Real-time analysis of COVID-19 – epidemiology, statistics and modelling in action

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1996

BSE/vCJD
in the UK

2001

FMD
in the UK

2003

SARS
in Hong Kong

2009

Pandemic
Influenza

2013/4

MERS
in Saudi
Arabia

2014/6

Ebola
in West
Africa

2016

Zika

2018…

Ebola
in DRC

2020…

COVID-19

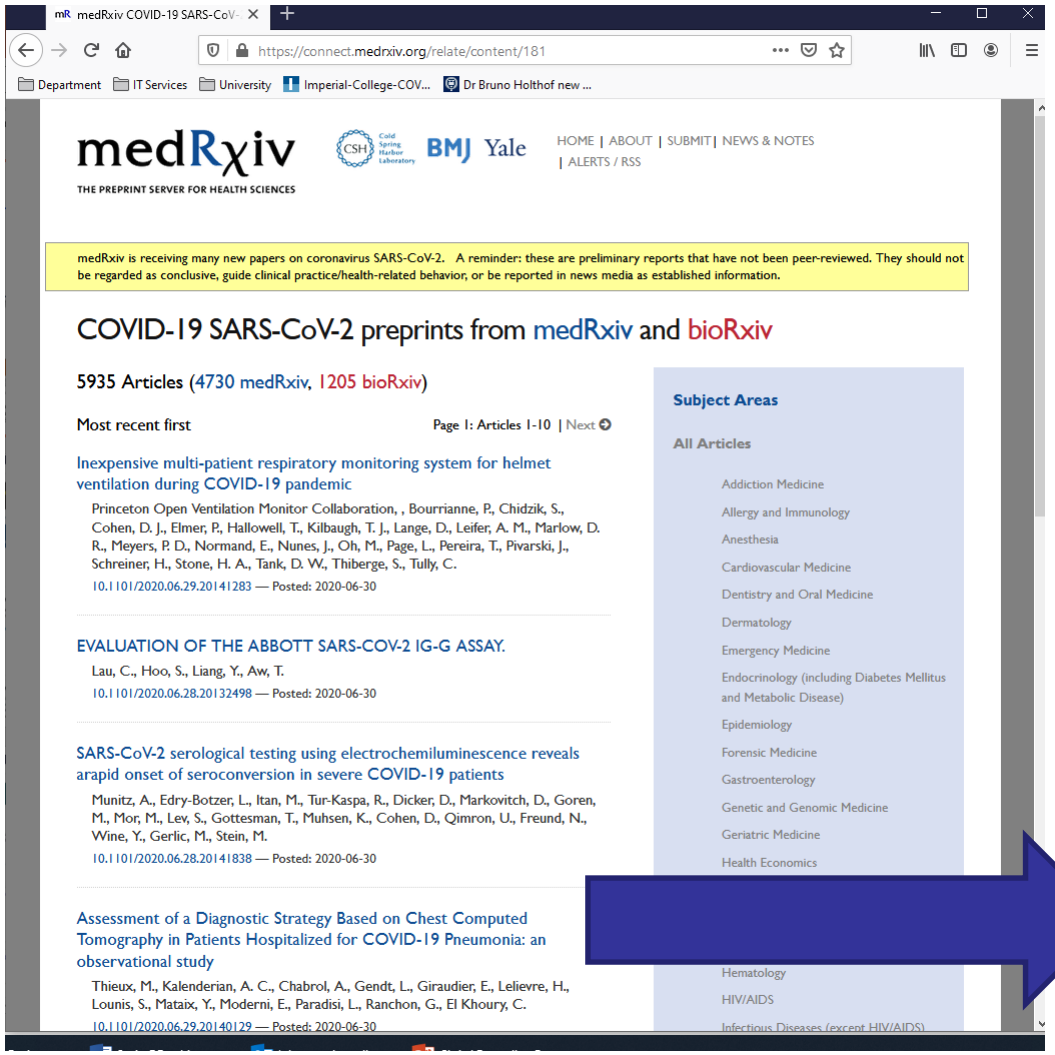
What do you most want to know?

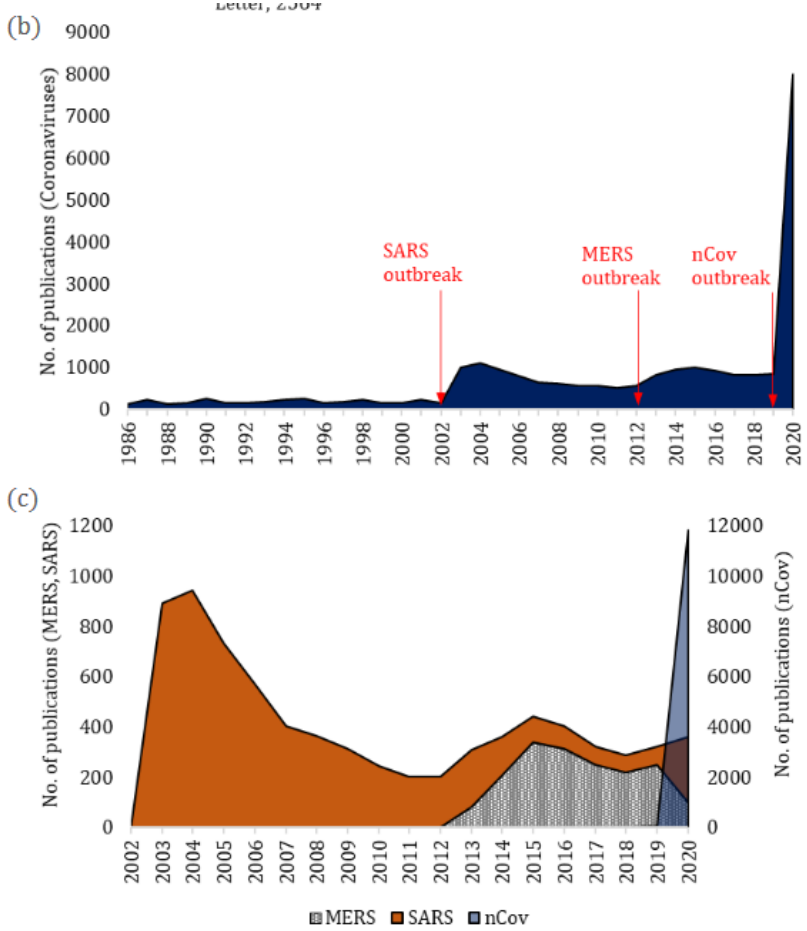
• What are the symptoms?	Characterise cases
• How many cases are there?	Estimate cases in source from exportations
• How many cases might there be?	Estimate epidemic growth
• How serious is the disease?	Estimate the CFR
• If someone is exposed to infection, how long till they know if they are free of infection?	Estimate the incubation period distribution
• How might we control the disease?	Consider options, including isolation, quarantine, vaccination, as data allow.

Relevant paper: Cori A., Donnelly CA, Dorigatti I, *et al.* Key data for outbreak evaluation: building on the Ebola experience. *Phil. Trans. R. Soc.* B372, 20160371, 2017. http://dx.doi.org/10.1098/rstb.2016.0371

Real-time analyses

As of 30 June 2020:





Temporal distributions of
(b) the number of Coronavirus studies,
(c) the SARS, MERS and Covid-19 studies.

from Haghani & Bliemer
https://www.biorxiv.org/content/10.1101/2020.05.31.126813v1.full

COVID-19

- COVID-19 reports
- COVID-19 planning tools
- COVID-19 scientific resources
- COVID-19 public resources
- COVID-19 publications

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COVID-19 reports

Since the emergence of the new coronavirus (COVID-19) in December 2019, we have adopted a policy of immediately sharing research findings on the developing pandemic. This page provides all publicly published online reports by the Imperial College COVID-19 Response Team.

Report 28: 18 June 2020

Excess non-COVID-19 deaths in England and Wales between 29th February and 5th June 2020

