_{eff}(t) = R_0\,S(t)/N$

# Infectious disease models



# Nowcasting and forecasting the potential domestic and international spread of the 2019-nCoV outbreak originating in Wuhan, China: a modelling study

*Joseph T Wu*, Kathy Leung*, Gabriel M Leung*

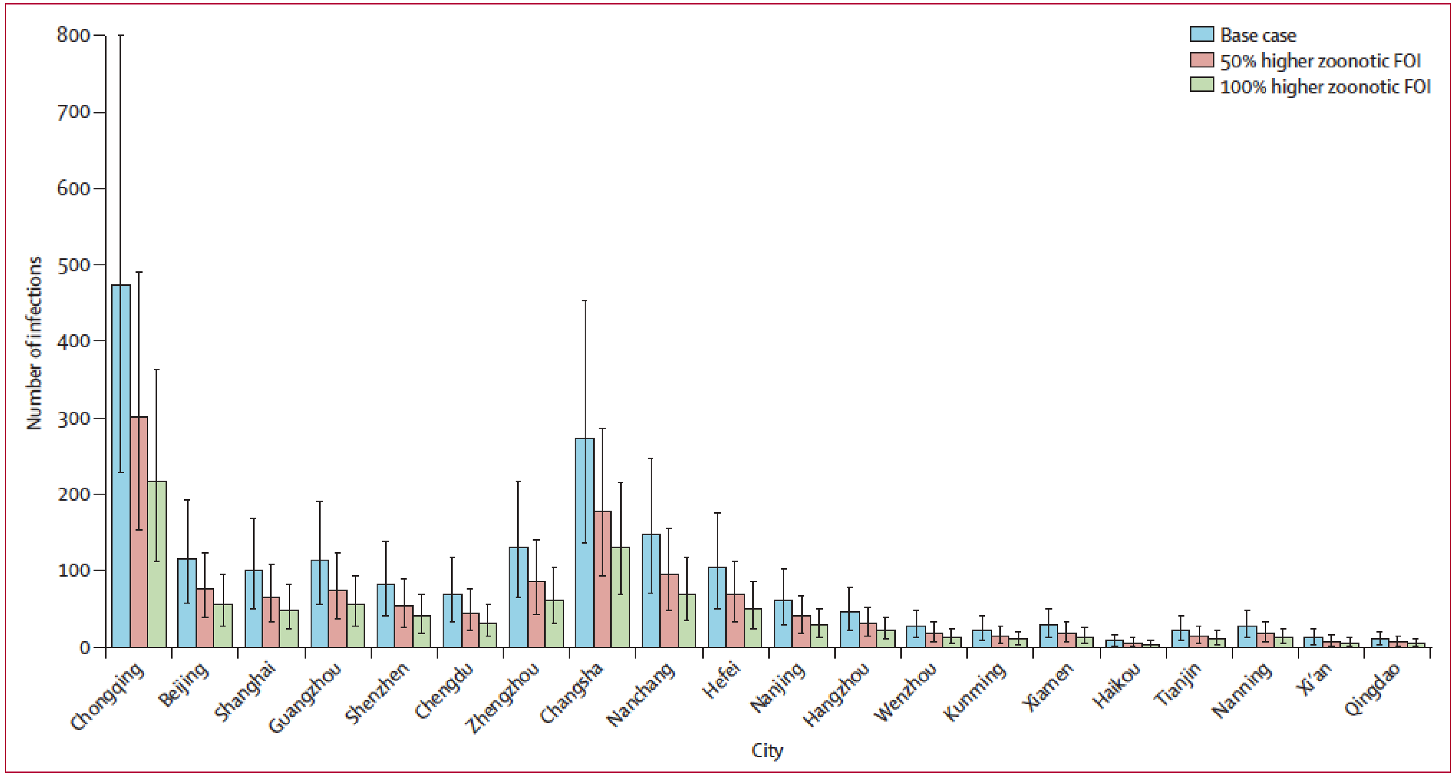



*Figure 3*: **Estimated number of cases exported to the Chinese cities to which Wuhan has the highest outbound travel volumes**
Estimates are as of Jan 26, 2020. Data are posterior means with 95% CrIs. FOI=force of infection.

