Predictions, role of interventions and the crisis of the virus in India: Data Science Call to Arms

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March 4, 2021

COPSS-NISS COVID-19 Webinar

Thanks to Xihong Lin for being my guiding light!

At the ISI Meeting in Marakesh, 2017

It takes an army of data warriors to make a difference…

Veera Baladandayuthapani

Mousumi Banerjee

Daniel Barker

Rupam Bhattacharyya

Debraj Bose

Jiacong Du

The
COV-IND-19
Study Group

Parikshit Ghosh

Aritra Halder

Michael Kleinsasser

Shariq Mohammed

Soumik Purkayastha

Ritoban Kundu

Bhramar Mukherjee

Debashree Ray

Alexander Rix

Maxwell Salvatore

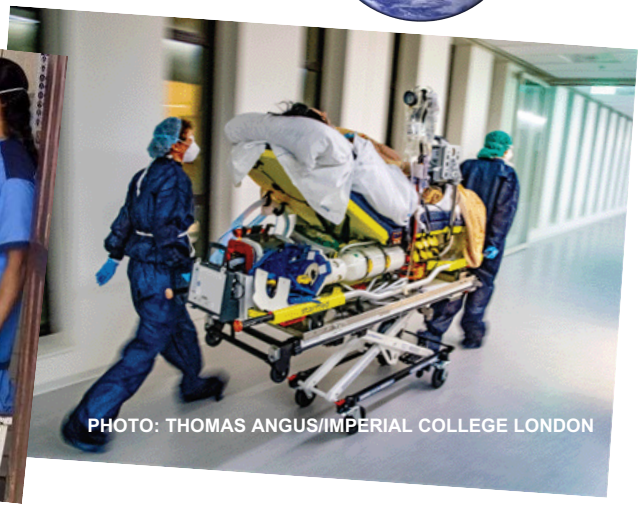
Peter Song

Lili Wang

Ritwik Bhaduri

COVID-19 Heroes

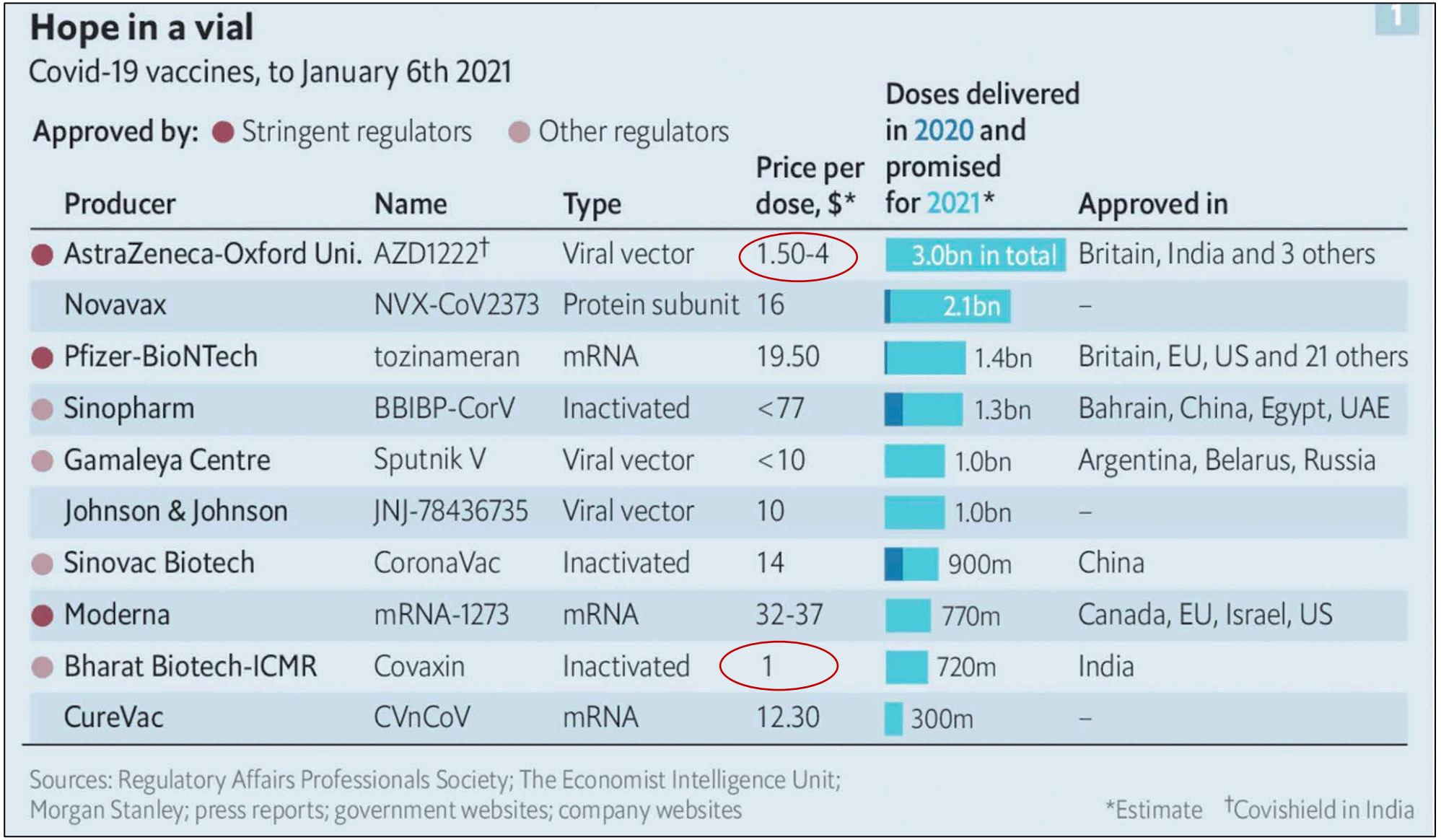
Thanks to the first responders of COVID19 crisis around the world!



December 14, 2020

First two healthcare workers get vaccinated at the University of Michigan

Safe, Efficacious, Affordable vaccines…



Hope in a vial

Covid-19 vaccines, to January 6th 2021

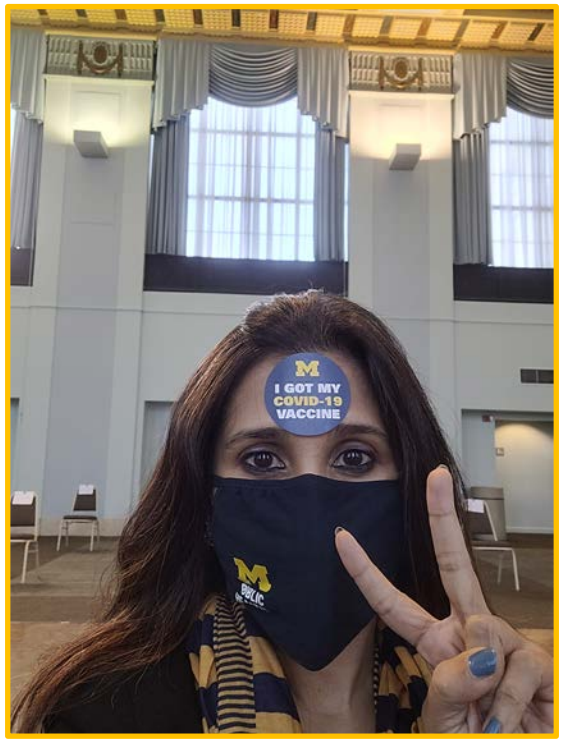
Approved by: ● Stringent regulators ● Other regulators

Producer	Name	Type	Price per dose, $*	Doses delivered in 2020 and promised for 2021*	Approved in
● AstraZeneca-Oxford Uni.	AZD1222†	Viral vector	1.50-4	3.0bn in total	Britain, India and 3 others
Novavax	NVX-CoV2373	Protein subunit	16	2.1bn	–
● Pfizer-BioNTech	tozinameran	mRNA	19.50	1.4bn	Britain, EU, US and 21 others
● Sinopharm	BBIBP-CorV	Inactivated	<77	1.3bn	Bahrain, China, Egypt, UAE
● Gamaleya Centre	Sputnik V	Viral vector	<10	1.0bn	Argentina, Belarus, Russia
Johnson & Johnson	JNJ-78436735	Viral vector	10	1.0bn	–
● Sinovac Biotech	CoronaVac	Inactivated	14	900m	China
● Moderna	mRNA-1273	mRNA	32-37	770m	Canada, EU, Israel, US
● Bharat Biotech-ICMR	Covaxin	Inactivated	1	720m	India
CureVac	CVnCoV	mRNA	12.30	300m	–

Sources: Regulatory Affairs Professionals Society; The Economist Intelligence Unit; Morgan Stanley; press reports; government websites; company websites