Find out more

Report 27: 15 June 2020

Adapting hospital capacity to meet changing demands during the COVID-19 pandemic

Find out more

Report 26: 8 June 2020

Reduction in mobility and COVID-19 transmission

Find out more

Report 25: 29 May 2020

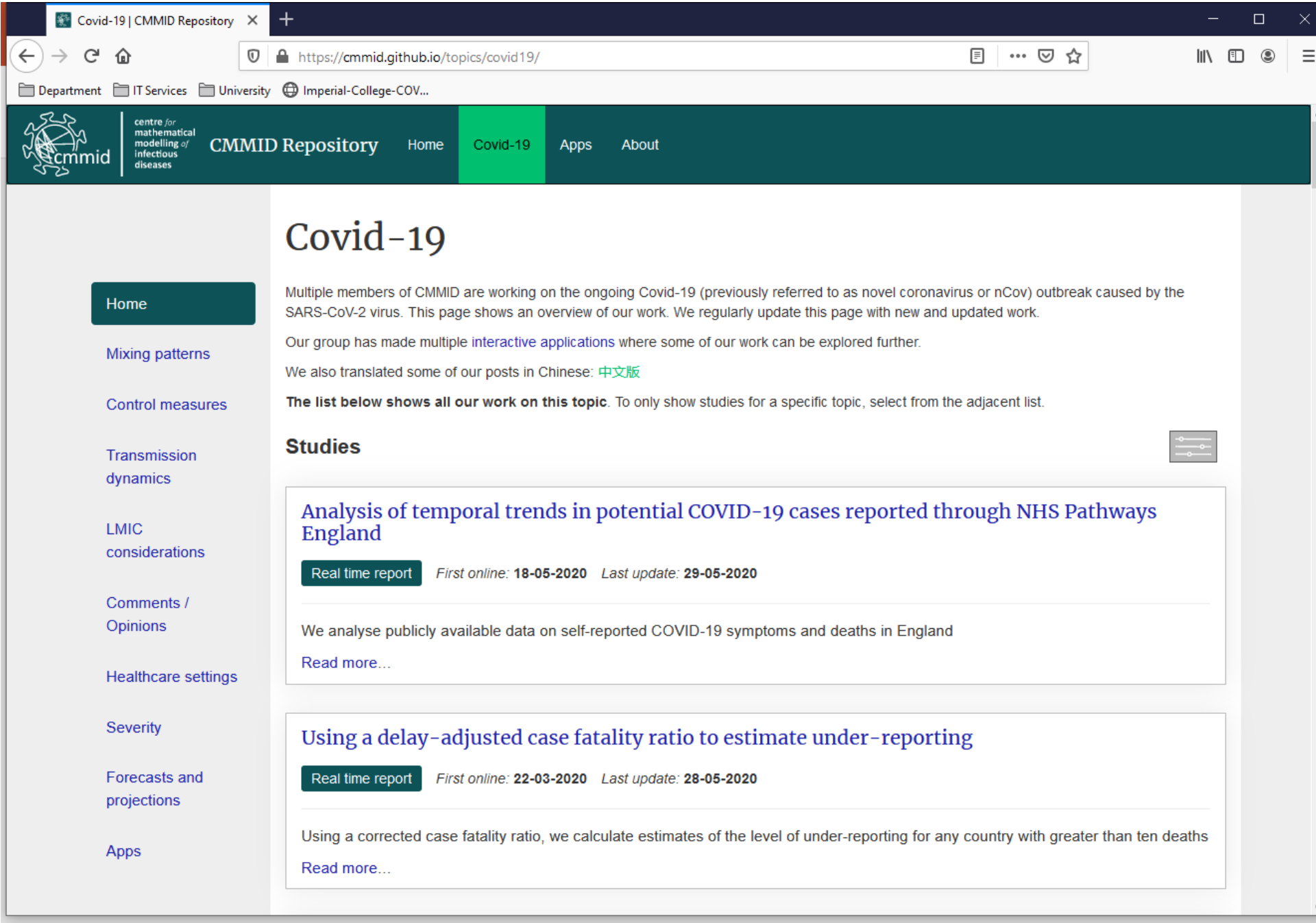
Response to COVID-19 in South

Report 24: 29 May 2020

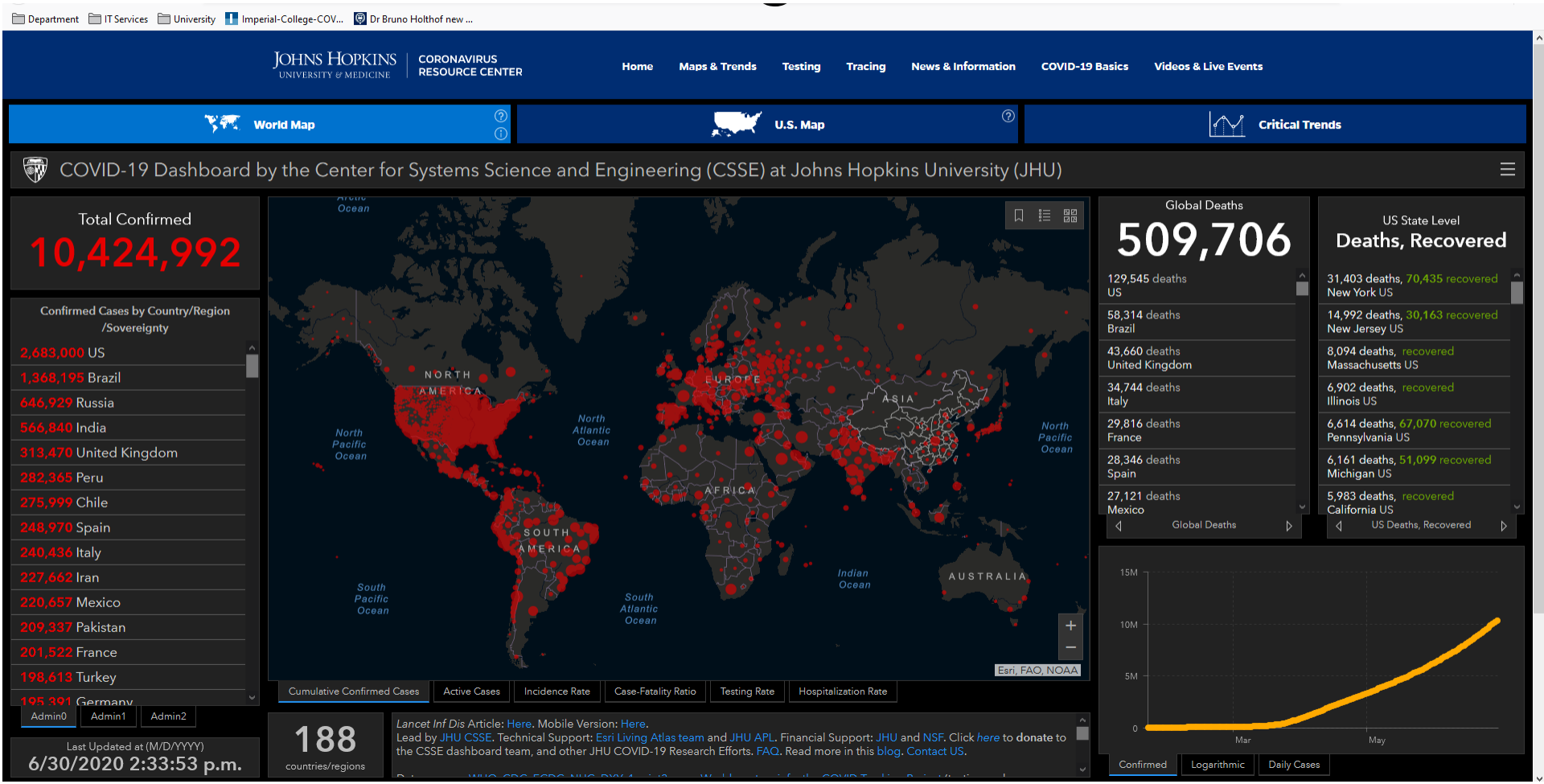
Anonymised and aggregated

Report 23: 21 May 2020

State-level tracking of COVID-19



https://cmmid.github.io/topics/covid19/



https://coronavirus.jhu.edu/map.html

Magnitude of the epidemic

$$Total\ number\ of\ cases = \frac{number\ of\ cases\ detected\ outside\ China}{probability\ any\ one\ case\ will\ be\ detected\ outside\ China}$$

where the probability any one case will be detected overseas (p) is given

$$p = daily\ probability\ of\ international\ travel \times mean\ time\ to\ detection\ of\ a\ case$$

The daily probability of travel is calculated by:

$$daily\ probability\ of\ international\ travel = \frac{daily\ outbound\ international\ travellers\ from\ Wuhan}{catchment\ population\ of\ Wuhan\ airport}$$

Finally, the mean time to detection can be approximated by:

$$mean\ time\ to\ detection = incubation\ period + mean\ time\ from\ onset\ of\ symptoms\ to\ detection$$

17 January 2020
Report 1

	Baseline	Smaller catchment	Shorter detection window
Exported number of confirmed cases	3	3	3
Daily international passengers travelling out of Wuhan International Airport	3,301	3,301	3,301
Effective catchment population of Wuhan International Airport	19 million	11 million	19 million
Detection window (days)	10 days	10 days	8 days
Estimated total number of cases (95% CI)	**1,723 (427 – 4,471)**	996 (246 – 2,586)	2,155 (535 – 5,590)

https://www.imperial.ac.uk/mrc-global-infectious-disease-analysis/covid-19/covid-19-reports/

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Health

New virus in China 'will have infected hundreds'

By James Gallagher
Health and science correspondent

18 January 2020 Share

Coronavirus pandemic

There were six coronaviruses known to infect people before the latest discovery

The number of people already infected by the mystery virus emerging in China is far greater than official figures suggest, scientists have told the BBC.

There have been **more than 60** confirmed cases of the new coronavirus, but UK experts estimate a figure nearer **1,700**.

Two people are known to have died from the respiratory illness, which appeared in Wuhan city in December.

"I am substantially more concerned than I was a week ago," disease outbreak scientist Prof Neil Ferguson, said.

The work was conducted by the MRC Centre for Global Infectious Disease Analysis at Imperial College London, which advises bodies including the UK government and the World Health Organization (WHO).

https://www.bbc.co.uk/news/health-51148303

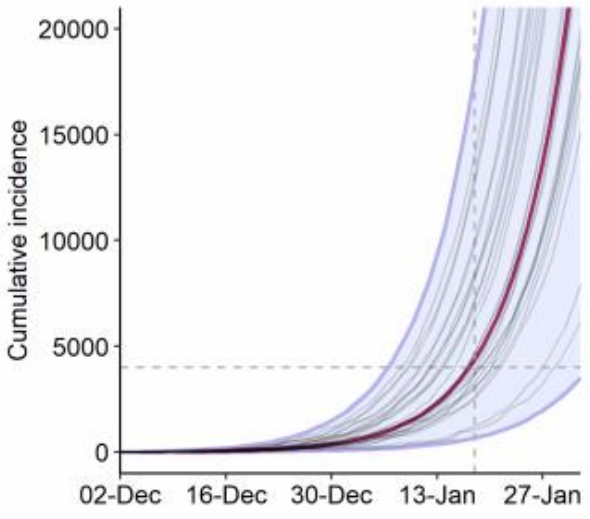
	17 January 2020 Report 1			22 January 2020 Report 2		
	Baseline	**Smaller catchment**	**Shorter detection window**	**Baseline**	**Smaller catchment**	**Shorter detection window**
Exported number of confirmed cases	3	3	3	7	7	7
Daily international passengers travelling out of Wuhan International Airport	3,301	3,301	3,301	3,301	3,301	3,301
Effective catchment population of Wuhan International Airport	19 million	11 million	19 million	19 million	11 million	19 million
Detection window (days)	10 days	10 days	8 days	10 days	10 days	8 days
Estimated total number of cases (95% CI)	**1,723 (427 – 4,471)**	996 (246 – 2,586)	2,155 (535 – 5,590)	**4,000 (1,700 – 7,800)**	2,300 (1,000 – 4,500)	5,000 (2,200 – 9,700)

https://www.imperial.ac.uk/mrc-global-infectious-disease-analysis/covid-19/covid-19-reports/

How have case numbers grown?

Table 1: Best-case, central and worst-case estimates of 2019-nCoV human-to-human R_0 compatible with either 4000 (top half of table) or 1000 (bottom half of table) total cases by 18/01/2020. Values of R_0 >1 represent self-sustaining human-to-human and are highlighted in red. Baseline estimates highlighted in bold.

Number of cases caused by zoonotic exposure	Assumed total number of cases by 18/01/2020	Best-case R_0	Central (median) R_0	Worst-case R_0
40	**4000**	**2.1**	**2.6**	**3.5**
80	4000	1.8	2.2	2.7
120	4000	1.7	2.0	2.4
160	4000	1.6	1.8	2.2
200	4000	1.5	1.7	2.0
40	1000	1.4	1.9	2.7
80	1000	1.2	1.5	2.0
120	1000	1.1	1.3	1.7
160	1000	1.0	1.2	1.5
200	1000	0.9	1.1	1.3



Assuming an 8.4 day average generation time

Natsuko Imai, Anne Cori, Ilaria Dorigatti, Marc Baguelin, Christl A. Donnelly, Steven Riley, Neil M. Ferguson
WHO Collaborating Centre for Infectious Disease Modelling, MRC Centre for Global Infectious Disease Analysis, J-IDEA, Imperial College London

Report 3, 25 January 2020 https://www.imperial.ac.uk/mrc-global-infectious-disease-analysis/covid-19/covid-19-reports/

Case fatality ratio

- Proportion of cases who eventually die from the disease;
- Often estimated by using aggregated numbers of cases and deaths at a single time point:
  - E.g.: case fatality ratios compiled daily by WHO during the SARS outbreak:

    estimate of the case fatality ratio:

    number of deaths / total number of cases.
  - Simple estimates of these reports can be misleading if, at the time of the analysis, the outcome (death or recovery) is unknown for an important proportion of patients.