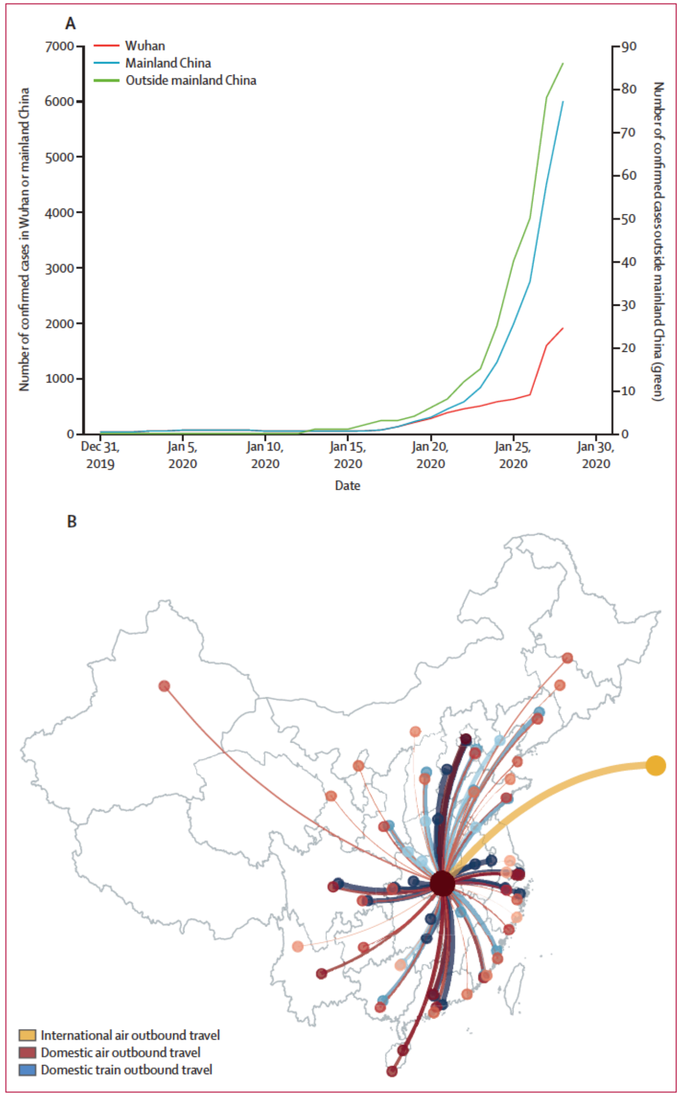


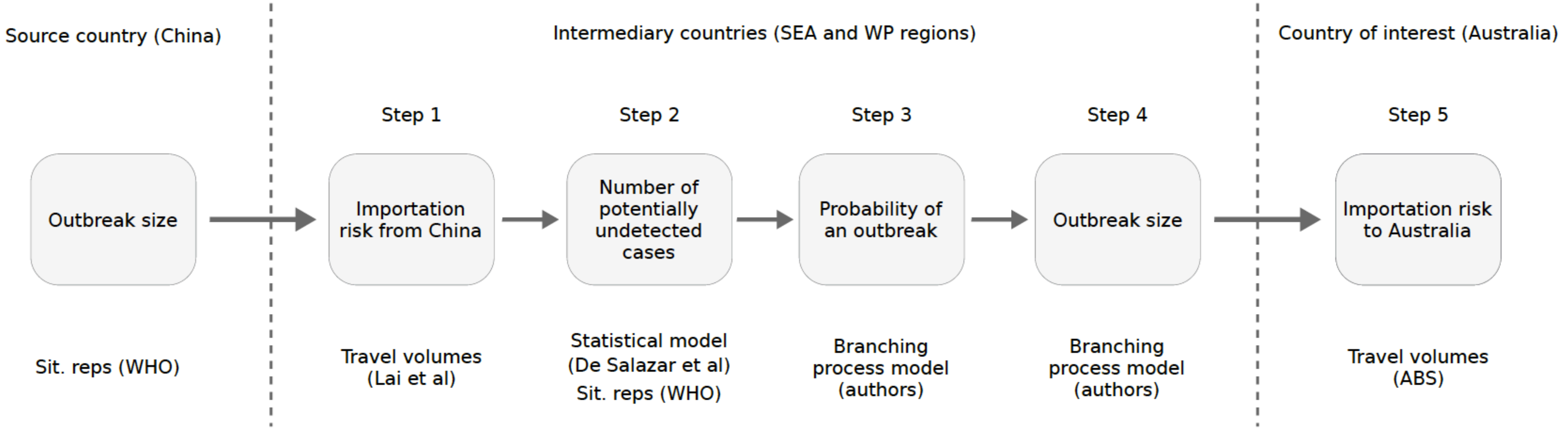

*Figure 1*: **Risk of spread outside Wuhan**
(A) Cumulative number of confirmed cases of 2019 novel coronavirus as of Jan 28, 2020, in Wuhan, in mainland China (including Wuhan), and outside mainland China. (B) Major routes of outbound air and train travel originating from Wuhan during *chunyun*, 2019. Darker and thicker edges represent greater numbers of passengers. International outbound air travel (yellow) constituted 13·5% of all outbound air travel, and the top 40 domestic (red) outbound air routes constituted 81·3%. Islands in the South China Sea are not shown.

Lancet Jan 31, 2020

# Modelling to interpret implications for Australia and our region

**Models developed in the Australian context were used to inform:**

- **Testing criteria (returned travellers) and epidemiological case definition**
- **Border measures and DFAT travel advisories (prospective risk assessment)**



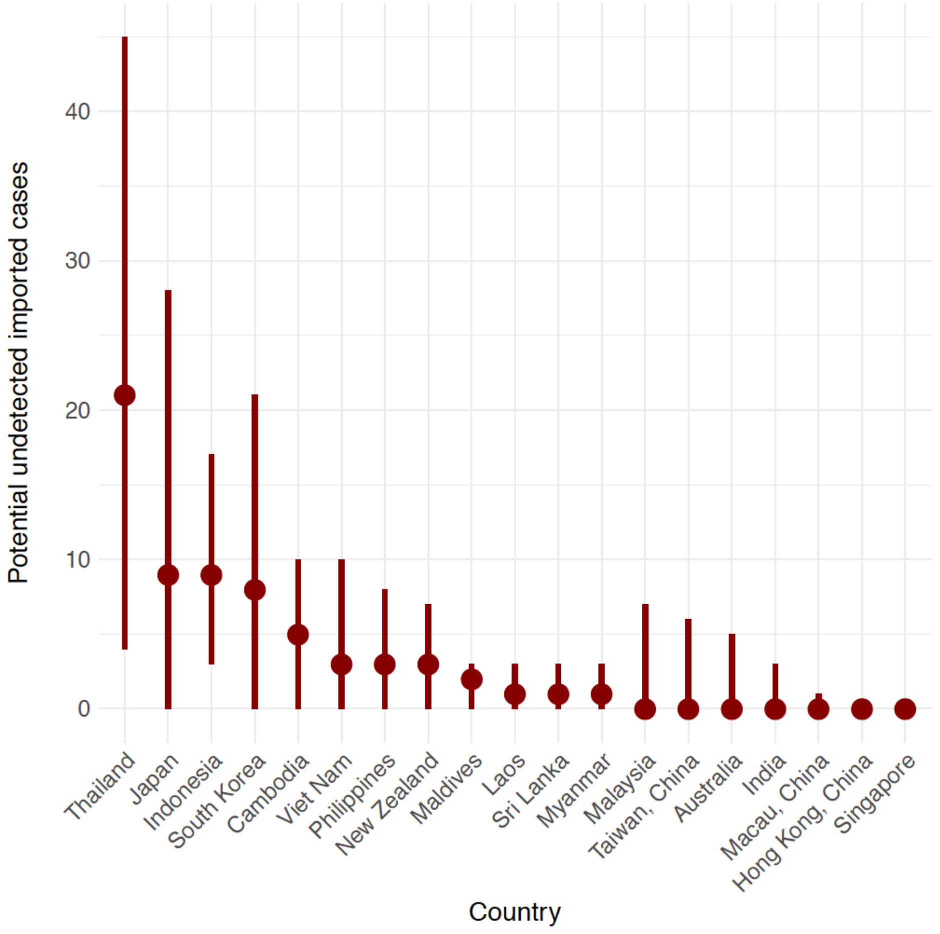

Shearer et al medRxiv https://doi.org/10.1101/2020.04.09.20057257

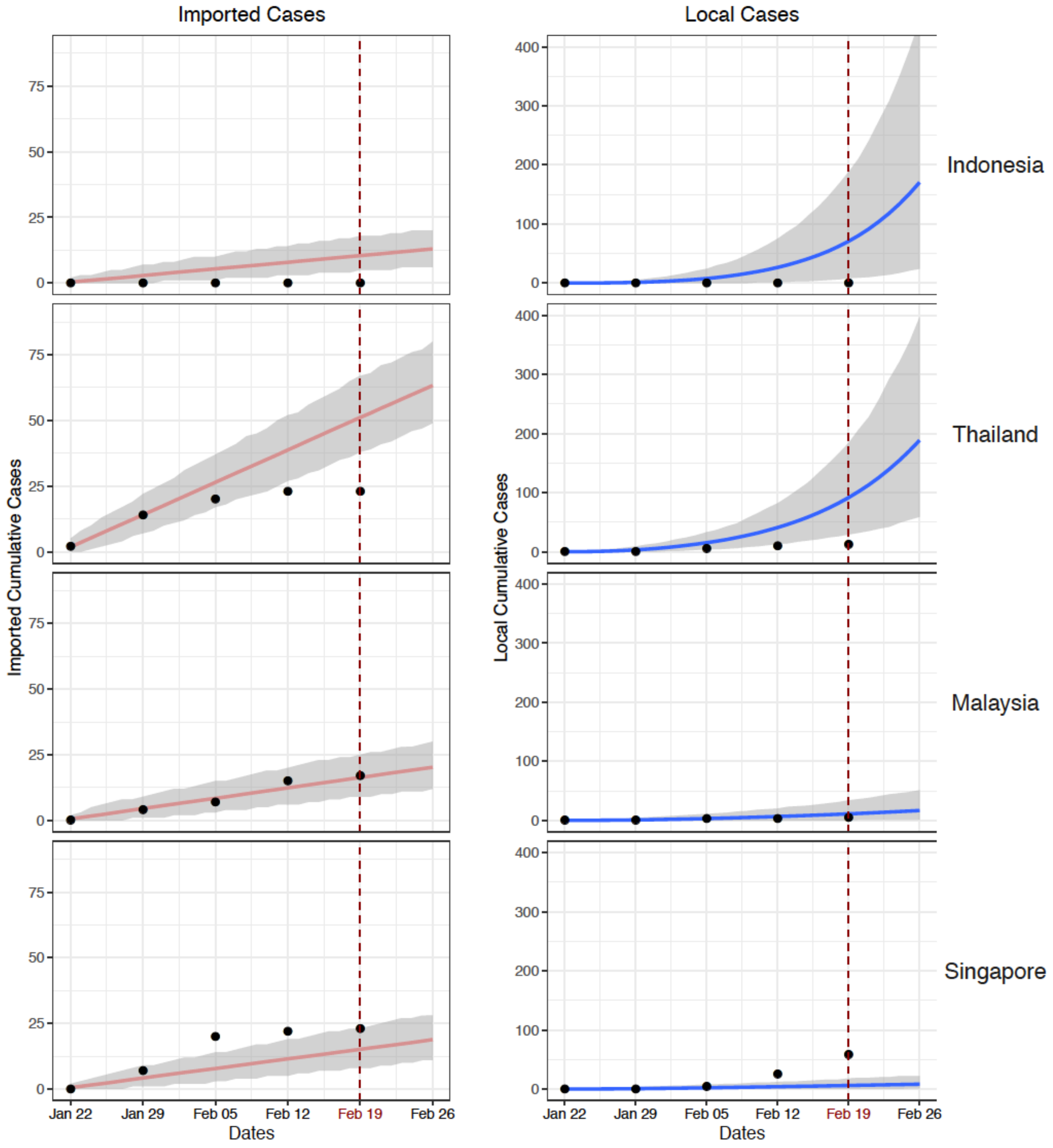
# Importation risk assessment (19 Feb 2020)