*Estimate †Covishield in India

Real world Effectiveness



The NEW ENGLAND JOURNAL of MEDICINE

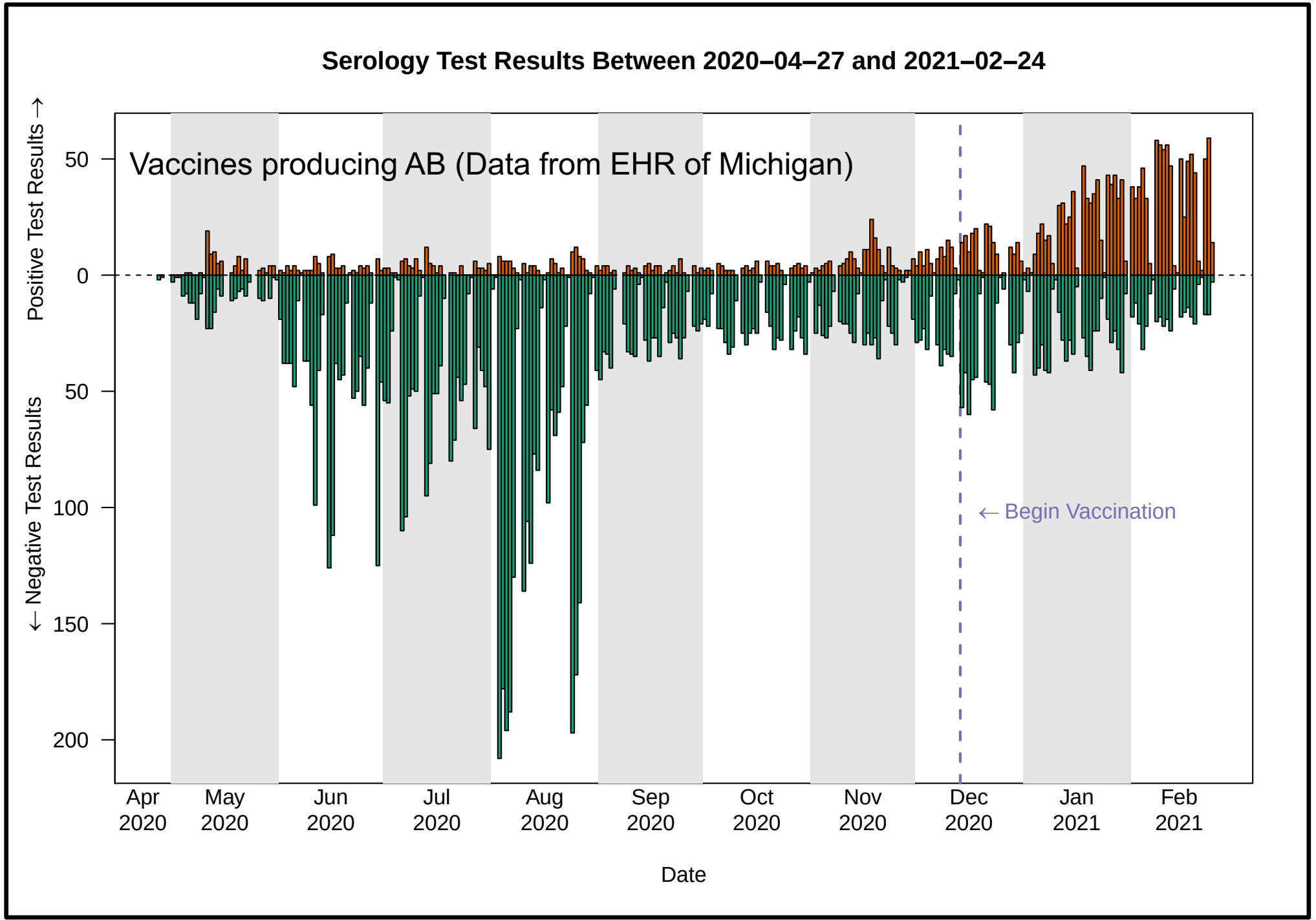
ORIGINAL ARTICLE

BNT162b2 mRNA Covid-19 Vaccine in a Nationwide Mass Vaccination Setting

Noa Dagan, M.D., Noam Barda, M.D., Eldad Kepten, Ph.D., Oren Miron, M.A., Shay Perchik, M.A., Mark A. Katz, M.D., Miguel A. Hernán, M.D., Marc Lipsitch, D.Phil., Ben Reis, Ph.D., and Ran D. Balicer, M.D.

RESULTS

Each study group included 596,618 persons. Estimated vaccine effectiveness for the study outcomes at days 14 through 20 after the first dose and at 7 or more days after the second dose was as follows: for documented infection, 46% (95% confidence interval [CI], 40 to 51) and 92% (95% CI, 88 to 95); for symptomatic Covid-19, 57% (95% CI, 50 to 63) and 94% (95% CI, 87 to 98); for hospitalization, 74% (95% CI, 56 to 86) and 87% (95% CI, 55 to 100); and for severe disease, 62% (95% CI, 39 to 80) and 92% (95% CI, 75 to 100), respectively. Estimated effectiveness in preventing death from Covid-19 was 72% (95% CI, 19 to 100) for days 14 through 20 after the first dose. Estimated effectiveness in specific subpopulations assessed for documented infection and symptomatic Covid-19 was consistent across age groups, with potentially slightly lower effectiveness in persons with multiple coexisting conditions.


Serology Test Results Between 2020–04–27 and 2021–02–24
Vaccines producing AB (Data from EHR of Michigan)
Positive Test Results →
← Negative Test Results
50
0
50
100
150
200
← Begin Vaccination
Apr 2020
May 2020
Jun 2020
Jul 2020
Aug 2020
Sep 2020
Oct 2020
Nov 2020
Dec 2020
Jan 2021
Feb 2021
Date

WORLD VIEW · 03 MARCH 2021

COVID vaccination studies: plan now to pool data, or be bogged down in confusion

Incompatible research designs will obscure essential answers about vaccine effectiveness. It's time to plan together.

Natalie Dean, Nature, 2021

Variants chasing Vaccines

	B.1.1.7	B.1.351	P.1
Alternate name	501Y.V1	501Y.V2	501Y.V3
Country identified	United Kingdom	South Africa	Brazil
Mutations	23	21	17
Spike mutations	8	9	10
Key RBD, spike mutations beyond N501Y in all	E69/70 deletion, P681H 144Y deletion, A570D	E484K, K417N, orf1b deletion	E484K, K417T, orf1b deletion
Other mutations, including N-terminal	T7161, S982A, D1118H	L18F, D80A, D215G, Δ242-244, R264I, A701V	L18F, T20N, P26S, D138Y, R190S, H655Y, T10271
Transmissibility Δ	>50% increased	No	No
Lethality Δ	Not resolved	?	?
Immune escape	Unclear	Yes	Yes
Vaccine efficacy reduction (preserved vs severe infections)	Partial; Novavax (96->86%); Astra Zeneca (84->75%)	Yes, reduced In 3 vaccine trials No efficacy w/ AZ	Likely Not established
Countries reported	93	46	22
US States reported	44	13	4

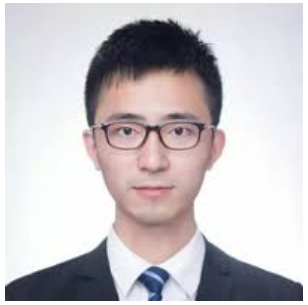
https://www.cdc.gov/coronavirus/2019-ncov/transmission/variant-cases.html, Courtesy Eric Topol

JIM Original Article

doi: 10.1111/joim.13213

Patterns of repeated diagnostic testing for COVID-19 in relation to patient characteristics and outcomes

S. Salerno[1,*], Z. Zhao[1,*], S. Prabhu Sankar[2,3], M. Salvatore[1], T. Gu[1], L. G. Fritsche[1,2,4], S. Lee[1,5], L. D. Lisabeth[6], T. S. Valley[7,8] & B. Mukherjee[1,2,6]



JAMA Network Open™

Original Investigation | Infectious Diseases

Characteristics Associated With Racial/Ethnic Disparities in COVID-19 Outcomes in an Academic Health Care System

Tian Gu, MS; Jasmine A. Mack, MPH; Maxwell Salvatore, MPH; Swaraaj Prabhu Sankar, MS; Thomas S. Valley, MD, MSc; Karandeep Singh, MD, MMSc; Brahmajee K. Nallamothu, MD, MPH; Sachin Kheterpal, MD, MBA; Lynda Lisabeth, PhD; Lars G. Fritsche, PhD; Bhramar Mukherjee, PhD

This Afternoon's Narrative: Focus on India

- Pre-lockdown forecasting
- Post-lockdown analysis
- Daily projection updates
- Underreporting of cases and deaths in India
- From numerical analysis to humanitarian data science

Phase 1: March and April

Predictions and role of interventions for COVID-19 outbreak in India

Crisis Of Virus in INDia (COV-IND)

COV-IND-19 Study Group
Mar 21 · 12 min read

Medium Article on March 20

Historic 21-day lockdown, predictions for lockdown effects and the role of data in this crisis of virus in India

COV-IND-19 Study Group
Apr 3 · 23 min read

Medium Article April 3

Open source code, data transparency and commitment to reproducible science: covind19.org