Proportion of observations censored in the SARS outbreak

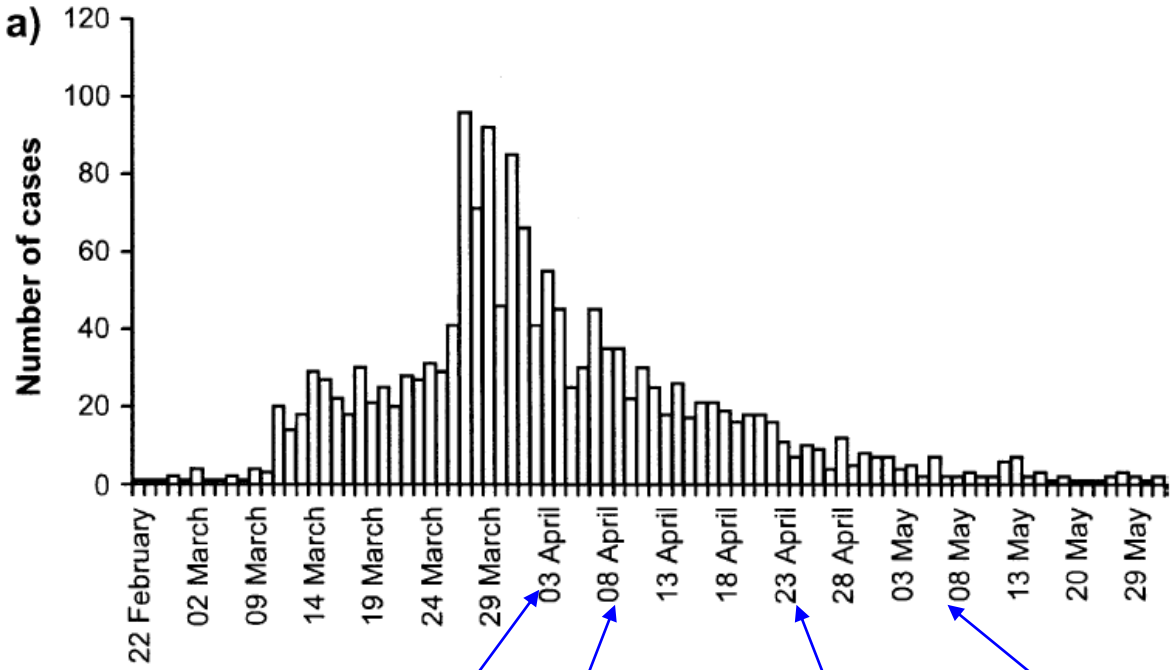


TABLE 1. Summary of the number of cases and the degree of censoring at different time points for the epidemic of severe acute respiratory syndrome in Hong Kong, 2003

	Date						
	April 2	April 9	April 16	April 23	April 30	May 7	May 14
No. of cases	925	1,201	1,367	1,489	1,547	1,582	1,607
% of observations censored	85.9	81.2	71.5	51.6	35.1	25.2	17.3

We do not know the outcome (death or recovery) yet.

[Ghani *et al. AJE*, 2005]

Simple methods

- Method 1:

$$CFR = \frac{D}{C}$$

D = Number of deaths

C = Total number of cases

- Method 2:

$$CFR = \frac{D}{(D + R)}$$

D = Number of deaths

R = Number recovered

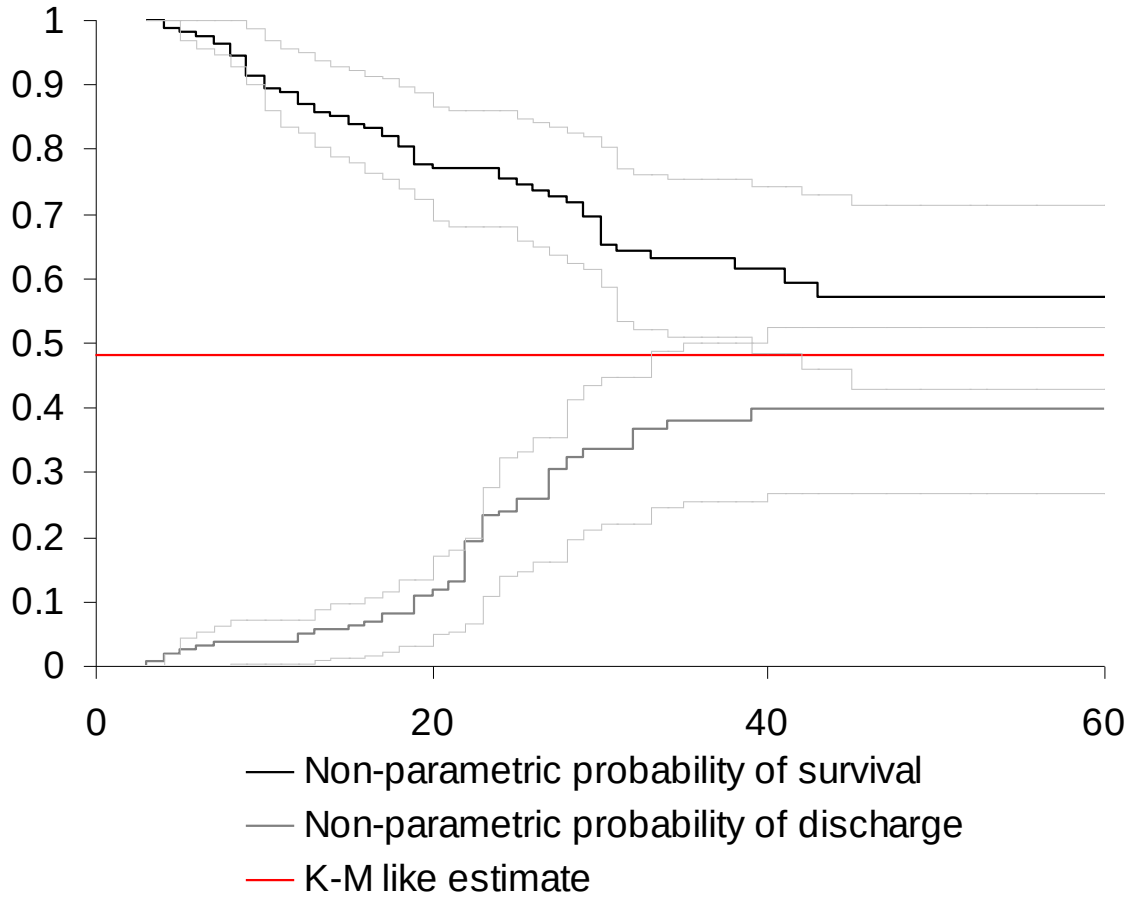
Adapted Kaplan-Meier method

To extrapolate incomplete survivor functions, assume that death/discharge rate at the tail occurs at the same rate as previously:

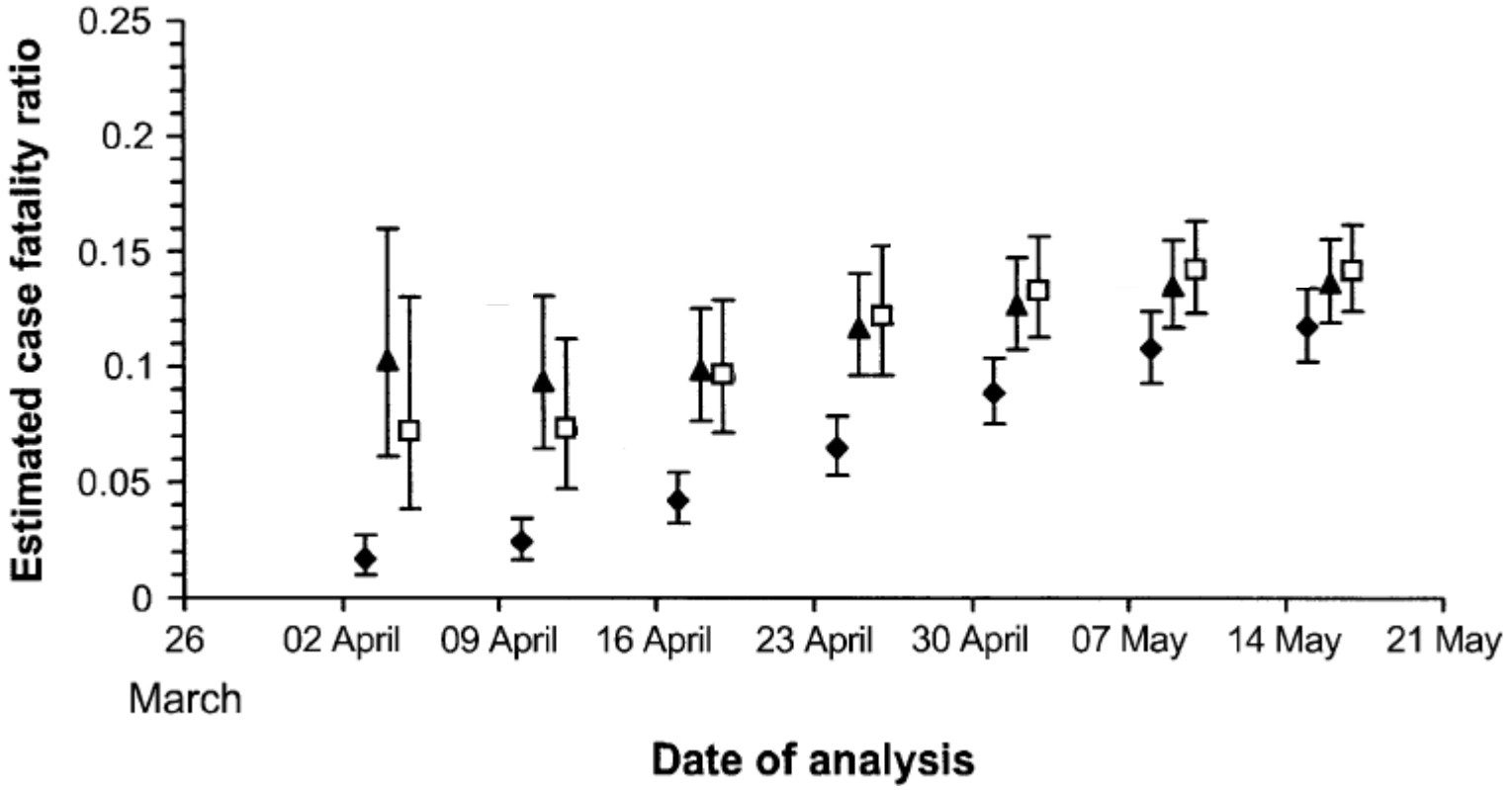
Proba death at the tail

$$\theta_0 = \frac{\hat{\theta}_0}{\left(\hat{\theta}_0 + \hat{\theta}_1\right)}$$

Proba discharge at the tail



Comparison of the estimates



(deaths/cases)

deaths/(deaths+recoveries)

[Ghani *et al. AJE*, 2005]

Misinterpretation of the trend

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SARS becoming deadlier: Officials

Friday, April 25, 2003 Posted: 12:41 AM EDT (0441 GMT)

HONG KONG, China -- As China takes drastic steps to contain the SARS virus, Hong Kong officials say the disease is proving more deadly than first thought.

Global concern is mounting over the rising death rate as authorities clamber to contain the virus, quarantining people, sealing off hospitals, closing schools and installing heat scanners at airports.

Officials in the former British colony of Hong Kong -- the hardest-hit area along with China -- on Thursday revised the death rate from SARS to 7.2 percent from 5 percent.