| | Monthly air travel from China (in thousands) (Step 1) | Expected imported cases (Step 1) | Reported imported cases (Step 2) | Estimated undetected cases (Step 2) | Estimated probability of local transmission (Step 3) | Estimated local cases (Step 4) | Monthly air travel to Australia (in thousands) (Step 5) |
|---|---|---|---|---|---|---|---|
| Thailand | 485.6 | 44 (27–68) | 23 | 21 (4–45) | 1 | 176 (59–397) | 50.1 |
| Japan | 382.8 | 35 (20–54) | 26 | 9 (0–28) | 1 | 97 (28–269) | 87.8 |
| Hong Kong, China | 244.4 | 22 (11–35) | 62 | 0 (0–0) | 1 | 13 (4–51) | 46.4 |
| Taiwan, China | 237.7 | 22 (11–34) | 28 | 0 (0–6) | 1 | 21 (5–77) | 21.4 |
| South Korea | 230.2 | 21 (10–34) | 13 | 8 (0–21) | 1 | 69 (17–202) | 30.9 |
| Malaysia | 150.6 | 14 (6–24) | 17 | 0 (0–7) | 0.99 | 14 (2–51) | 47.0 |
| Singapore | 138.6 | 13 (5–22) | 23 | 0 (0–0) | 0.98 | 7 (1–22) | 73.2 |
| Viet Nam | 115.6 | 11 (4–18) | 8 | 3 (0–10) | 0.99 | 19 (2–69) | 38.0 |
| Indonesia | 99.6 | 9 (3–17) | 0 | 9 (3–17) | 1 | 142 (24–444) | 107.9 |
| Cambodia | 64.3 | 6 (1–11) | 1 | 5 (0–10) | 1 | 45 (3–187) | 5.0 |
| Macau, China | 62.3 | 6 (1–11) | 10 | 0 (0–1) | 0.88 | 3 (1–12) | < 2.0 |
| Philippines | 61.6 | 6 (1–11) | 3 | 3 (0–8) | 0.99 | 36 (3–145) | 33.2 |
| New Zealand | 29.5 | 3 (0–7) | 0 | 3 (0–7) | 0.94 | 37 (2–226) | 244.7 |
| India | 26.0 | 3 (0–6) | 3 | 0 (0–3) | 0.77 | 5 (1–32) | 71.9 |
| Sri Lanka | 13.8 | 2 (0–4) | 1 | 1 (0–3) | 0.62 | 4 (1–29) | 12.2 |
| Maldives | 12.2 | 2 (0–3) | 0 | 2 (0–3) | 0.85 | 22 (1–186) | < 2.0 |
| Myanmar | 10.4 | 1 (0–3) | 0 | 1 (0–3) | 0.6 | 14 (1–146) | < 2.0 |
| Laos | 8.6 | 1 (0–3) | 0 | 1 (0–3) | 0.6 | 14 (1–146) | < 2.0 |

Shearer et al medRxiv https://doi.org/10.1101/2020.04.09.20057257

# Undetected cases and local transmission risk

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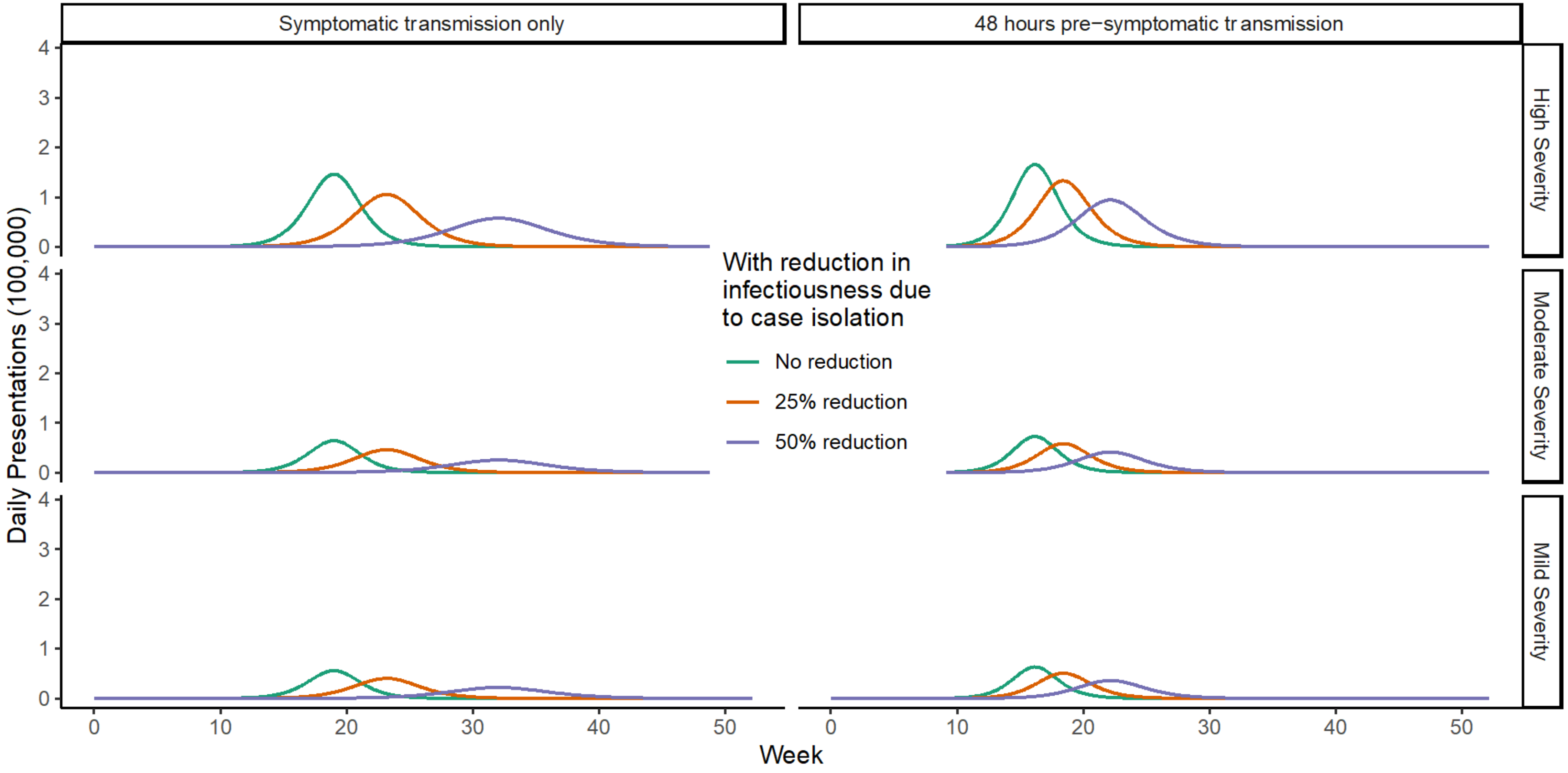
# How did we start estimating likely impact in Australia?