Unlocking the 40-day national lockdown in India: There is no magic key

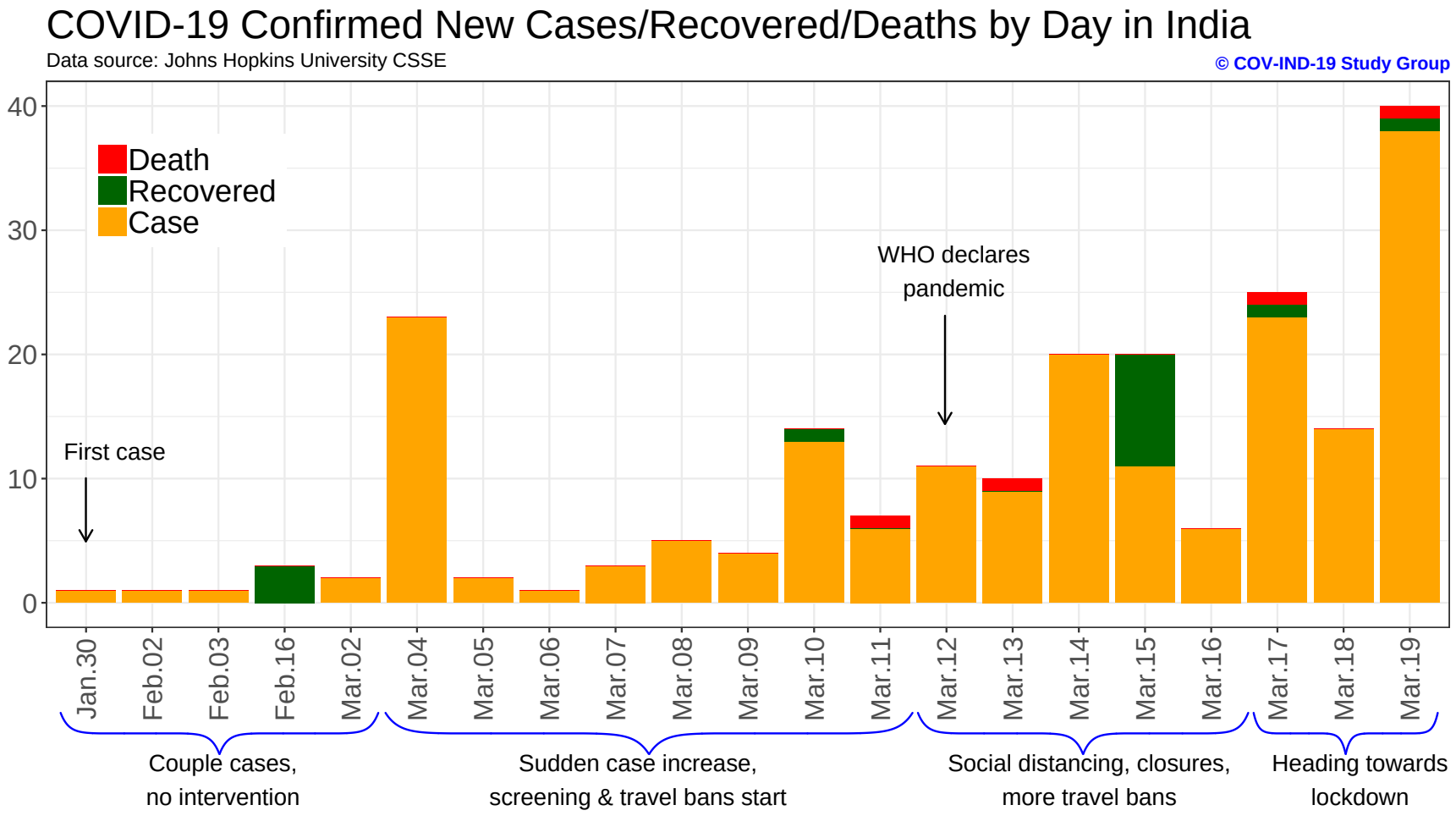
COV-IND-19 Study Group

Apr 24 · 15 min read

[Medium Article April 24]

[Published Paper Harvard Data Science Review]

When we started this work



Source: https://www.pharmaceutical-technology.com/news/india-covid-19-coronavirus-updates-status-by-state/

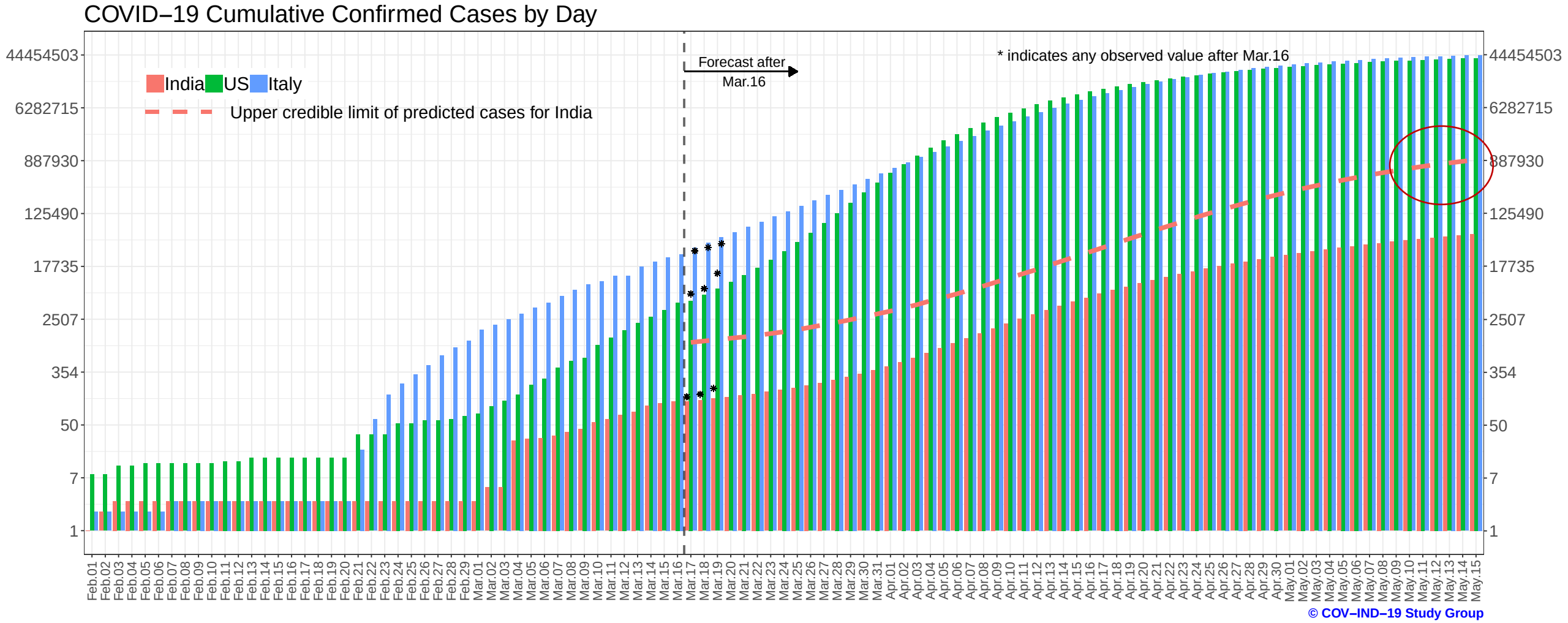
Distribution of COVID-19 related risk factors in India

Table 2. Proportion of population in specifically vulnerable subgroups at potentially high risk of COVID-19 severity risk in India

Metric	Number† (in millions)	Year	Source
Uninsured	1,104	2014	Prinja et al. 2019
Population over 65	92.5	2020 (est.)	CIA World Factbook
Hypertension (men)*	175.7	2015/16	Gupta & Ram 2019
Hypertension (women)*	132.6	2015/16	Gupta & Ram 2019
People with cardiovascular disease*	78.7	2016	Prabhakaran et al. 2018
Population with COPD*	75.9	2016	Lancet 2018
Population with asthma*	45.5	2016	Lancet 2018
Develop cancer by age 75 (men)**	70.3	2018	NICPR
Develop cancer by age 75 (men)**	62.3	2018	NICPR
Population with diabetes (adult)	122.8	-	IDF
Access to inpatient department facilities***	731.4	2012	IMS Institute 2013
Access to outpatient department***	1,104	2012	IMS Institute 2013

† based on 2020 est. of 1.38 billion from UN Department of Economic and Social Affairs
** age-standardized; ** risk; *** defined as within 5 kilometer distance of home or work*
Abbrev.: COPD, chronic obstructive pulmonary disease; IDF, International Diabetes Federation; NICPR, National Institute of Cancer Prevention and Research

Pre-lockdown forecast (No Intervention)



Media coverage

OPINION

FROM TOI PRINT EDITION

THE TIMES OF INDIA

'Epidemiologic models show we need aggressive measures in the early phase ... lockdown buys us time'

April 1, 2020, 3:00 AM IST Pratigyan Das in Melange | Edit Page, India, Q&A, World | TOI

India may have 97k-1.3mn Covid-19 infections by mid-May, shows projection

INDIA Updated: Mar 24, 2020 10:42 IST

Binayak Dasgupta

Hindustan Times

Historic 21-day National Lockdown: March 25

On **Tuesday March 24th, 2020 evening** India's Prime Minister Narendra Modi announces a 21-day lockdown, noting that it is crucial in India's battle against Covid-19 (India Today).