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The New York Times

Health

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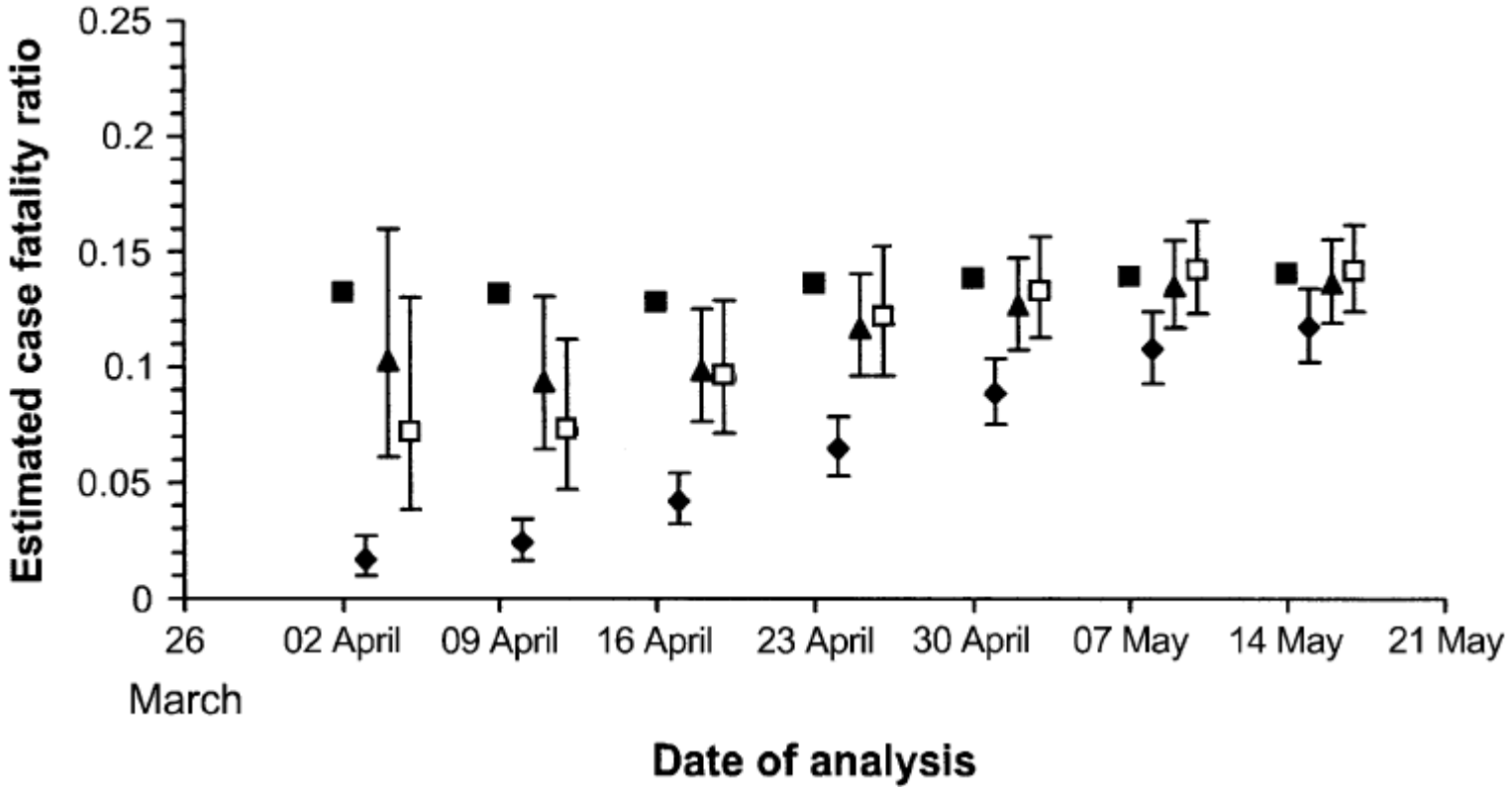
Death Rate From Virus More Than Doubles, Varying Sharply by Country

By LAWRENCE K. ALTMAN
Published: April 22, 2003

The death rate from severe acute respiratory syndrome has more than doubled, to 5.6 percent, since the epidemic was first detected in mid-March, causing deep concern among health officials.

Although the overall death rate, according to World Health Organization statistics, has hovered around 4 percent in the last three weeks, it has varied widely among the 26 countries, plus Hong Kong, with cases of the disease, known as SARS.

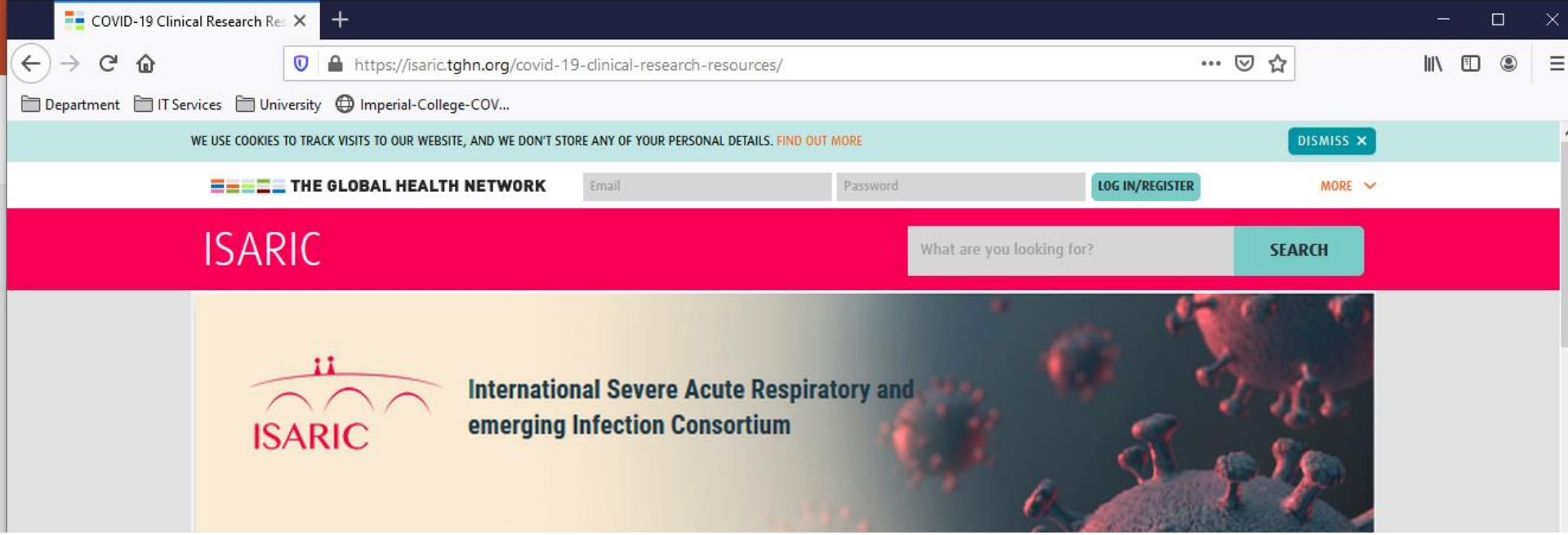
Comparison of the estimates

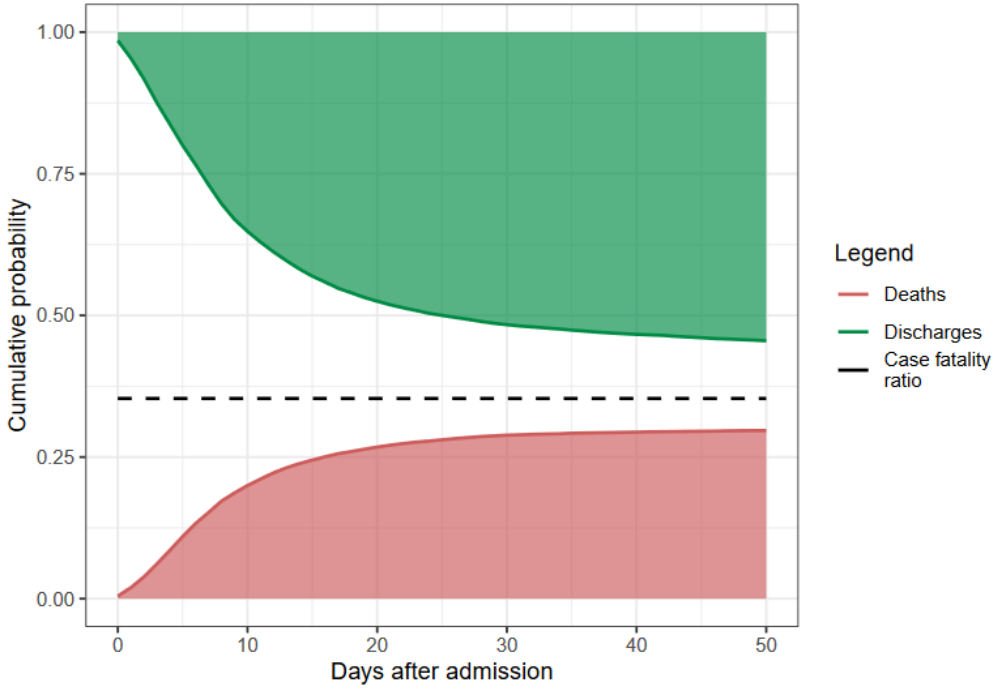


(deaths/cases)

deaths/(deaths+recoveries)

[Ghani *et al. AJE*, 2005]



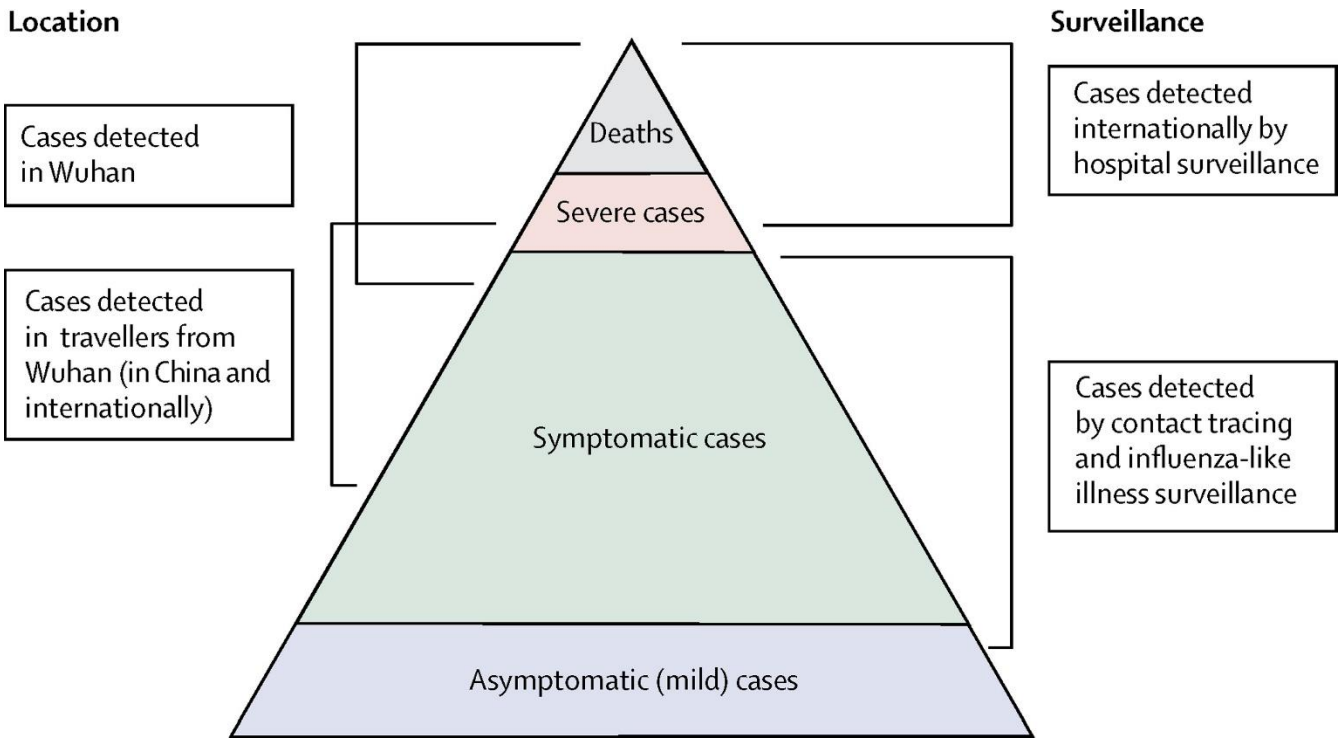


Probabilities of death (red curve) and recovery (green curve).

The black line indicates the case fatality ratio (CFR).

The point estimate of the CFR is 35% (95% CI: 34-36%).