Moss, McCaw, McVernon (early February 2020)

# Model of COVID-19 infection

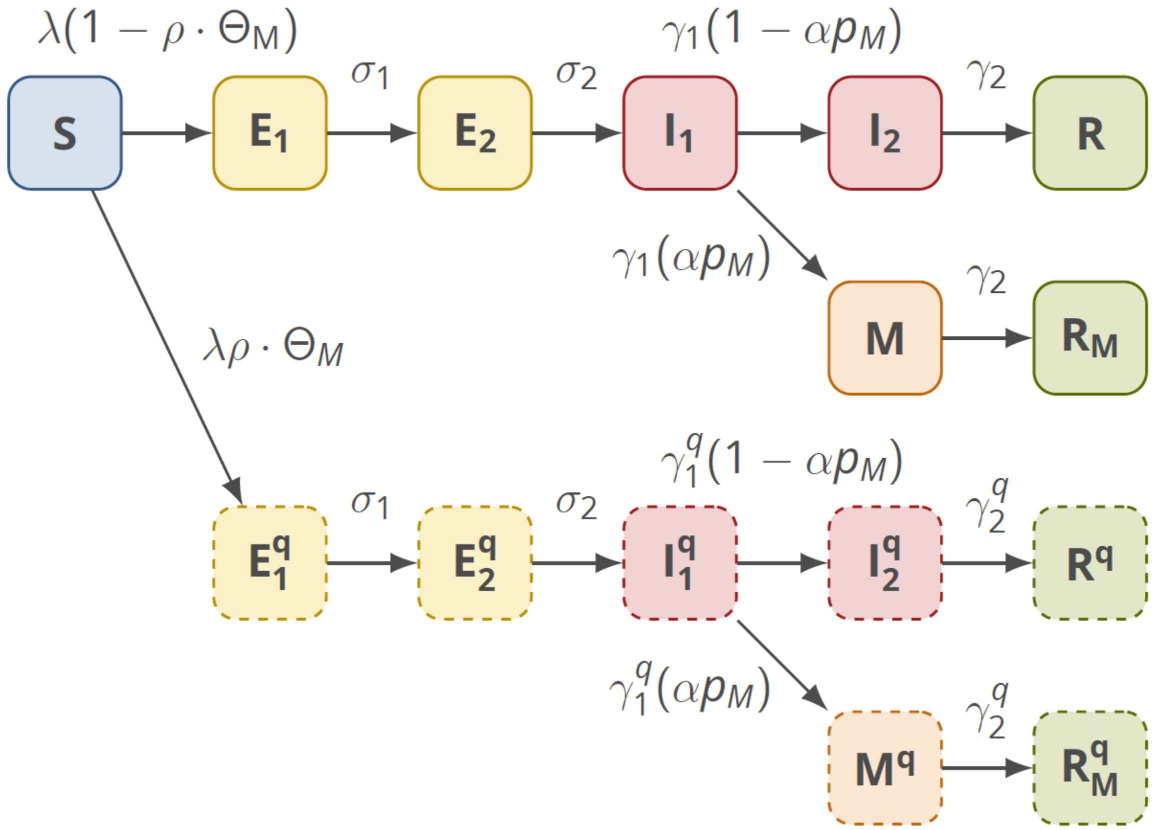
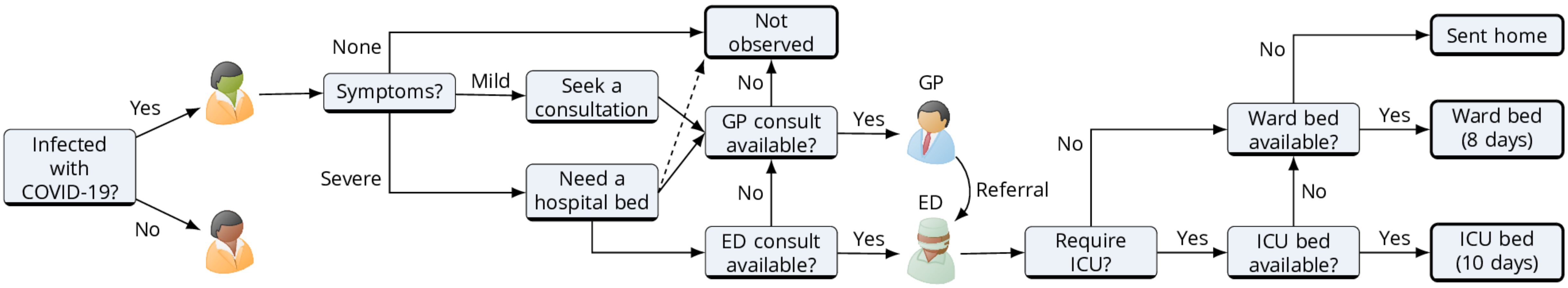



Figure 1: Model diagram. Some proportion $p_M$ of presenting cases are ascertained and isolated. Quarantined persons (shown with dashed borders) exert a lesser force of infection than non-quarantined persons.

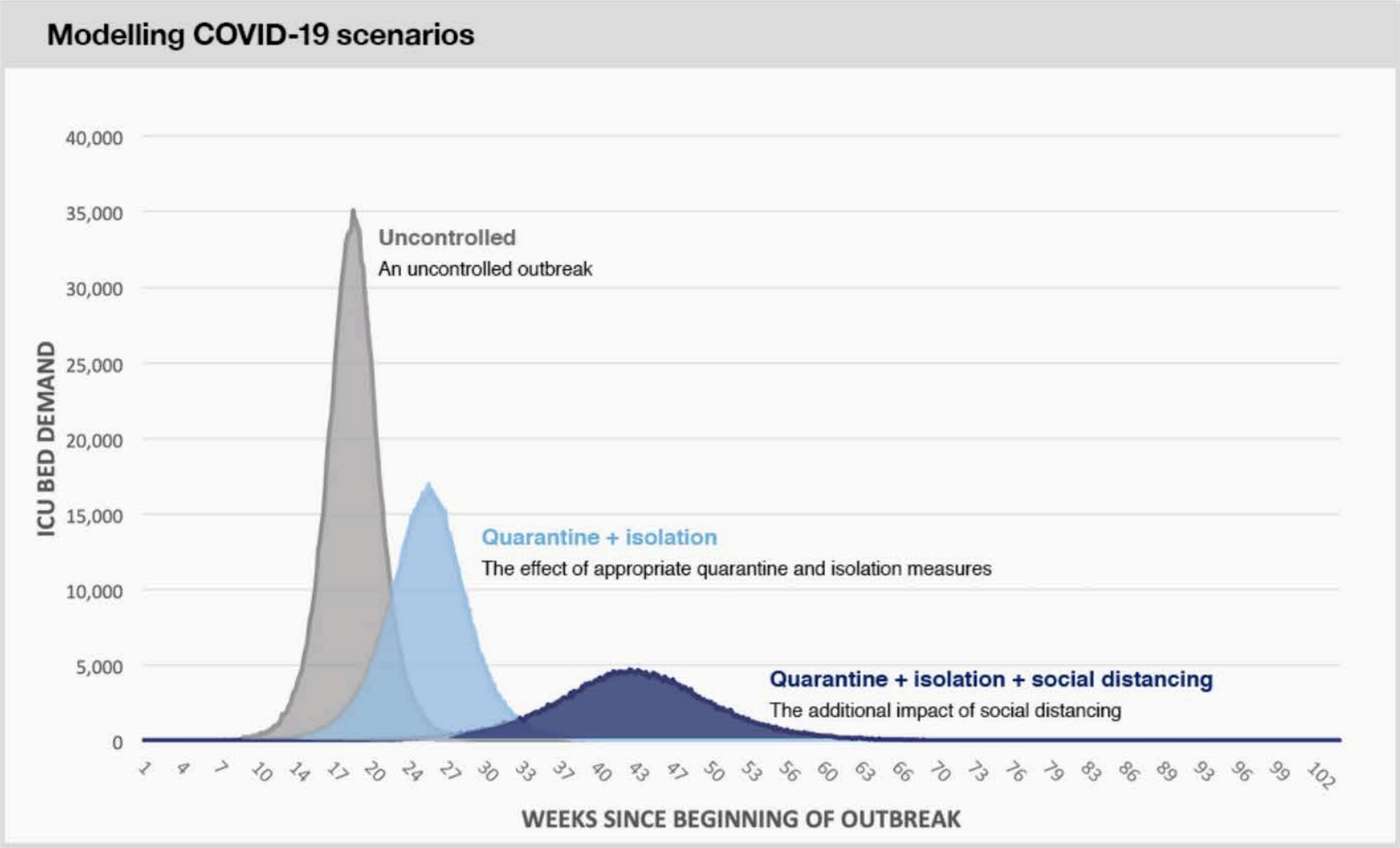
Moss et al medRxiv https://doi.org/10.1101/2020.04.07.20056184