Since then there has been more than 1100 media clips from our work with a reach of 6.0 billion. Prominent media coverage includes WSJ, Washington Post, NYT, The Times of India, BBC, NPR, Der Spiegel, The Wire, The Guardian and major Indian National TV channels.


Migrant workers walk back to their villages along the Mumbai Pune highway during the lockdown in Mumbai, India © AP

Indian coronavirus lockdown triggers exodus of migrant workers to rural areas (ft.com)

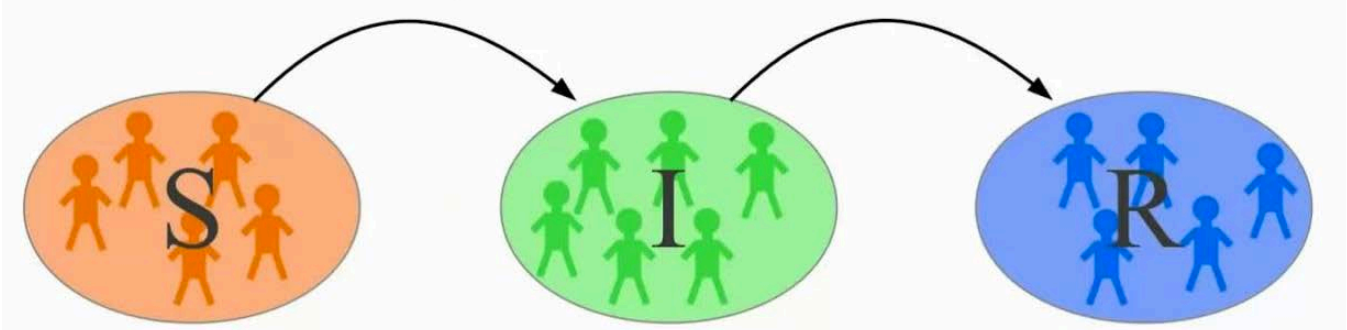
Millions light candles in a collective display of solidarity called for by Prime Minister Narendra Modi (dw.com)

Forecasting Models (India specific)

- ICMR
- Cambridge
- Armed Forces
- Sourish Das (CMI)
- Ohio State University
- INDSCISIM
- The Indian Super Model
- Youyang Gu https://covid19-projections.com/
- And many more in the last few months…

SIR model: fundamentals

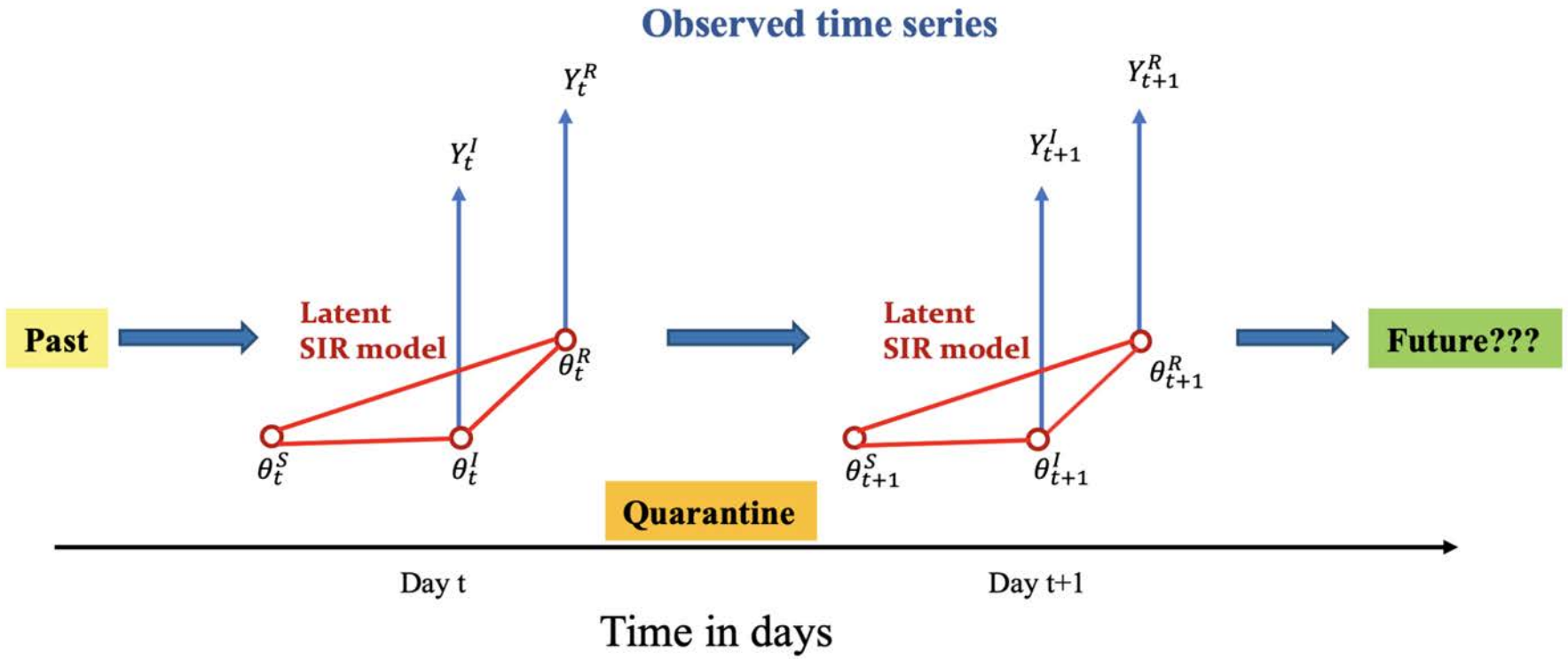
- **Structure:** Each person is in one of three ‘states’.



- **Utility:** Can model transmissions using count data.
- **Challenge:** True proportions unknown!

Facing the challenge: extended SIR

- **Idea:** Introduce a latent Markov prevalence process.



Wang et al, 2020, eSIR package on R CRAN

eSIR model: hierarchical formulation and solution

$$\frac{d\theta_t^S}{dt} = -\beta\theta_t^S\theta_t^I, \quad \frac{d\theta_t^I}{dt} = \beta\theta_t^S\theta_t^I - \gamma\theta_t^I, \quad \frac{d\theta_t^R}{dt} = \gamma\theta_t^I.$$

Compartmental Specification

$\boldsymbol{\tau}$: All other parameterx

$$Y_t^I|\boldsymbol{\theta_t}, \boldsymbol{\tau} \sim Beta(\lambda^I\theta_t^I, \lambda^I(1-\theta_t^I)),$$
$$Y_t^R|\boldsymbol{\theta_t}, \boldsymbol{\tau} \sim Beta(\lambda^R\theta_t^R, \lambda^R(1-\theta_t^R)).$$

$R_{eff} = \beta/\gamma$

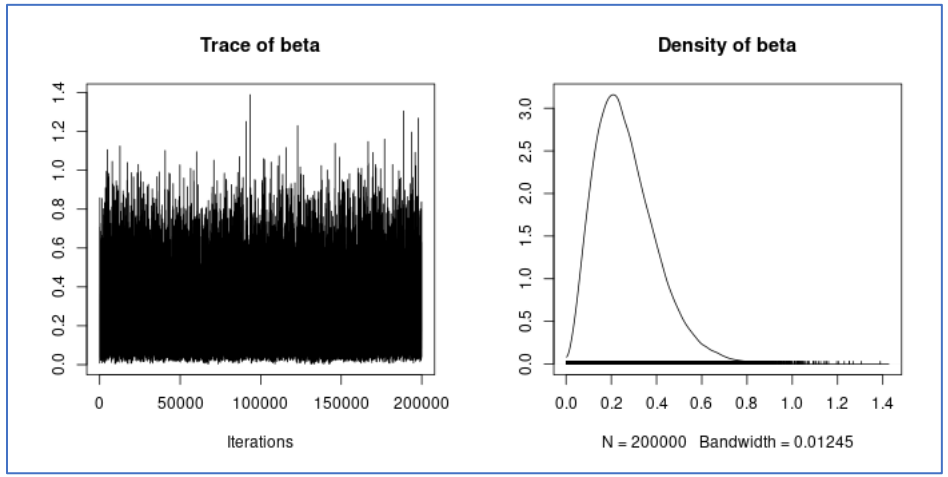
Building autocorrelation

$$\boldsymbol{\theta_t}|\boldsymbol{\theta_{t-1}}, \boldsymbol{\tau} \sim Dirichlet(\kappa f(\boldsymbol{\theta_{t-1}}, \beta, \gamma)).$$

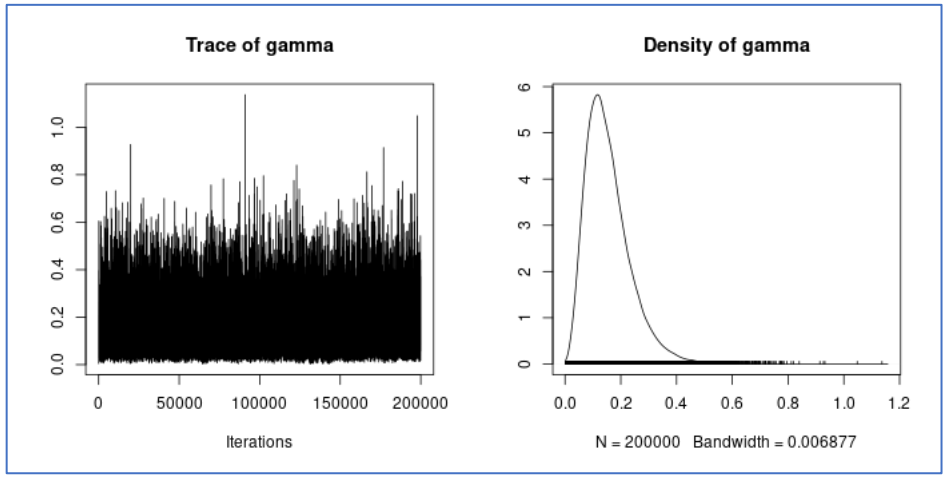
- Given the values at the previous step, the system can then be solved for f using approximations.