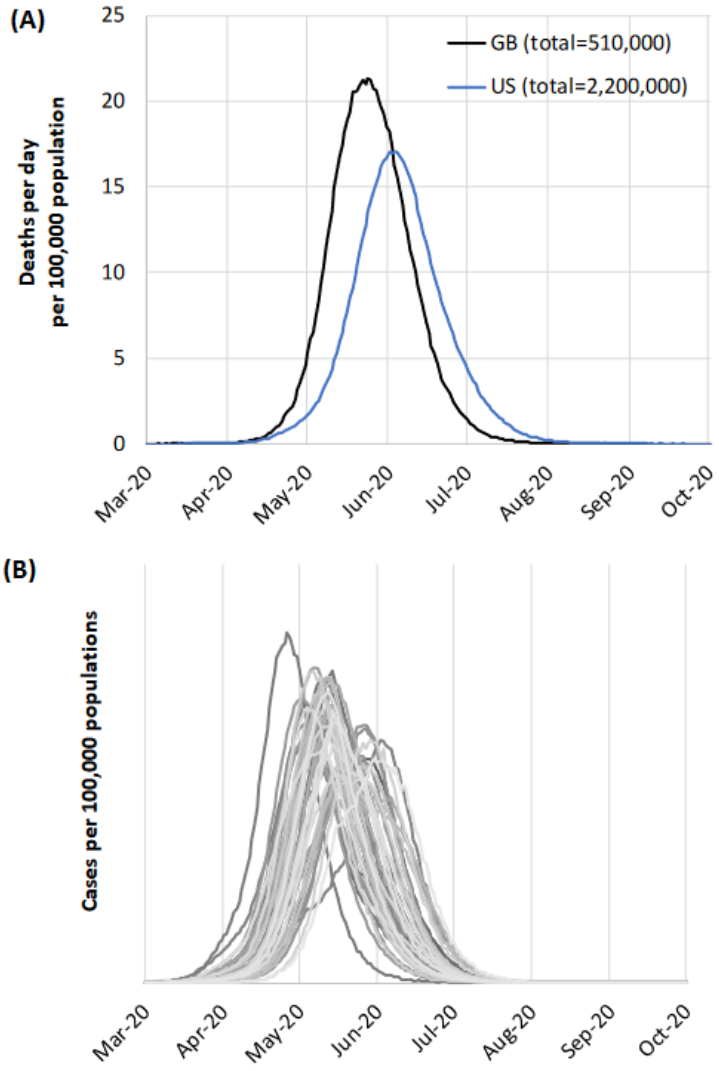
CFR vs IFR



Verity et al. The Lancet Infectious Diseases 2020 20669-677DOI: (10.1016/S1473-3099(20)30243-7)

IFR estimates

Authors	Estimate	When available	Where
Verity *et al*. Imperial College London	1% (0.5-4)	Posted 10 Feb	https://www.imperial.ac.uk/media/imperial-college/medicine/mrc-gida/2020-02-10-COVID19-Report-4.pdf
	0.66% (0.39-1.33)	Posted 13 Mar Pub. 30 Mar	https://www.medrxiv.org/content/10.1101/2020.03.09.20033357v1 https://www.thelancet.com/pdfs/journals/laninf/PIIS1473-3099(20)30243-7.pdf
Chow *et al*. National Institutes of Health	0.17% (0.05-0.9) first week 0.8% (0.2-4) as of 15 April	Posted 5 May	https://www.medrxiv.org/content/10.1101/2020.04.29.20083485v1
Grewelle & De Leo Stanford	1.04% (0.77-1.38)	Posted 18 May	https://www.medrxiv.org/content/10.1101/2020.05.11.20098780v1
Rosenfeld *et al.* Institute for Disease Modelling	0.9%	"Results as of May 25"	https://covid.idmod.org/data/Modeling_countermeasures_for_balanced_reopening_King_County_Washington.pdf
Wood *et al.* University of Bath	0·43% (0·23–0·65) China 0·55% (0·30–0·82) UK 0·20% (0·11–0·30) India	Pub. 28 May	https://www.thelancet.com/journals/laninf/article/PIIS1473-3099(20)30437-0/fulltext



Individual-based simulations of transmission was used to explore scenarios of unmitigated epidemics, mitigated epidemics and suppressed epidemics in the UK and elsewhere.

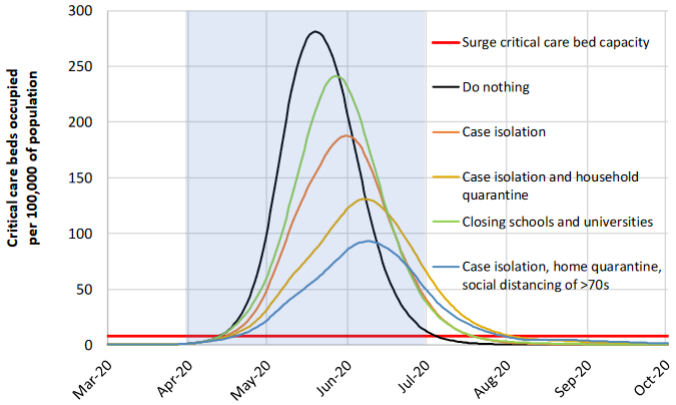


Figure 1: Unmitigated epidemic scenarios for GB and the US. (A) Projected deaths per day per 100,000 population in GB and US. (B) Case epidemic trajectories across the US by state.

https://www.imperial.ac.uk/media/imperial-college/medicine/mrc-gida/2020-03-16-COVID19-Report-9.pdf Published 16 Mar 2020

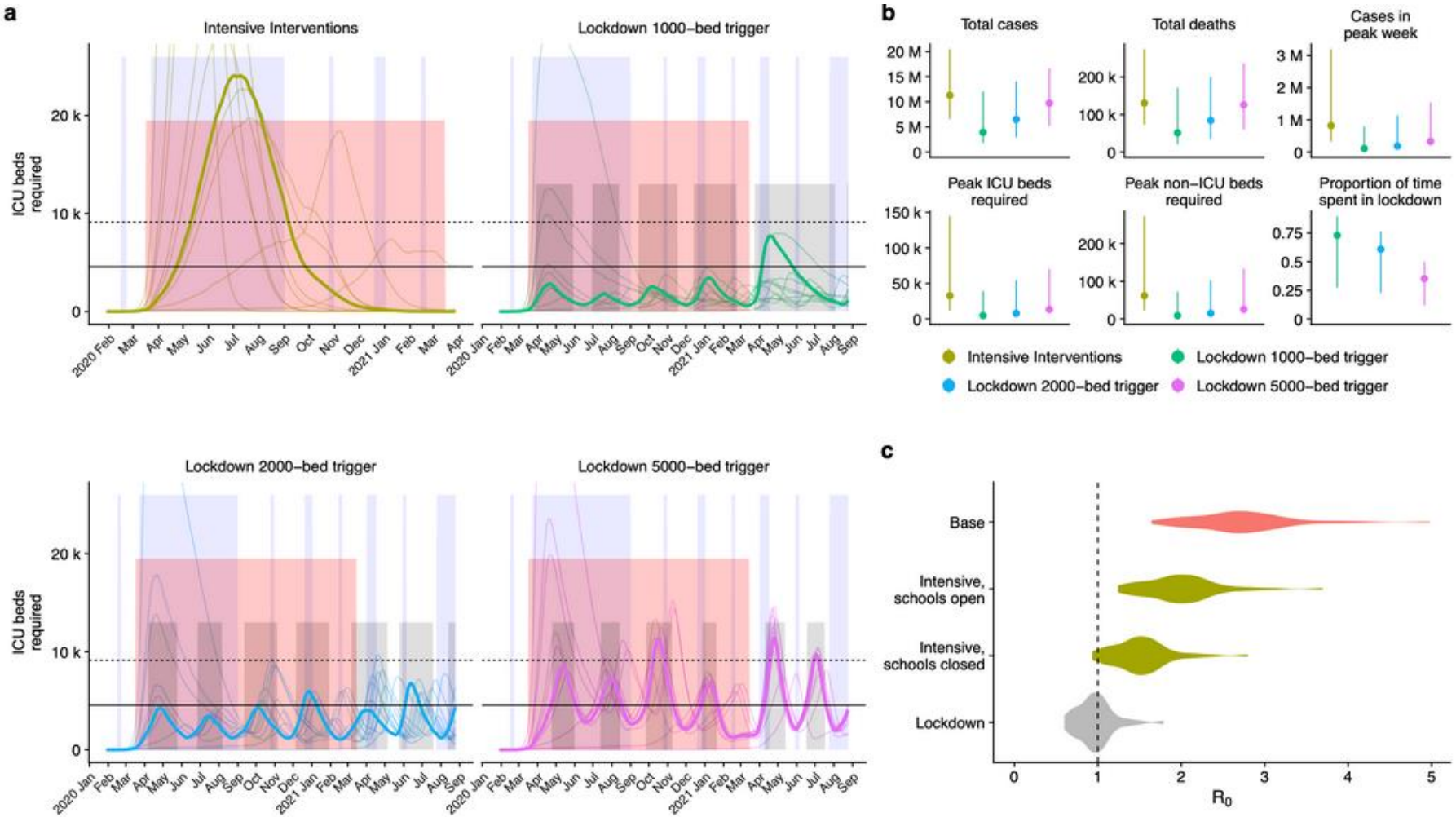


Figure: Projected impact of intensive control measures with reactive lockdowns. (a) Dynamics of the epidemic under different triggers for introduction and lifting of lockdowns (median timing of lockdowns shown as grey shaded areas). Bolded lines show ICU bed occupancy in the median run under each scenario. Horizontal guides show the estimated number of ICU beds in the UK as of January 2020 (solid line) and with a hypothetical doubling of capacity (dashed line). Blue shaded regions show school closures, while the pink shaded region shows a background period of intensive interventions. (b) Summary of epidemic runs. (c) Estimated distribution of R0 under three different interventions: intensive social distancing with schools open and closed, and lockdown.

https://cmmid.github.io/topics/covid19/uk-scenario-modelling.html Published 1 Apr 2020