# Clinical pathways model



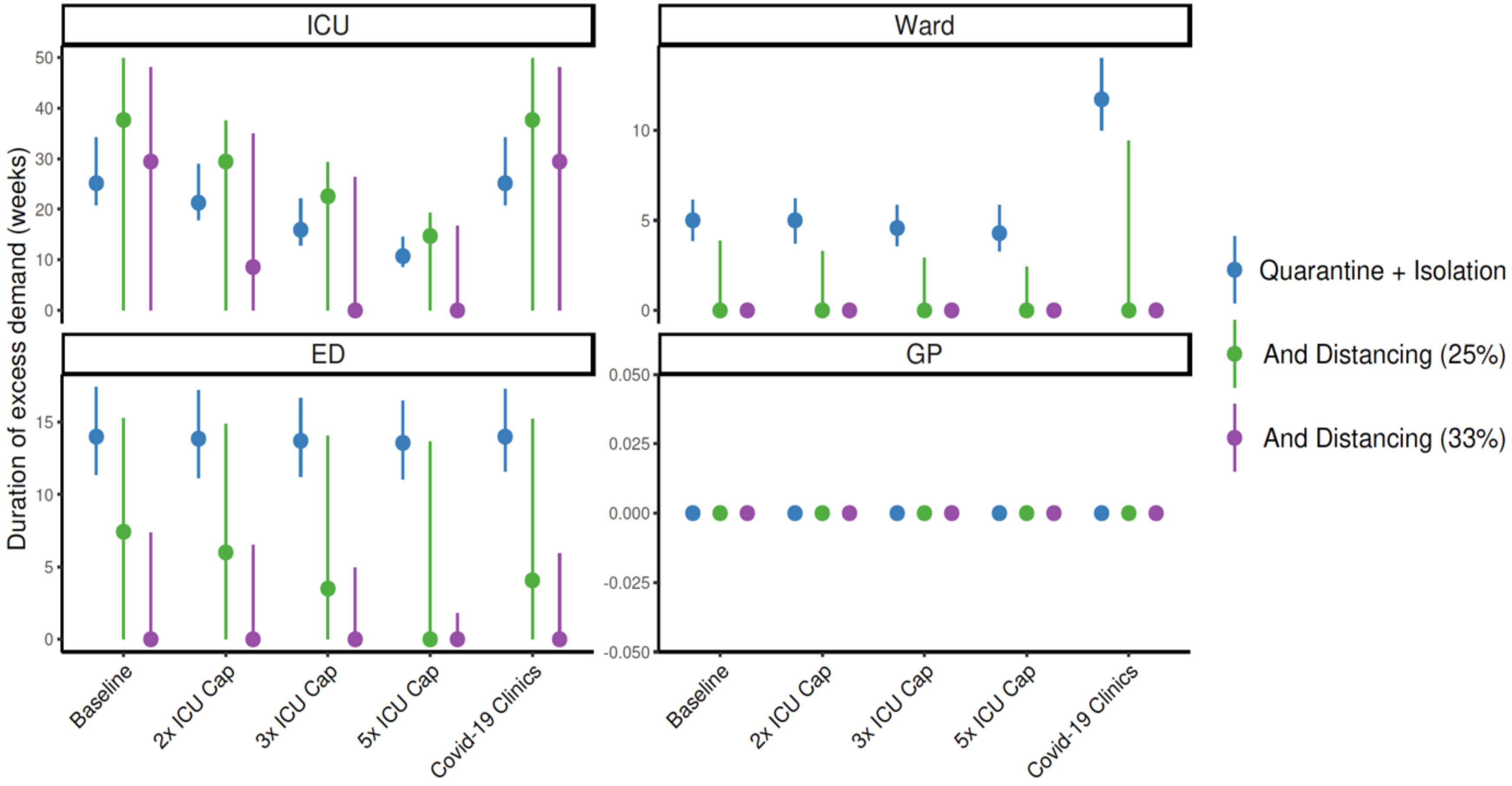
# Modelled measures to flatten the curve*

Coronavirus (COVID-19)




*Not based on Australian case data.