Trace plots and posterior density plots

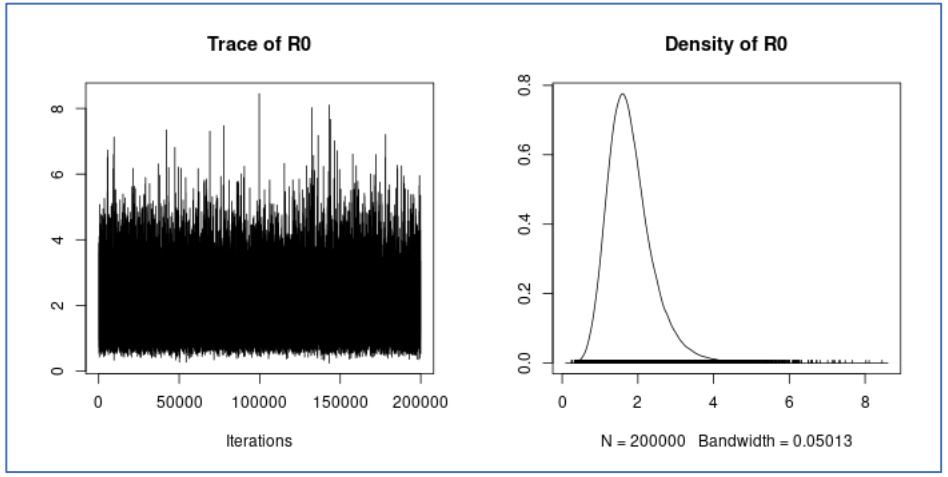
β



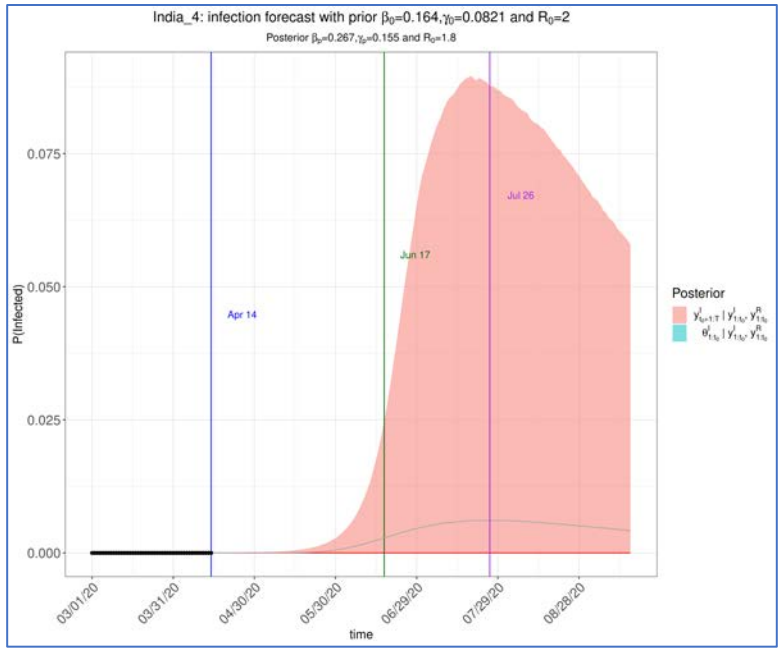
γ

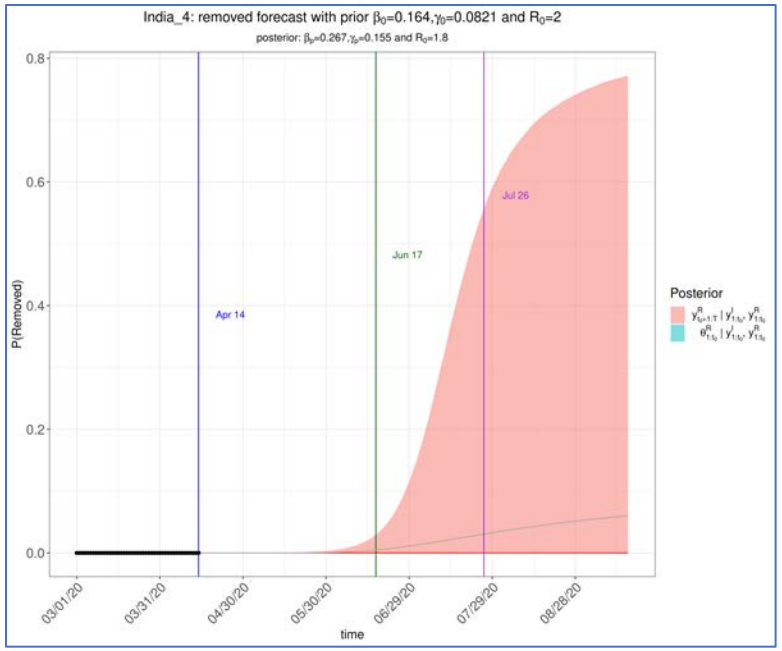


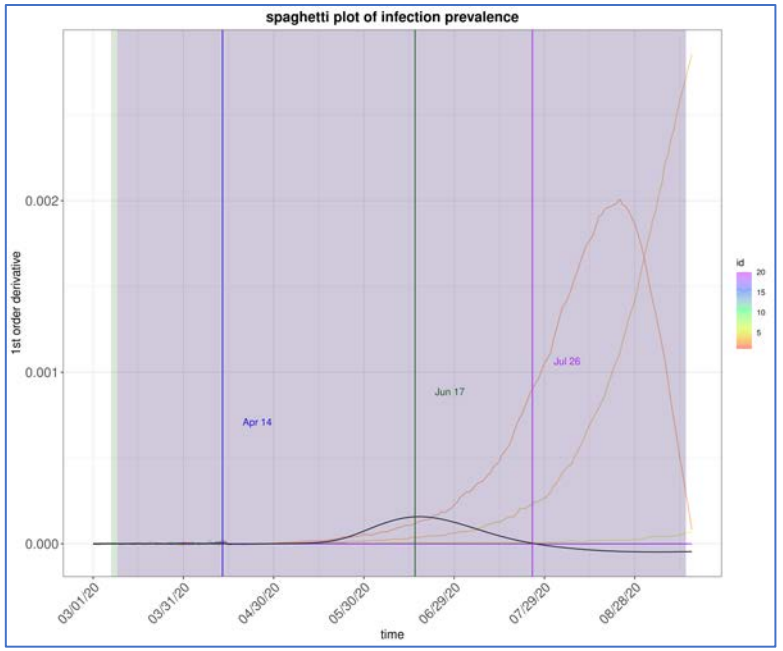
R_0



Posterior distributions of *Y and θ*





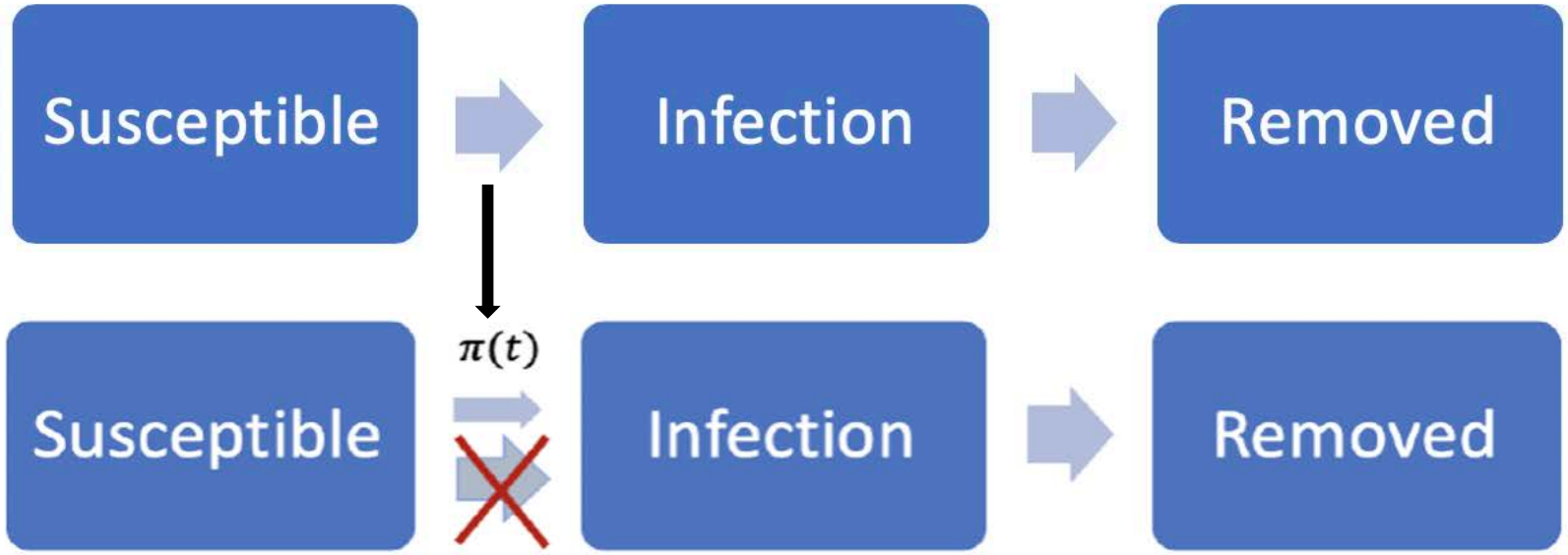