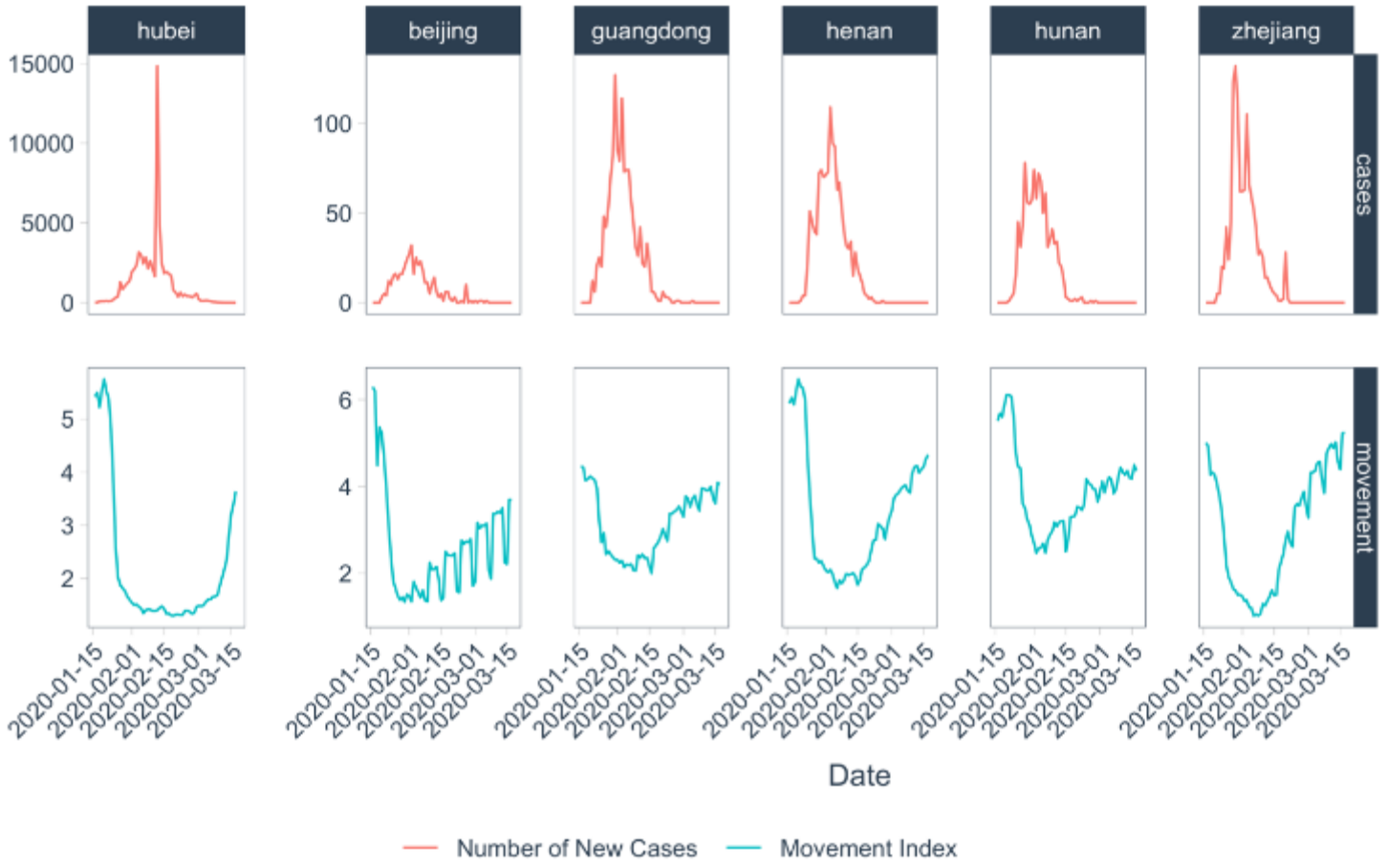
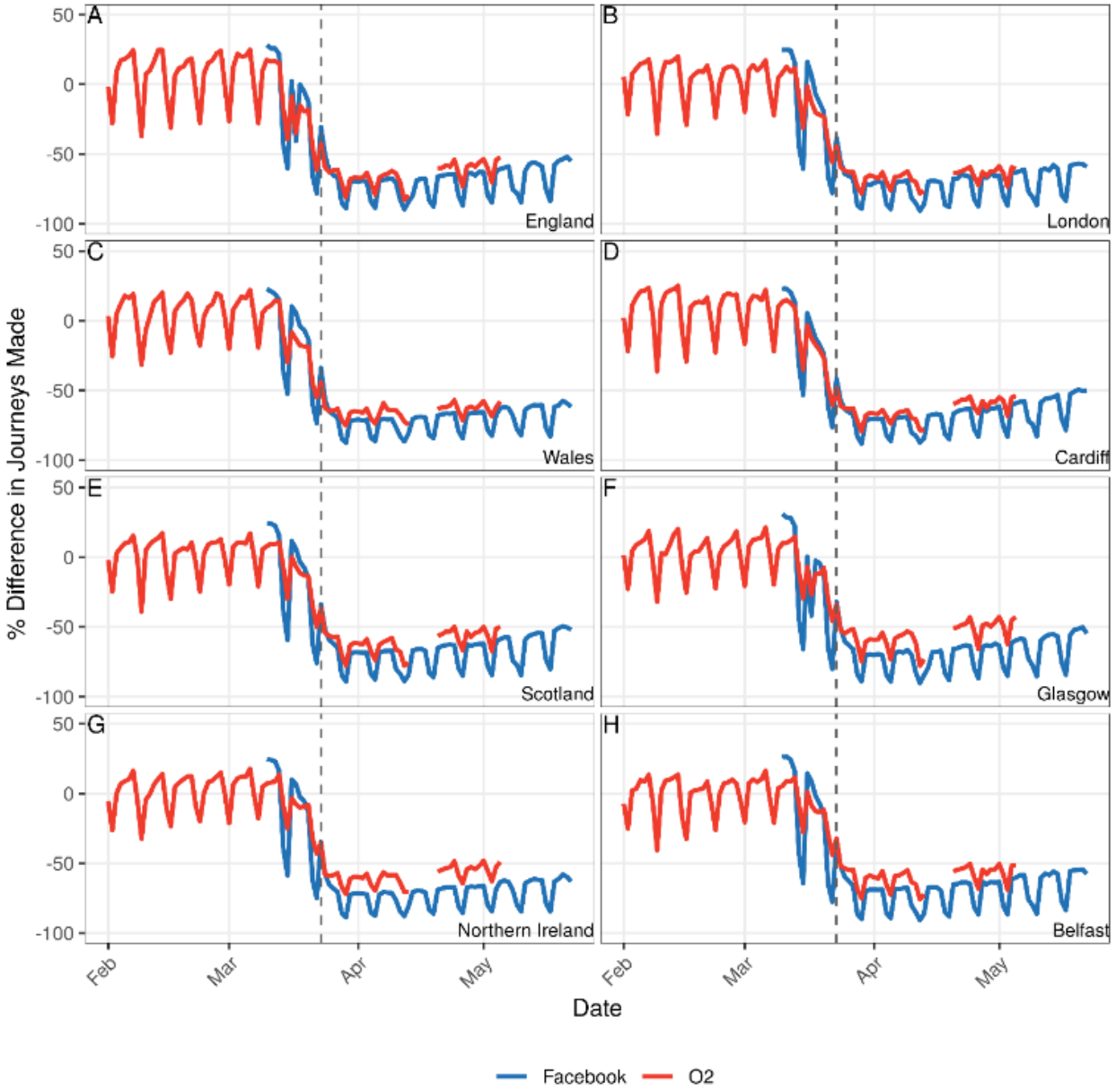


Figure 1. Plots of daily new confirmed cases (red line, top row) and daily movement index (Exante Data Inc, NY, blue line, bottom row) for Hubei, Beijing, Guangdong, Henan, Hunan, and Zhejiang. The cyclic movement patterns seen in Beijing and toward the end of February in Zhejiang are the result of decreased travel on weekends.

https://www.imperial.ac.uk/media/imperial-college/medicine/mrc-gida/2020-03-24-COVID19-Report-11.pdf published 24 Mar 2020



https://www.imperial.ac.uk/media/imperial-college/medicine/mrc-gida/2020-05-29-COVID19-Report-24.pdf Published 29 May

We would like to thank O2 and Facebook Data for Good for making their data available to us.

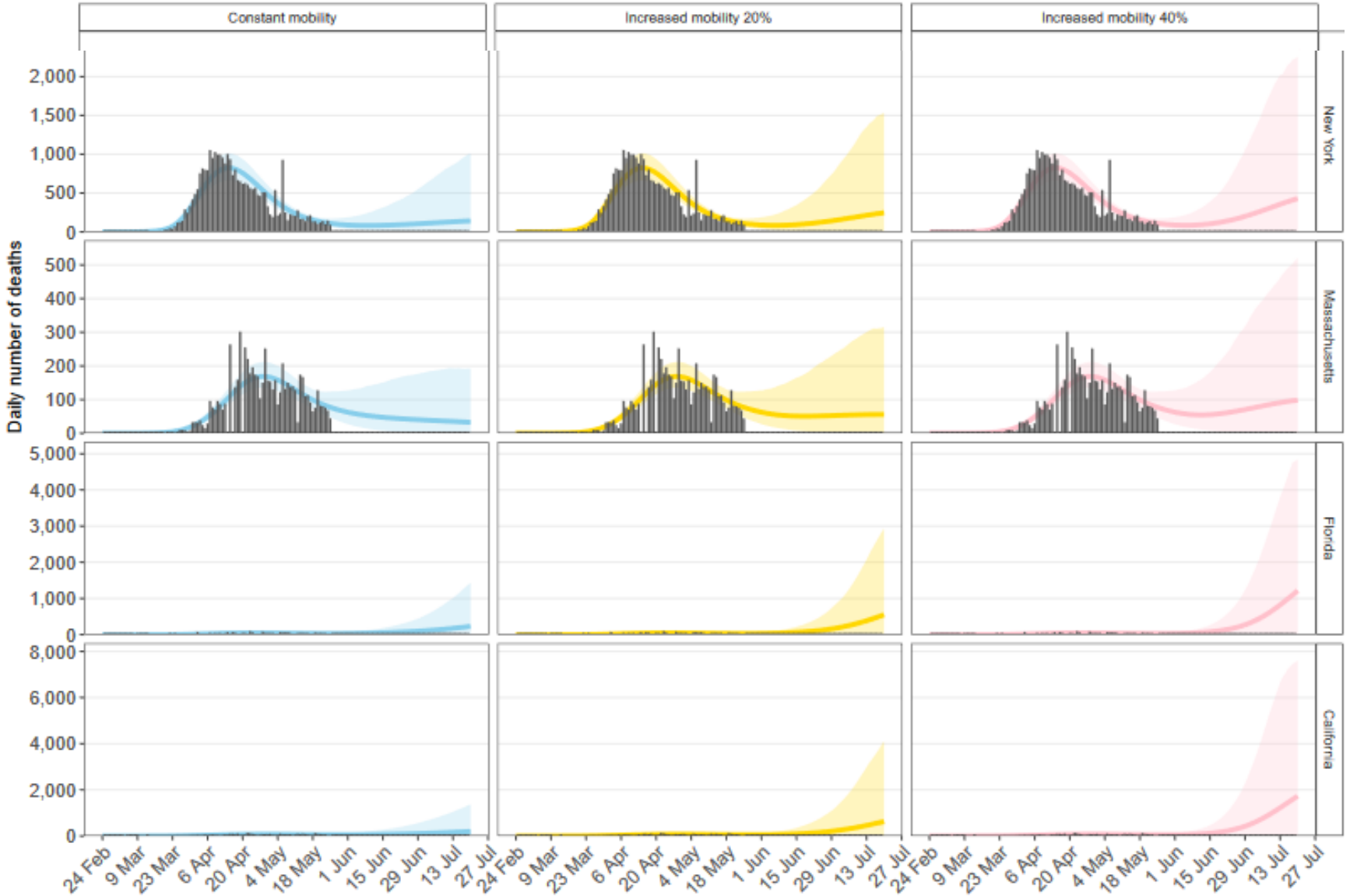


Figure 8: State-level scenario estimates of deaths for Washington, New York, Massachusetts, Florida and California. The

https://www.imperial.ac.uk/media/imperial-college/medicine/mrc-gida/2020-05-28-COVID19-Report-23-version2.pdf Published 28 May 2020