# Can we meet demand?

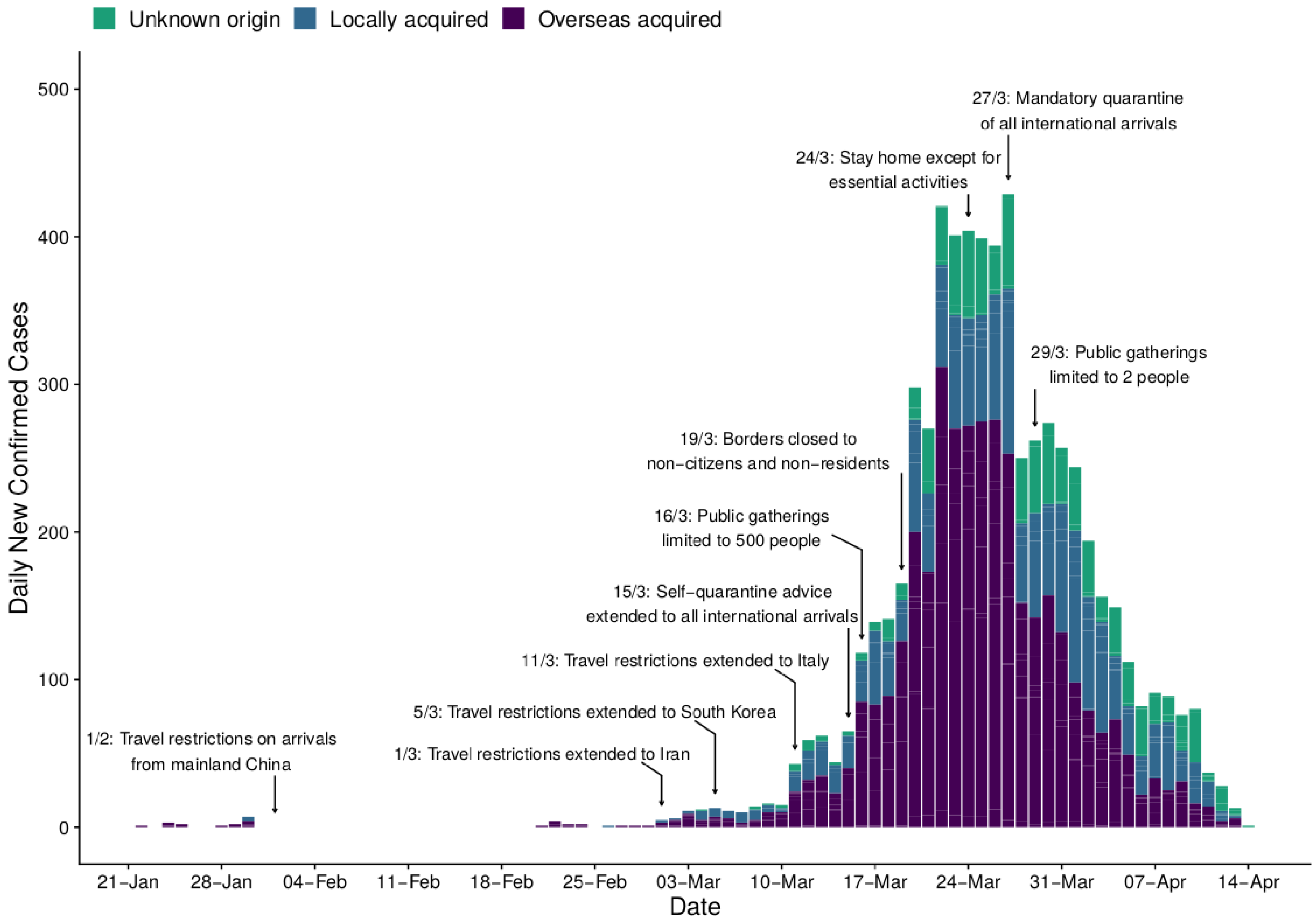



The duration of time during which ICU, ward and ED capacity is exceeded falls with distancing measures

Corresponding access to needed ICU care rises across scenarios, from 30%, to 80% or 100% with a greater degree of distancing

The model provides a reality check on measures needed to keep cases within feasible (expanded) capacity

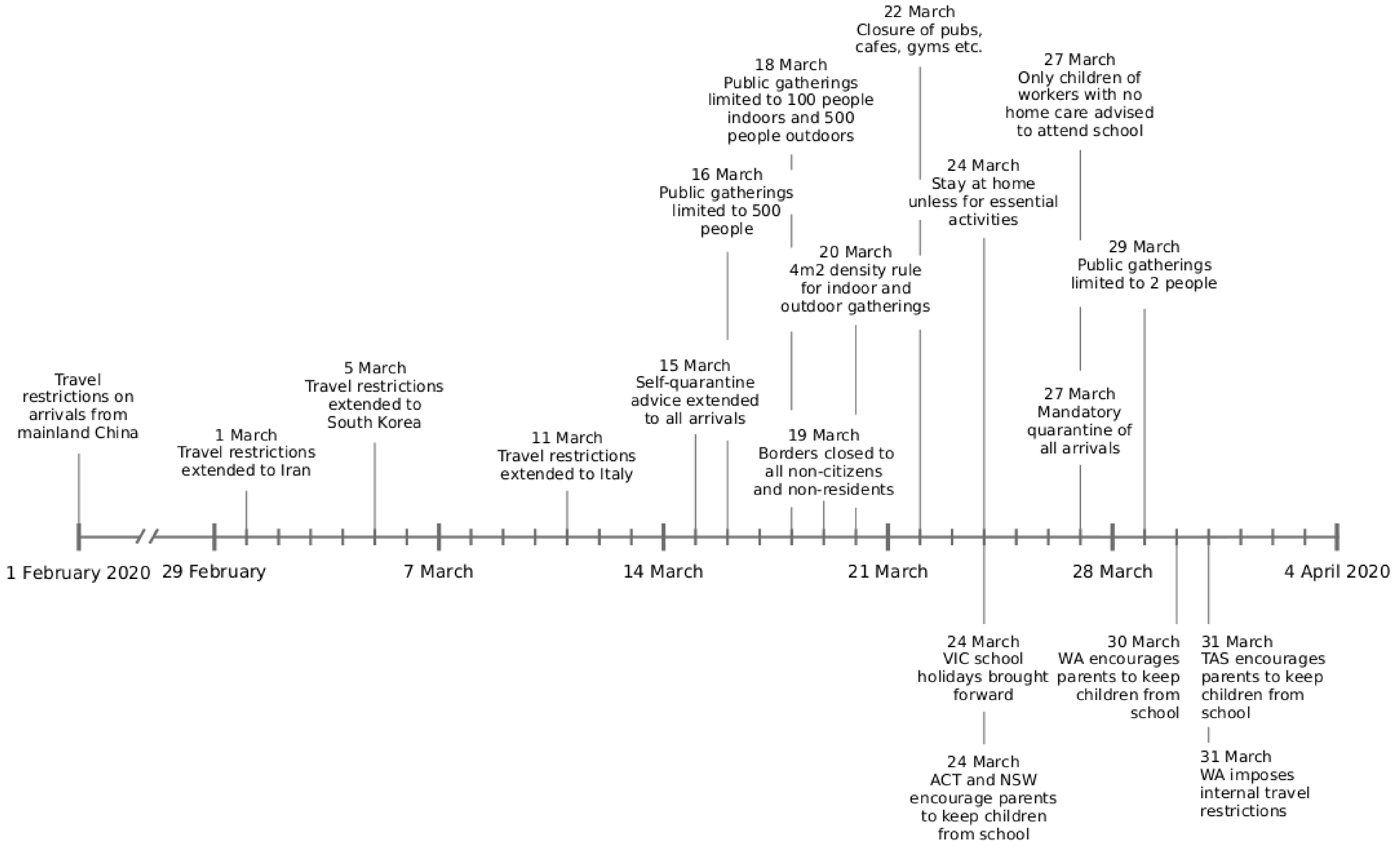
# The Australian epidemic through mid April