In compartment I

In compartment R

Daily Incidence

Modeling interventions

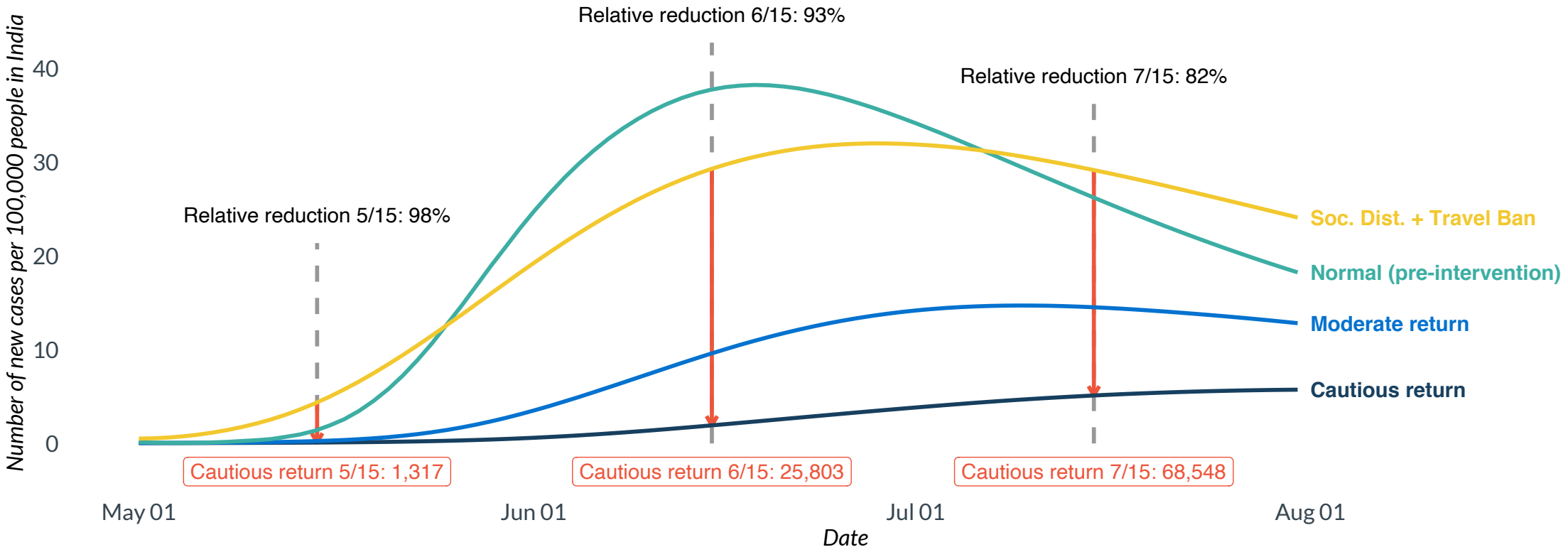


$$\frac{d\theta_t^S}{dt} = -\beta\pi(t)\theta_t^S\theta_t^I, \quad \frac{d\theta_t^I}{dt} = \beta\pi(t)\,\theta_t^S\theta_t^I - \gamma\theta_t^I, \quad \frac{d\theta_t^R}{dt} = \gamma\theta_t^I.$$