Google's COVID-19 Community Mobility Report

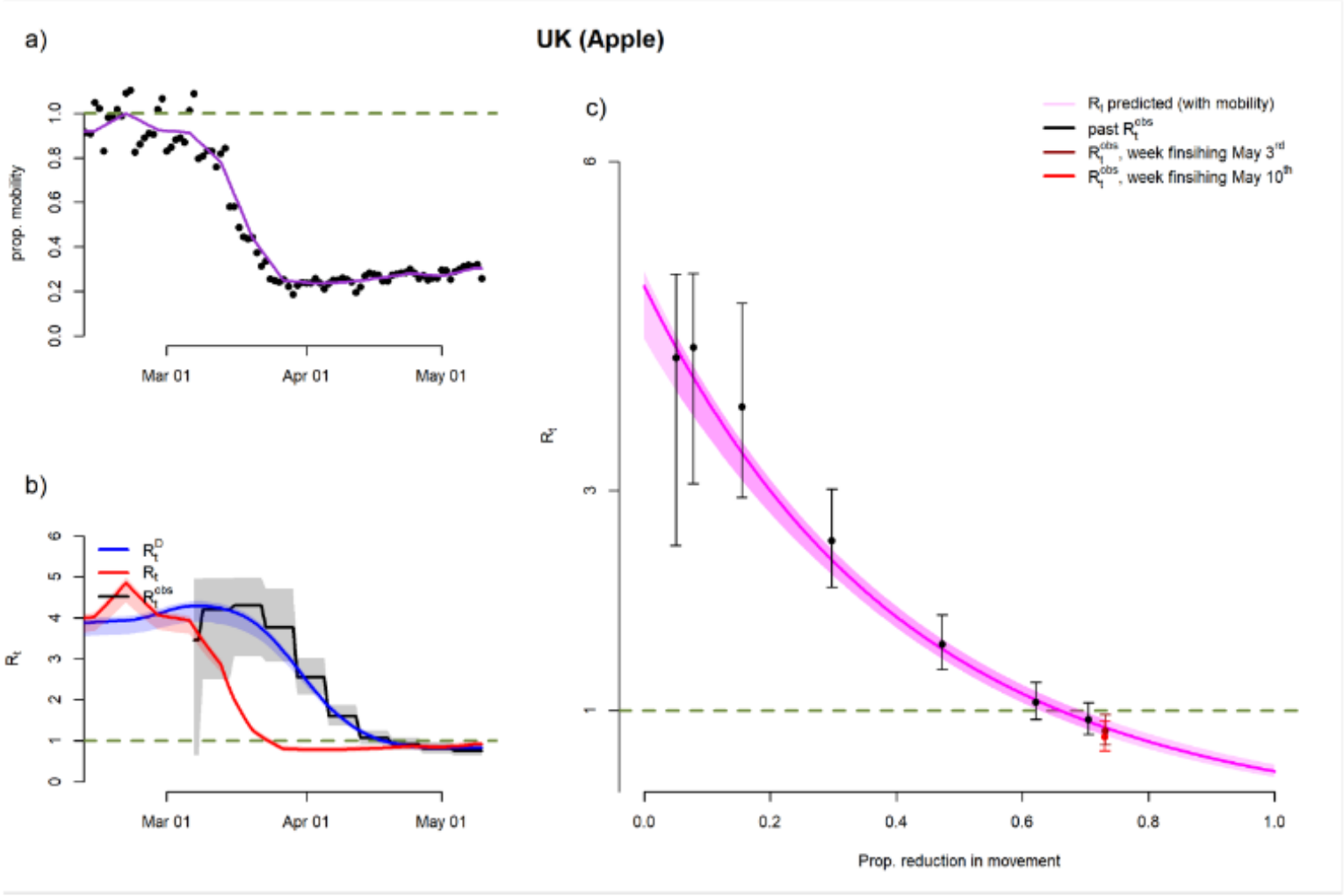
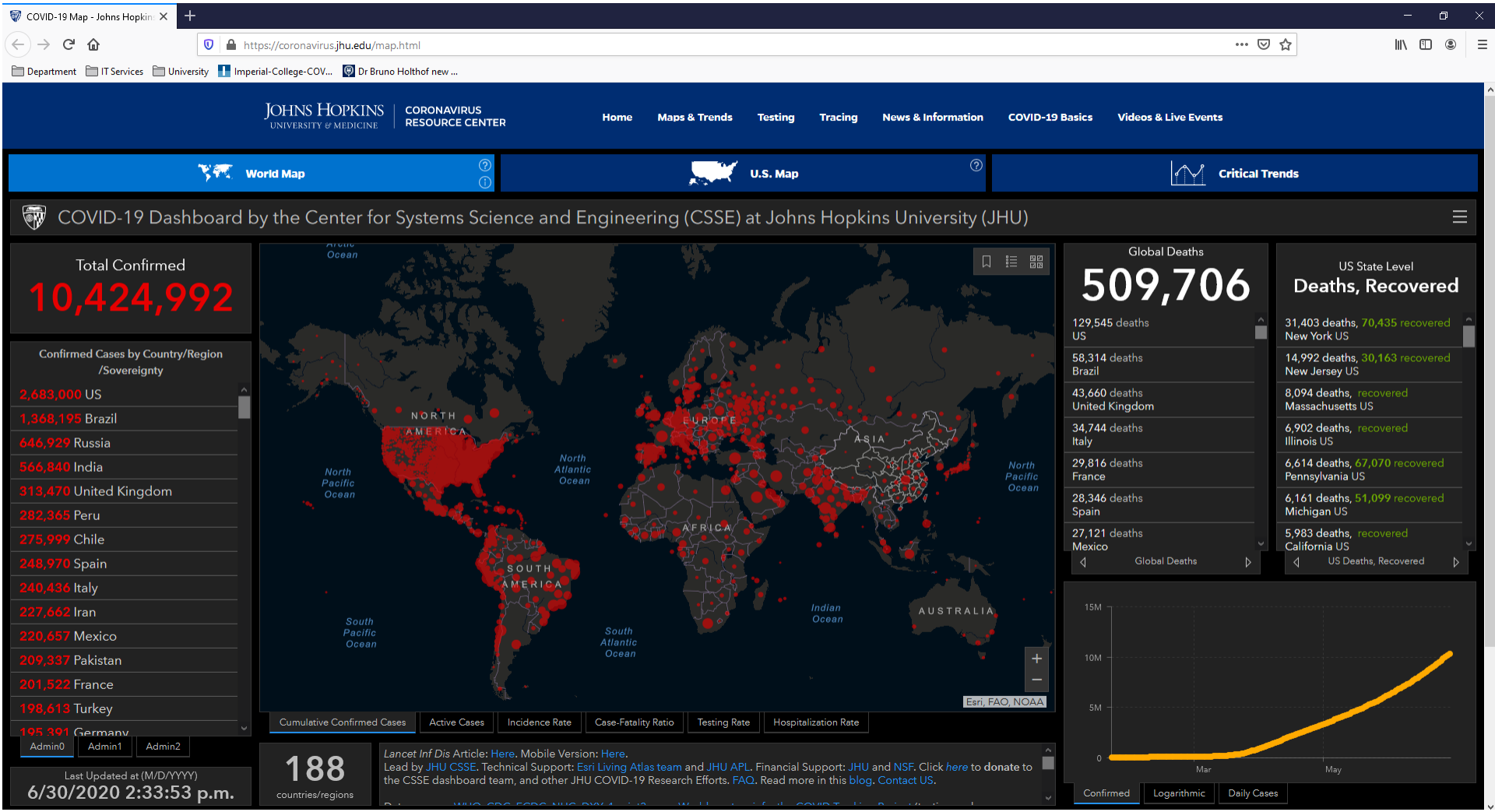


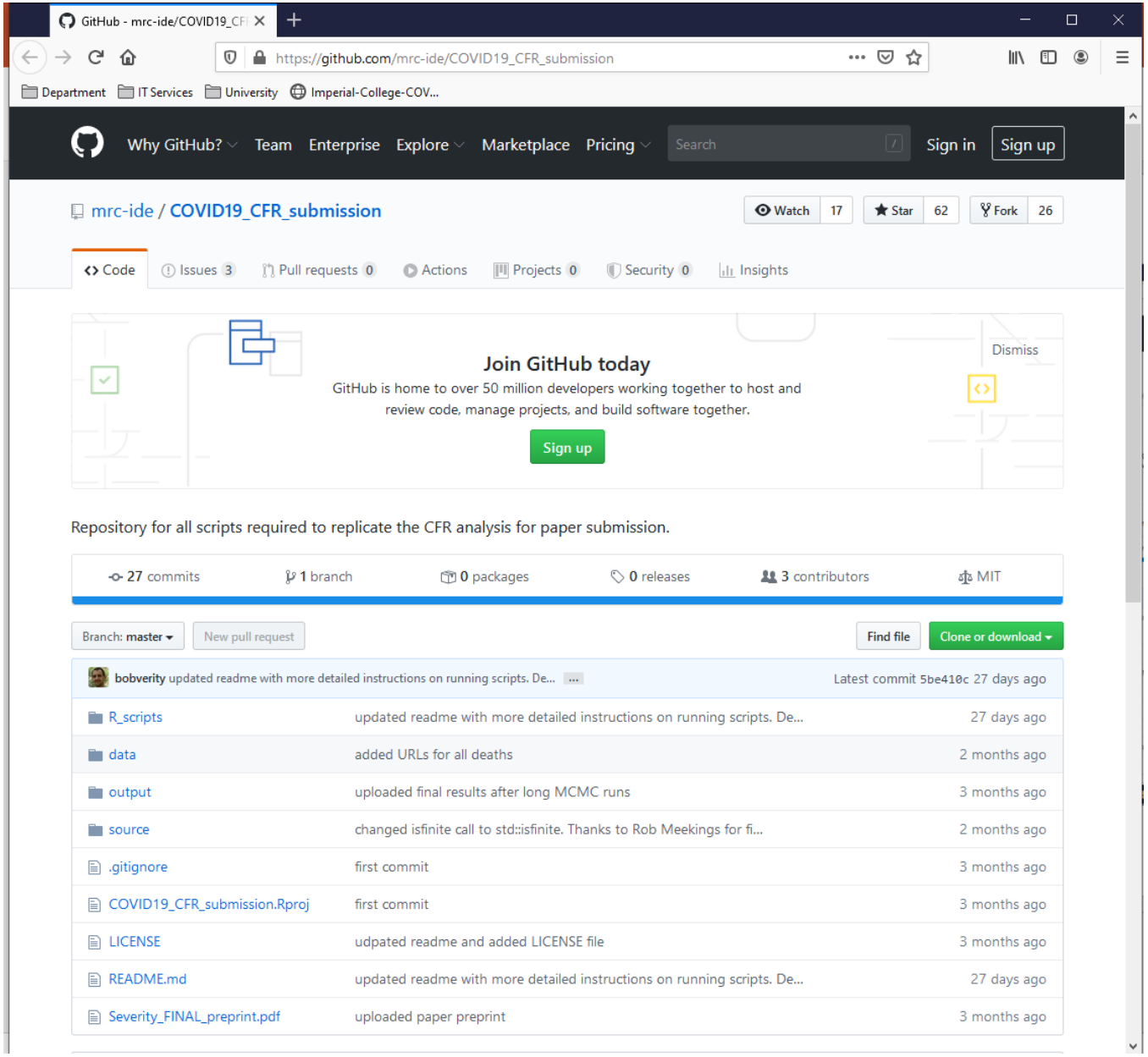
Figure 1: Relationship between mobility and transmission. **a)** Smoothed Apple mobility (purple line) and daily mobility (aggregated and scaled over the data streams). **b)** Estimated daily reproduction number for new

Looking forward… more data



https://coronavirus.jhu.edu/map.html

Looking forward… more code



https://github.com/mrc-ide/COVID19_CFR_submission

Looking forward… more open reviews

Evidence of initial success for C

https://wellcomeopenresearch.org/articles/5-81

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RESEARCH ARTICLE

Evidence of initial success for China exiting COVID-19 social distancing policy after achieving containment [version 1; peer review: 2 approved]

Kylie E C Ainslie [1*], Caroline E. Walters [1*], Han Fu[1*], Sangeeta Bhatia [1], Haowei Wang[1], Xiaoyue Xi[2], Marc Baguelin[1], Samir Bhatt[1], Adhiratha Boonyasiri[3], Olivia Boyd [1], Lorenzo Cattarino[1], Constanze Ciavarella[1], Zulma Cucunuba[1], Gina Cuomo-Dannenburg [1], Amy Dighe[1], Ilaria Dorigatti[1], Sabine L van Elsland [1], Rich FitzJohn[1], Katy Gaythorpe[1], Azra C Ghani[1], Will Green[1], Arran Hamlet[1], Wes Hinsley[1], Natsuko Imai [1], David Jorgensen[1], Edward Knock[1], Daniel Laydon[1], Gemma Nedjati-Gilani[1], Lucy C Okell [1], Igor Siveroni [1], Hayley A Thompson[1], H Juliette T Unwin [1], Robert Verity[1], Michaela Vollmer[1], Patrick G T Walker[1], Yuanrong Wang[1], Oliver J Watson [1,4], Charles Whittaker[1], Peter Winskill[1], Christl A Donnelly [1,5], Neil M Ferguson[1], Steven Riley[1]

[*] Equal contributors

Author details

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Abstract

Background: The COVID-19 epidemic was declared a Global Pandemic by WHO on 11 March 2020. By 24 March 2020, over 440,000 cases and almost 20,000 deaths had been reported worldwide. In response to the fast-growing epidemic, which began in the Chinese city of Wuhan, Hubei, China imposed strict social distancing in Wuhan on 23 January 2020 followed closely by similar measures in other provinces. These interventions have impacted economic productivity in China, and the ability of the Chinese economy to resume without restarting the epidemic was not clear.
Methods: Using daily reported cases from mainland China and Hong Kong SAR, we estimated transmissibility over time and compared it to daily within-city movement, as a proxy for economic activity.
Results: Initially, within-city movement and transmission were very strongly correlated in the five mainland provinces most affected by the epidemic and Beijing. However, that correlation decreased rapidly after the initial sharp fall in transmissibility. In general, towards the end of the study period, the correlation was no longer apparent, despite substantial increases in within-city movement. A similar analysis for Hong Kong shows that intermediate levels of local activity were maintained while avoiding a large outbreak. At the very end of the study period, when China began to experience the re-introduction of a small number of cases from Europe and the United States, there is an apparent up-tick in transmission.