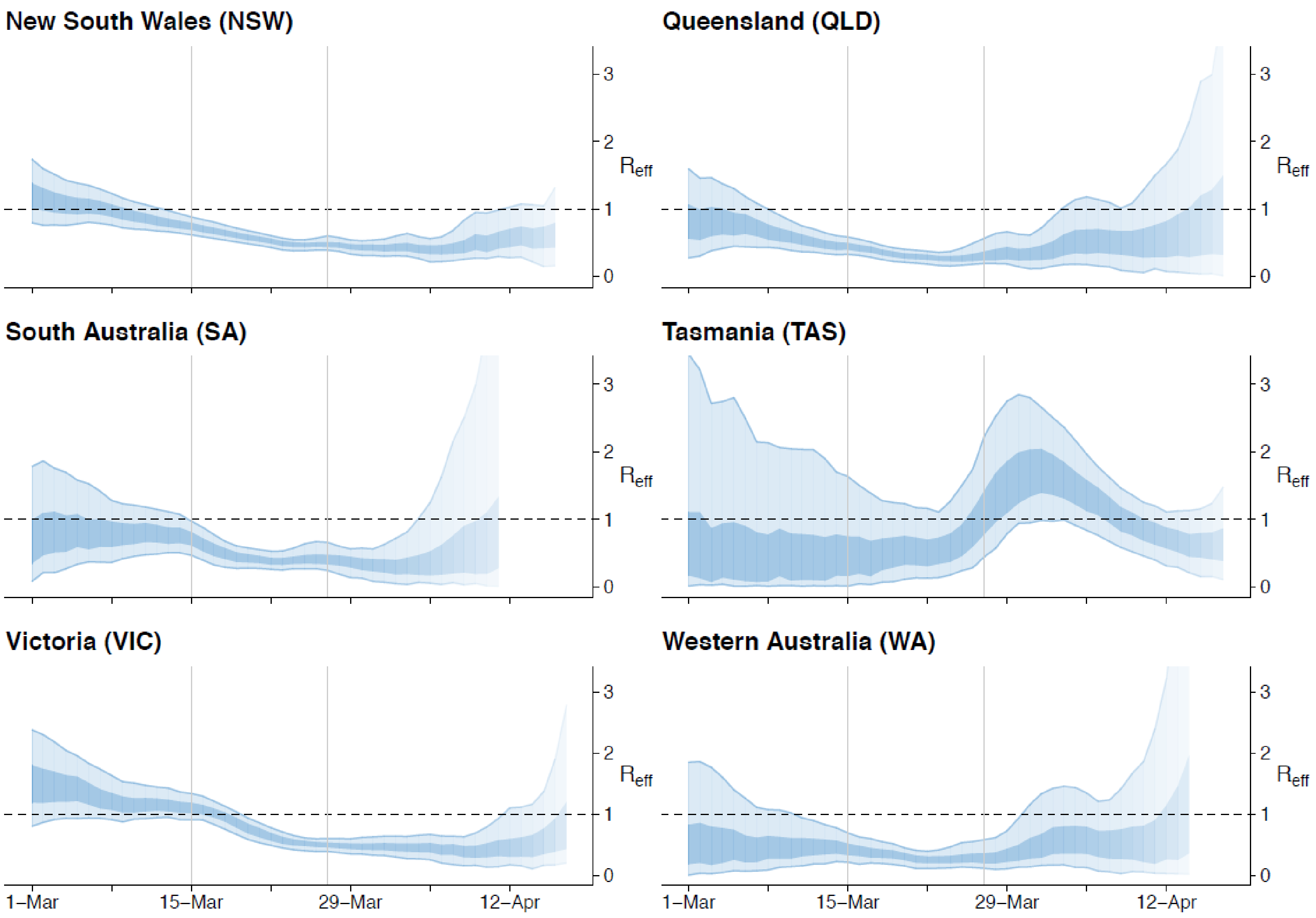

**Epidemic control based on public health measures**

**The population remain largely susceptible**

**National announcements**



# $R_{eff}(t)$ - the effective reproduction number



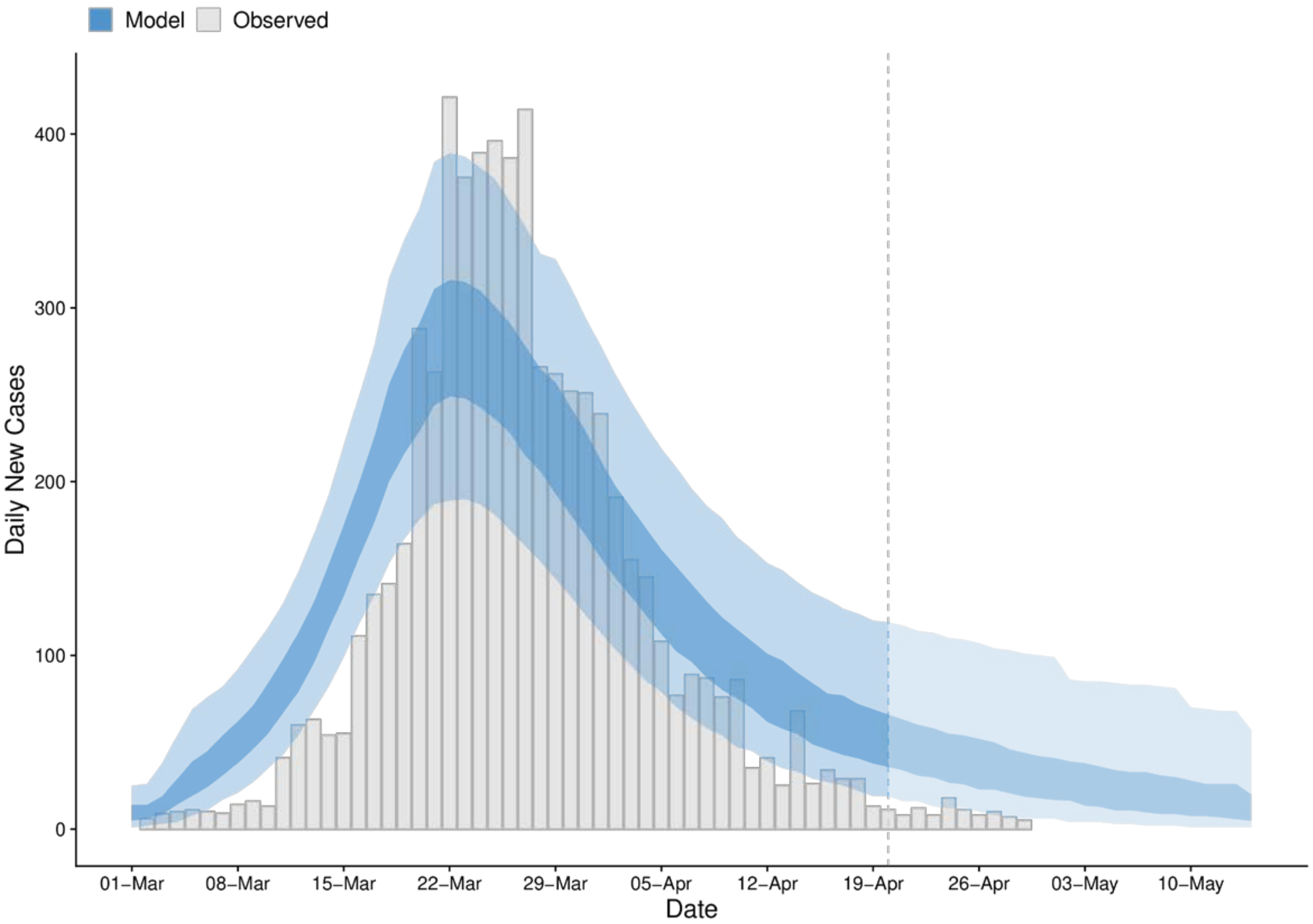

**$R_{eff}(t)$ is the number of secondary cases produced by a primary case at time $t$, accounting for the interventions in place**

**Estimated using an extended version of the LSHTM EpiNow package:**

- **infectiousness of importations is varied based on policy setting**
- **reporting delays accounted for**
- **symptom onset inferred where missing in line-listed data**