Long term projection and forecasting scenarios

b. Predicted number of new COVID-19 cases in India under hypothetical scenarios

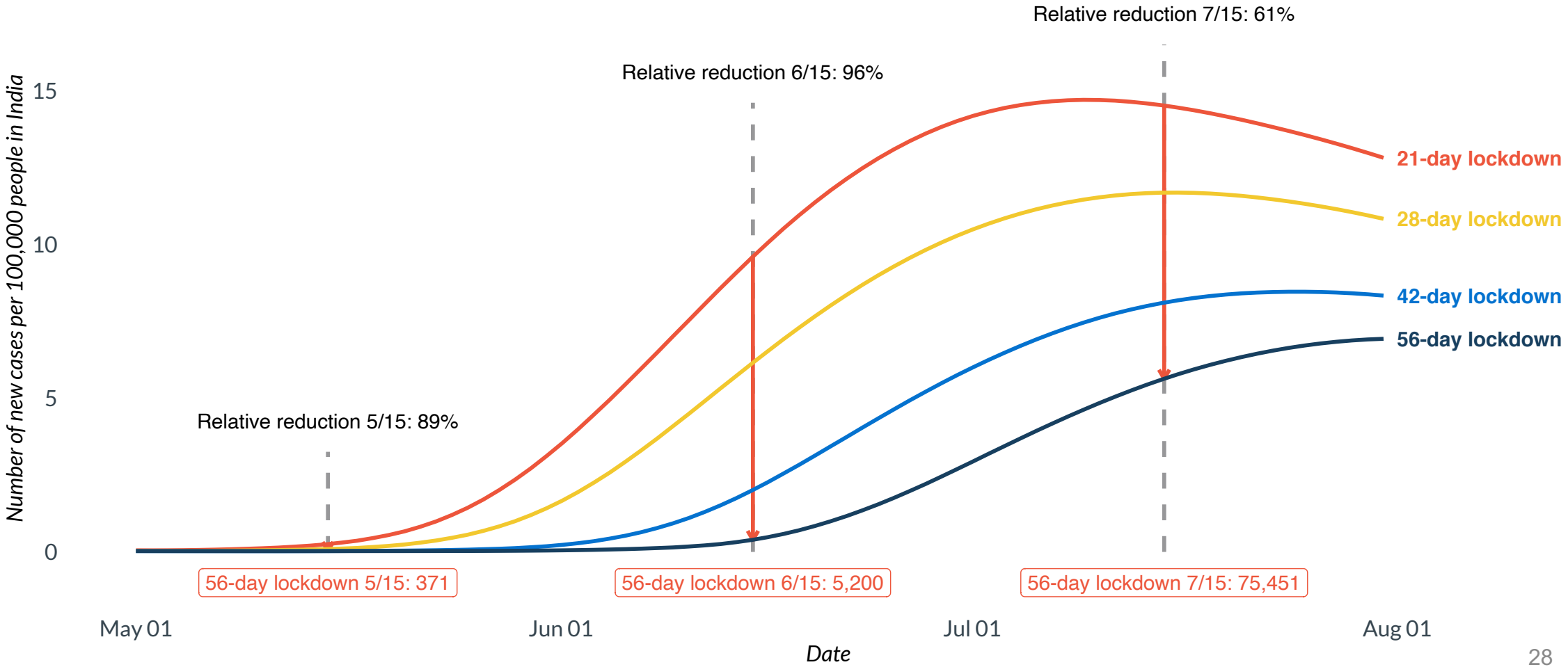
as of 14 April 2020; quick adherence



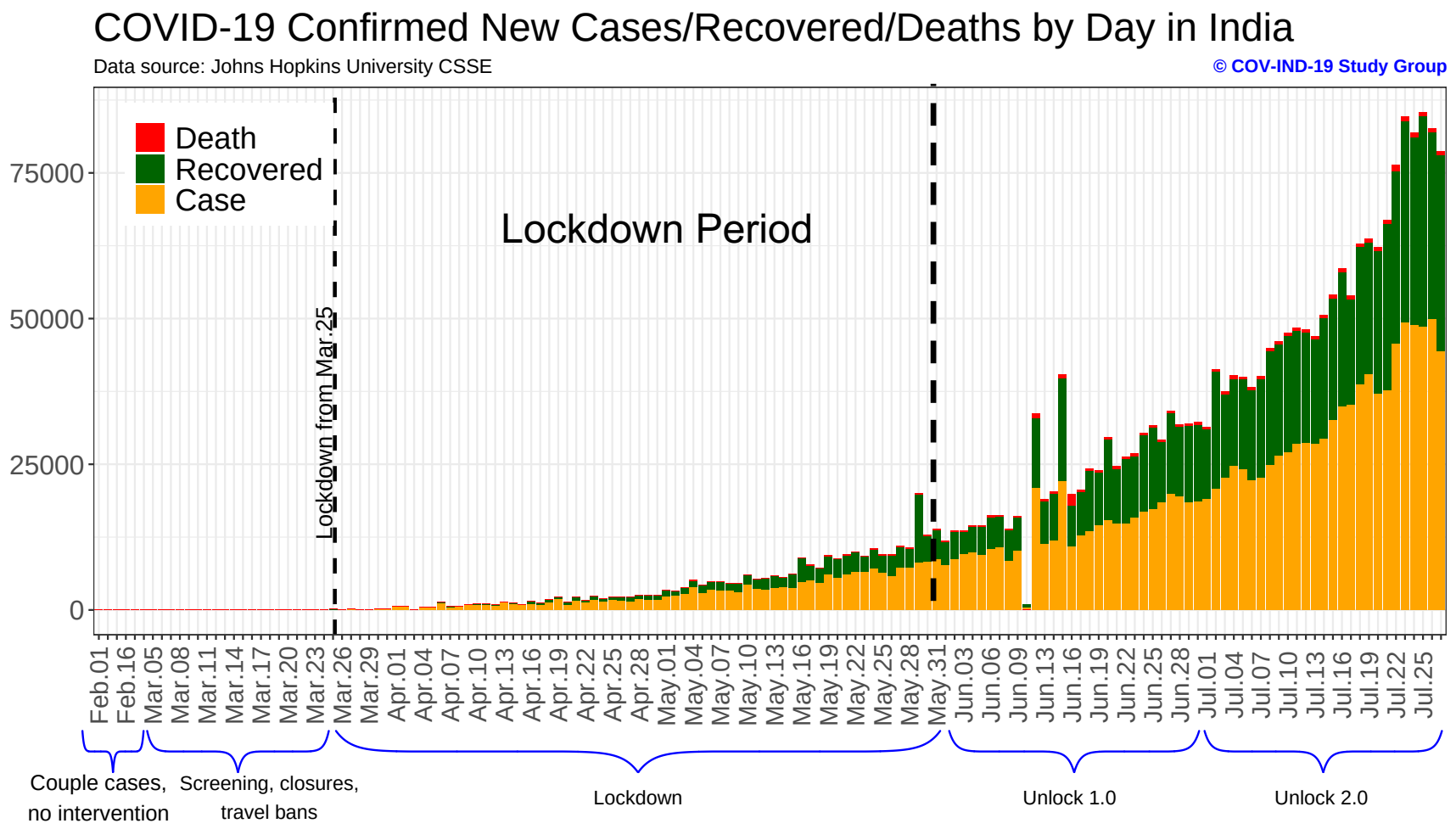
Lockdown duration - incidence

b. Predicted number of daily COVID-19 infections under varying lockdown lengths

as of 14 April, 2020; quick adherence



Was lockdown effective in India?



Scaling up health care infrastructure

Health Care Capacity	Then	End of 2020
Tests per day	3000	A million
Price of RT-PCR	Rs. 12,000-15,000	Rs. 400-950
ICU Beds	21000	63000
Isolation Beds	173000	1.55 million
COVID care centers	1900	15400

Characterizing Nation versus State Heterogeneity

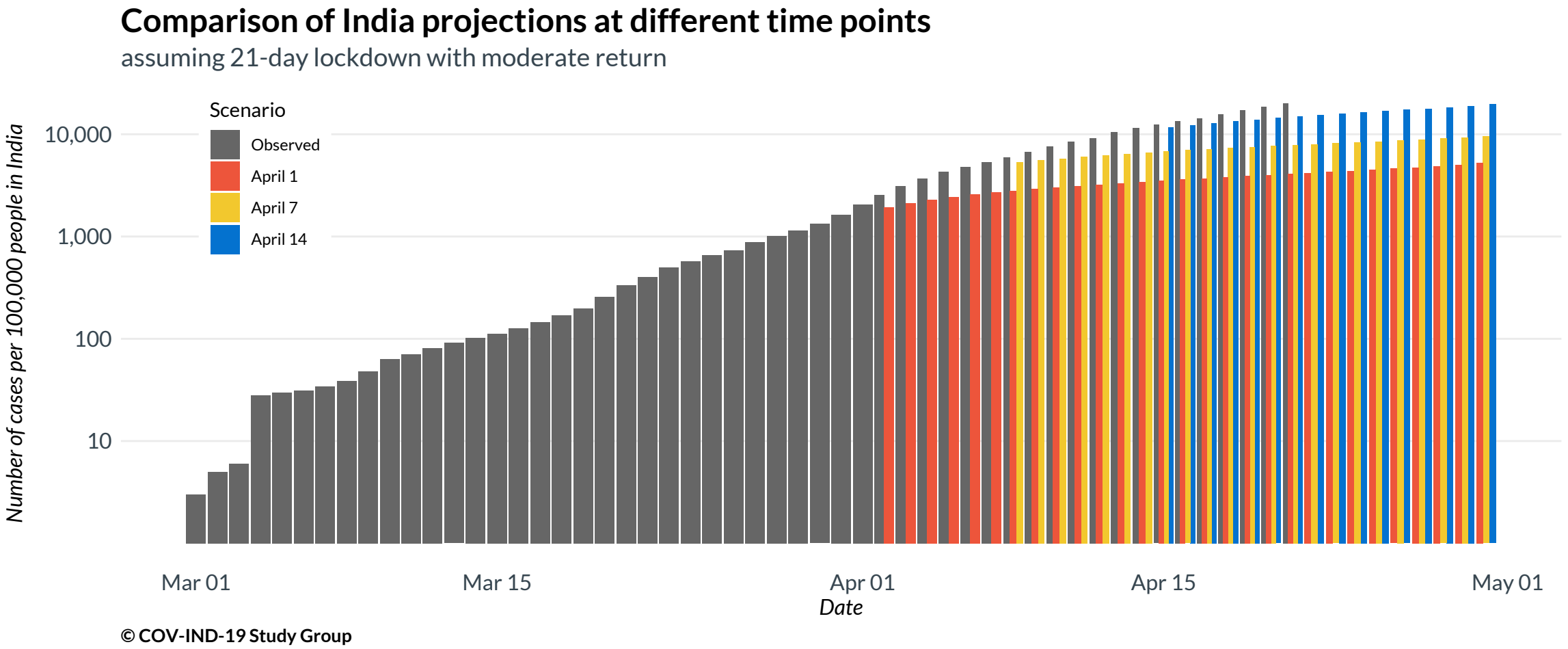
Open access Original research

BMJ Open

Comprehensive public health evaluation of lockdown as a non-pharmaceutical intervention on COVID-19 spread in India: national trends masking state-level variations