Open Peer Review

Reviewer Status ✓ ✓

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	1	2
Version 1 28 Apr 20	✓ read	✓ read

1. **Alex R. Cook**, National University of Singapore, Singapore, Singapore
2. **Sheila Bird**, University of Cambridge, Cambridge, UK

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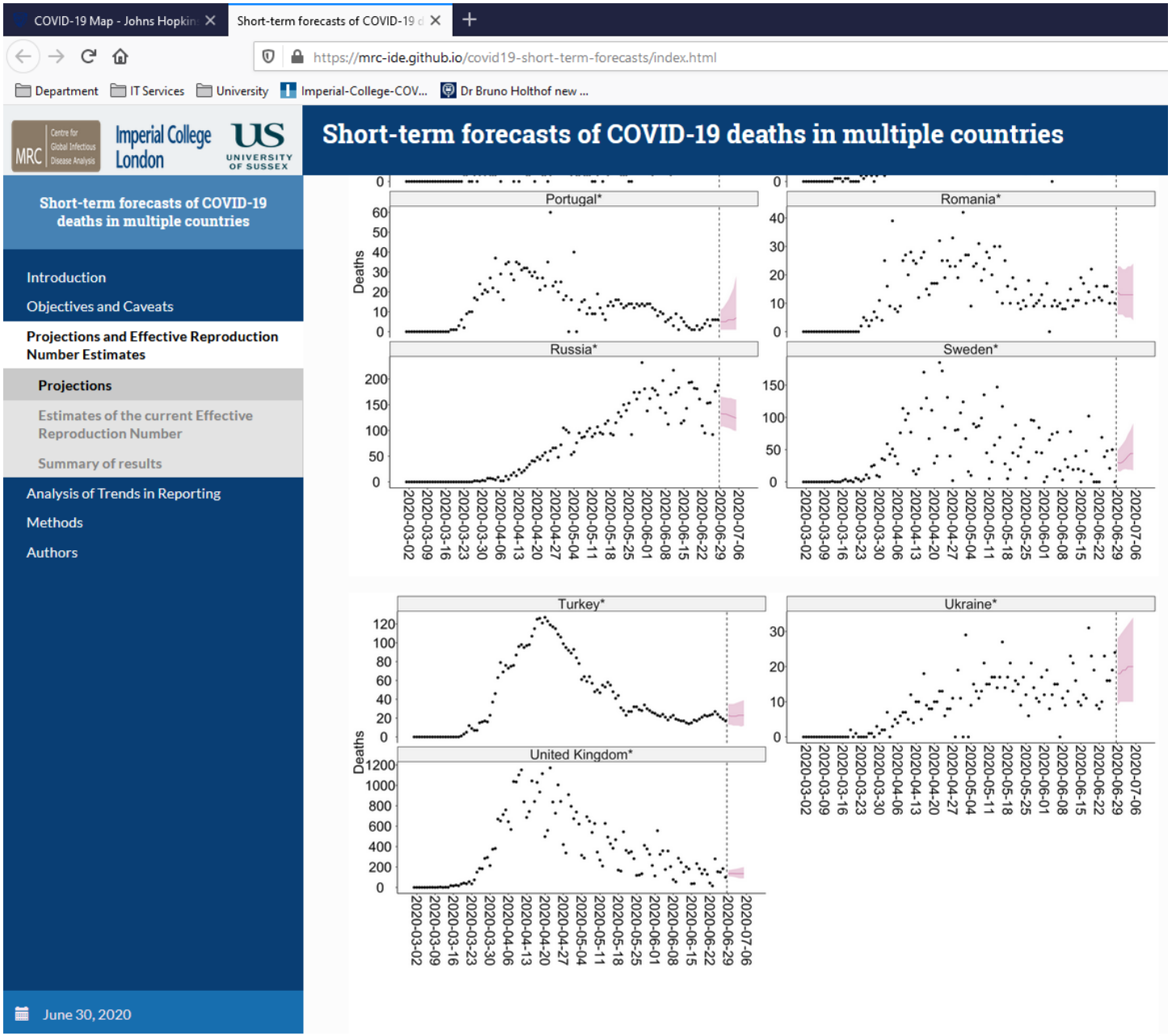
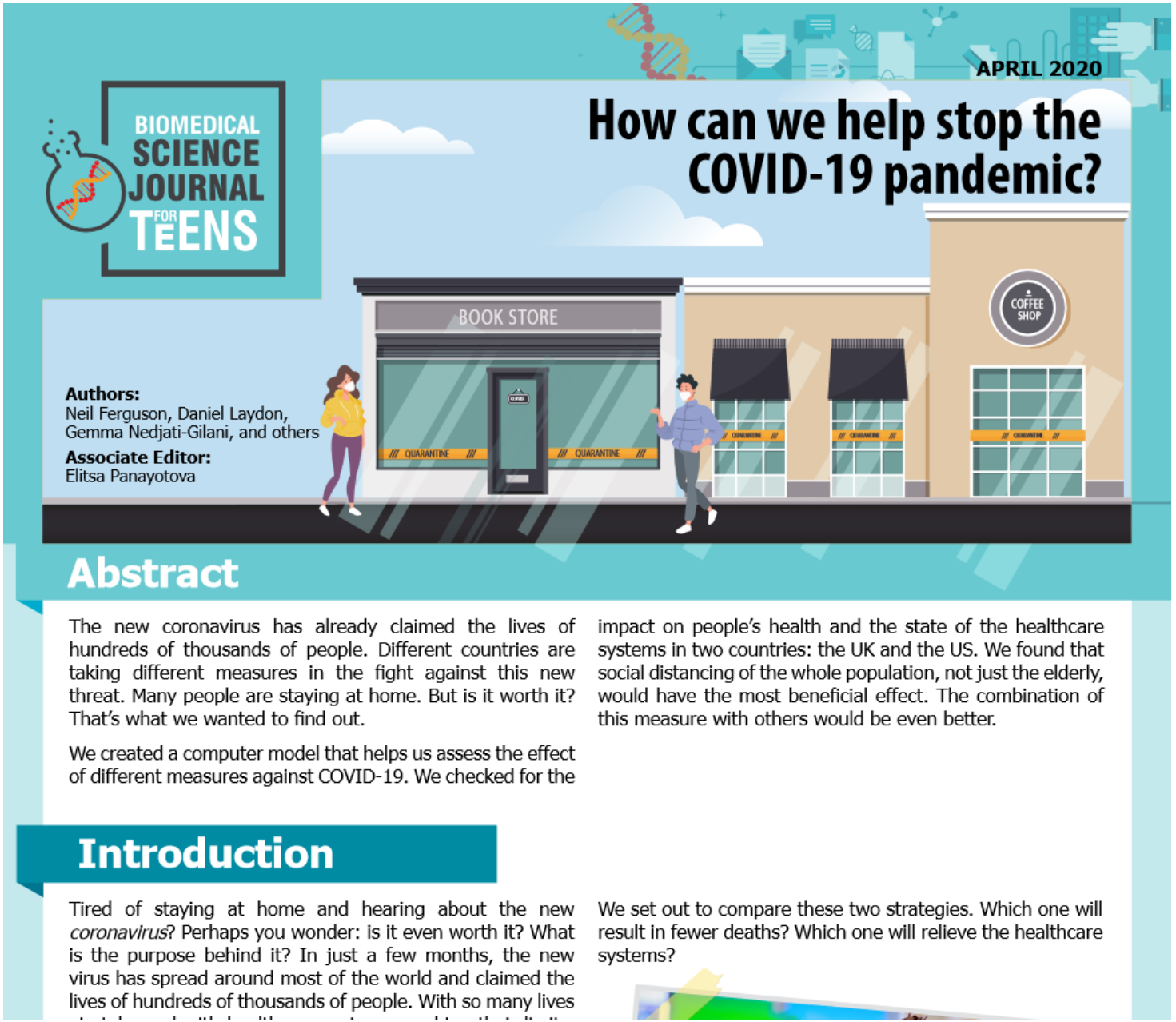
Looking forward… more updates



https://mrc-ide.github.io/covid19-short-term-forecasts/index.html

Looking forward… more public engagement



BIOMEDICAL SCIENCE JOURNAL FOR TEENS

APRIL 2020

How can we help stop the COVID-19 pandemic?

BOOK STORE

COFFEE SHOP

QUARANTINE

QUARANTINE

Authors:
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Abstract

The new coronavirus has already claimed the lives of hundreds of thousands of people. Different countries are taking different measures in the fight against this new threat. Many people are staying at home. But is it worth it? That's what we wanted to find out.

We created a computer model that helps us assess the effect of different measures against COVID-19. We checked for the impact on people's health and the state of the healthcare systems in two countries: the UK and the US. We found that social distancing of the whole population, not just the elderly, would have the most beneficial effect. The combination of this measure with others would be even better.

Introduction

Tired of staying at home and hearing about the new *coronavirus*? Perhaps you wonder: is it even worth it? What is the purpose behind it? In just a few months, the new virus has spread around most of the world and claimed the lives of hundreds of thousands of people. With so many lives

We set out to compare these two strategies. Which one will result in fewer deaths? Which one will relieve the healthcare systems?

https://www.imperial.ac.uk/media/imperial-college/medicine/mrc-gida/2020-04-28-SJK-Report-9.pdf

ROYAL STATISTICAL SOCIETY

DATA | EVIDENCE | DECISIONS

Celebrating Florence Nightingale's 200th Anniversary

STATISTICIAN • NURSE • REFORMER

"When I am no longer even a memory, just a name, I hope my voice may perpetuate the great work of my life. God bless my dear old comrades of Balaclava and bring them safe to shore."

Florence Nightingale (1820-1910)

A man for our time

Sir Austin Bradford Hill

(1897 – 1991)

"All scientific work is incomplete—whether it be observational or experimental.

All scientific work is liable to be upset or modified by advancing knowledge.

That does not confer upon us a freedom to ignore the knowledge we already have, or to postpone the action that it appears to demand at a given time."