Imports less infectious
Until 14 March: 50%
15/3 – 27/3: 80%
Since 28/3: 99%

# Epidemic forecasts



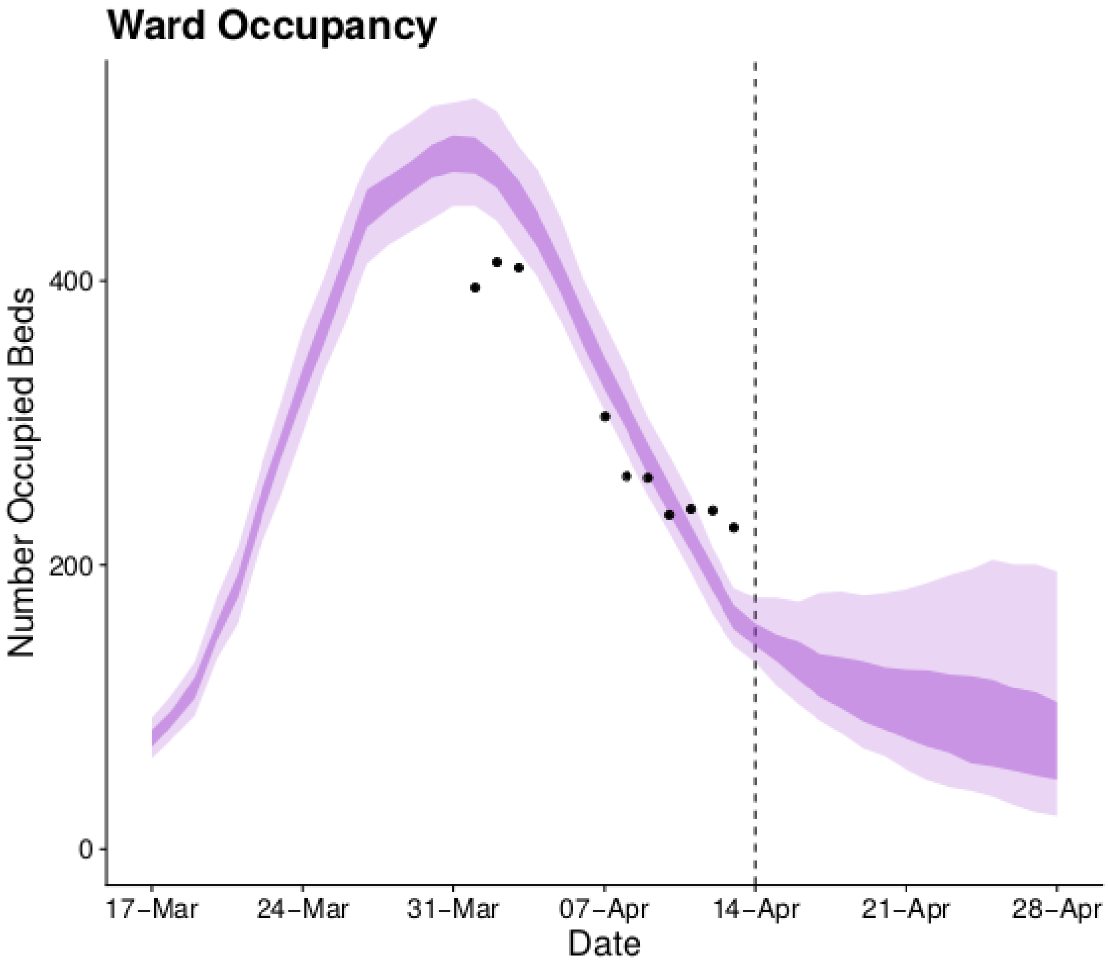

**Particle filter approach as per influenza seasonal forecasting.**

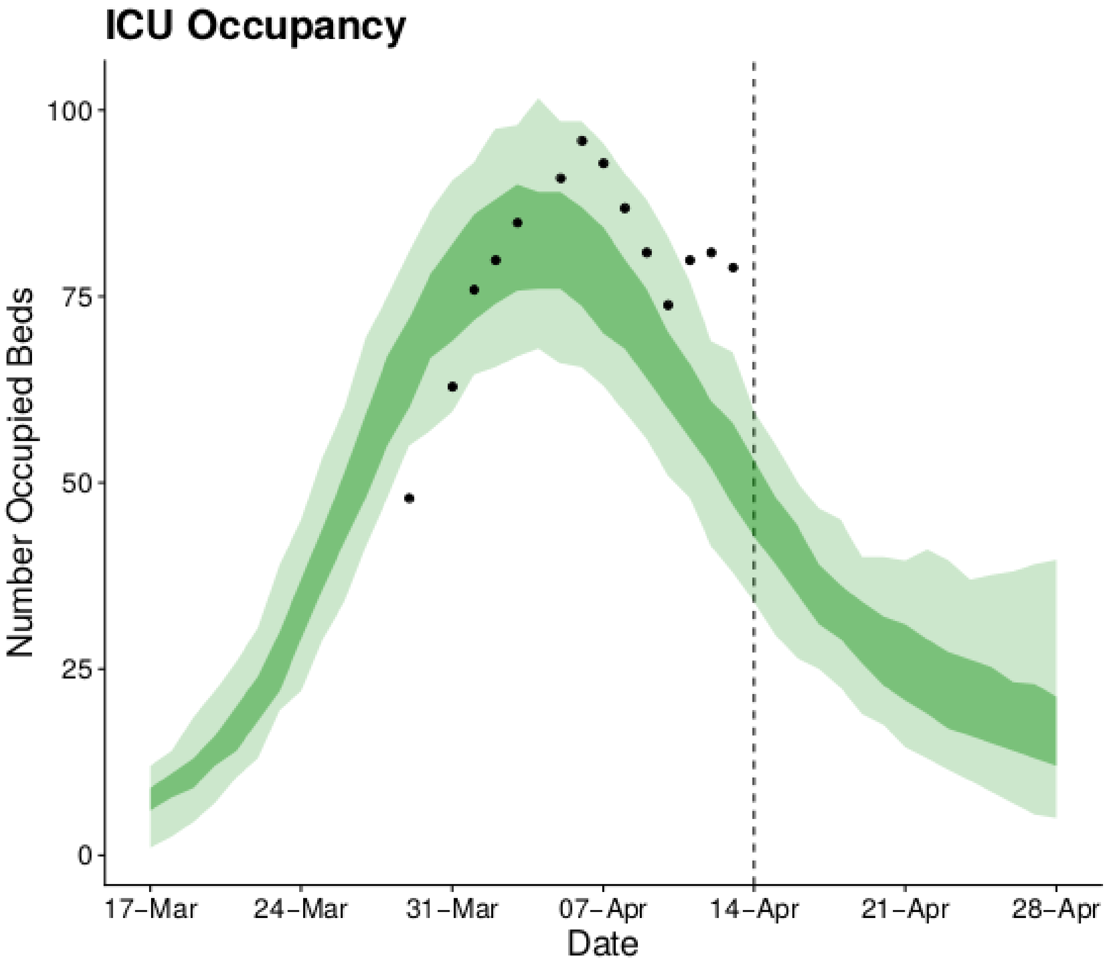
**No single `Australian' epidemic but numbers small in many states - epidemic is difficult to fit with some clear trends in error structure**

**SEEIIR model fit uses $R_{eff}(t)$ estimates to population particles, applied to case data through early April**

**Forecast from 21st April.**

# Projected hospitalization and ICU occupancy



# In conclusion

**Models have helped to inform understanding of COVID-19 epidemiology and spread globally**

**Scenario models developed in the preparedness phase support a combined public health, clinical and whole of society response to mitigate disease impact**

**Current estimates of the effective reproduction number indicate that current measures in place are successfully constraining the epidemic**

**Ongoing evaluation of a carefully staged relaxation of interventions is needed to ensure that we do not exceed health sector capacity**

**The ‘exit strategy’ will be a journey, not a destination, but that is another talk!**

# Acknowledgements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**SPARK (DFAT CHS)**

**DST Group (Peter Dawson)**

**US DTRA**

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**UniMelb Maths/Stats: James McCaw**

**UniMelb CIS: Nic Geard, Nefel Tellioglu**

**Doherty Institute: Jodie McVernon, Trish Campbell, Miranda Smith**

**Uni Adelaide: Andrew Black, James Walker, Dennis Liu, Joshua Ross**

**JCU: Emma McBryde, Adeshina Adekunle, Michael Meehan**

**ANU: Kathryn Glass**

**UNSW and Kirby: James Wood, Deb Cromer**

**Curtin: Nick Golding**

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