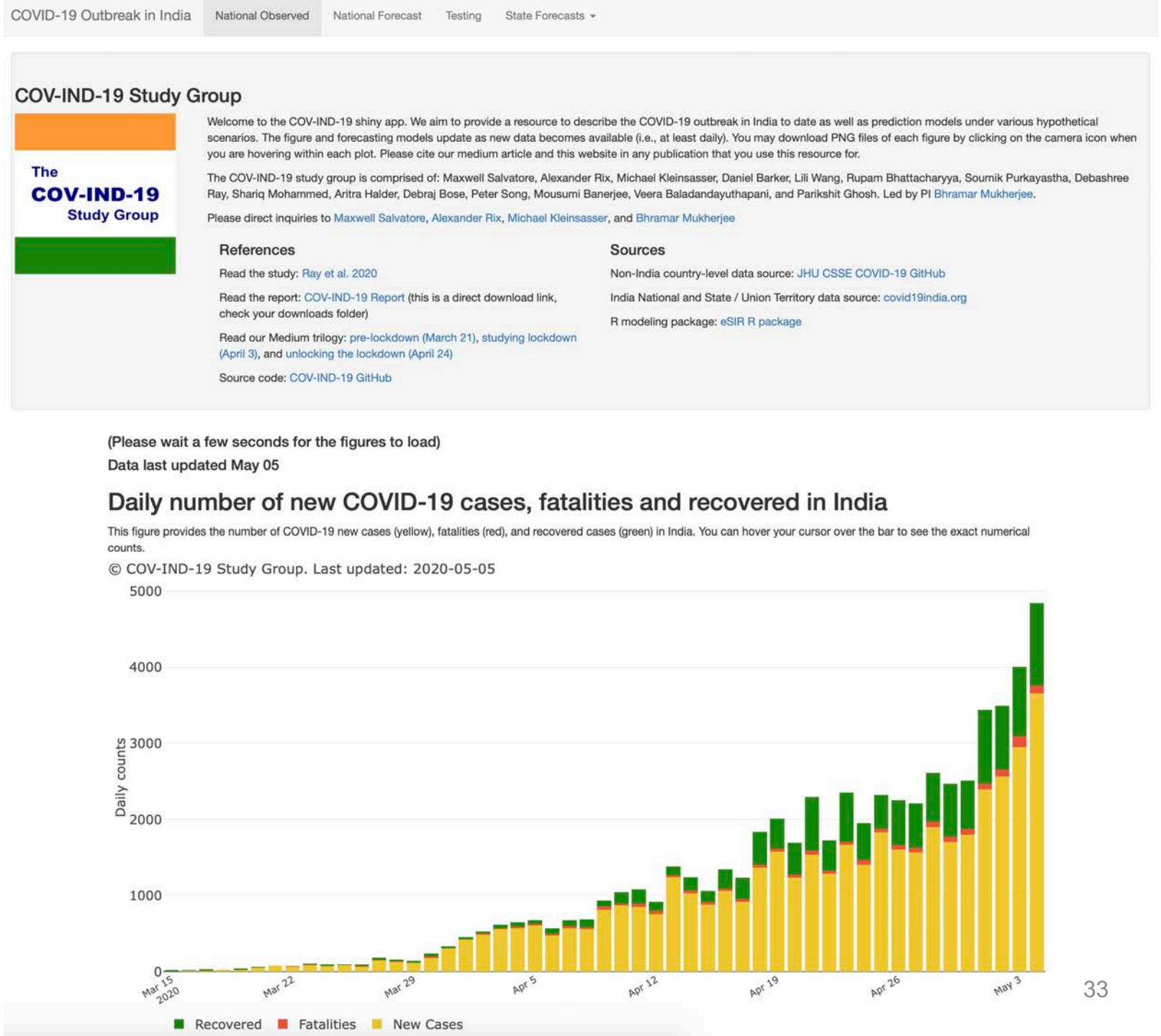
Maxwell Salvatore,[1,2] Deepankar Basu,[3] Debashree Ray,[4,5] Mike Kleinsasser,[1] Soumik Purkayastha ,[1] Rupam Bhattacharyya,[1] Bhramar Mukherjee [1,2]

Phase 2: Updating projections was important



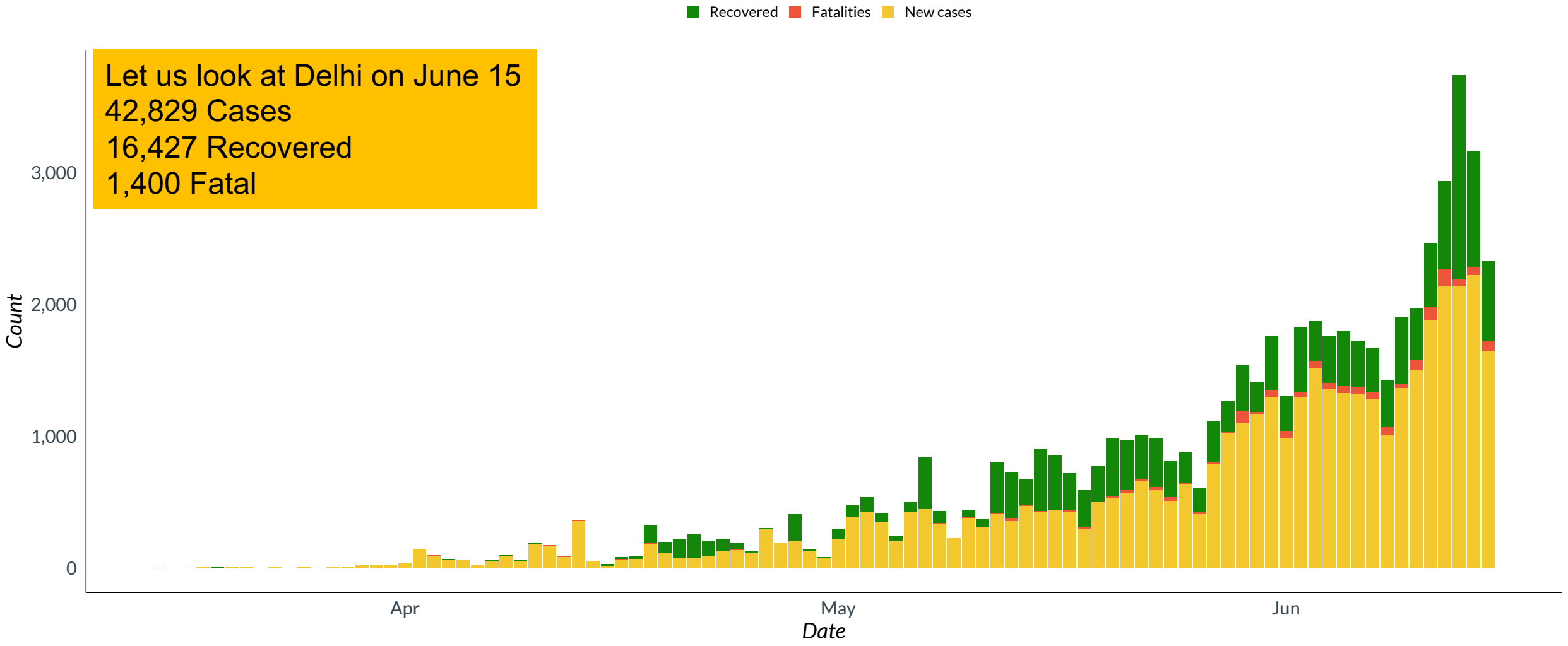
COVIND19.org
(Please check it out!)

Our contribution and service as data scientists



Daily number of COVID-19 cases, fatalities, and recovered in Delhi

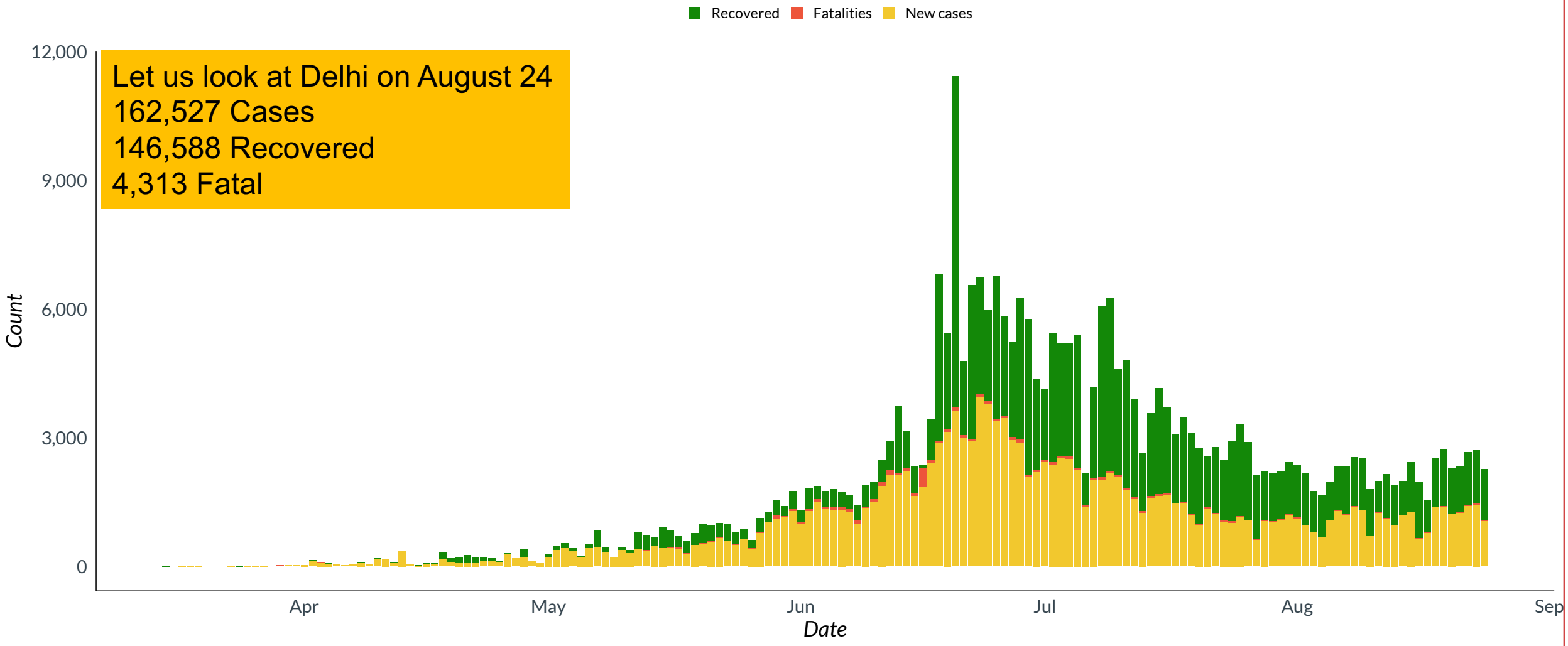
as of June 15



Source: covid19data.org

Daily number of COVID-19 cases, fatalities, and recovered in Delhi

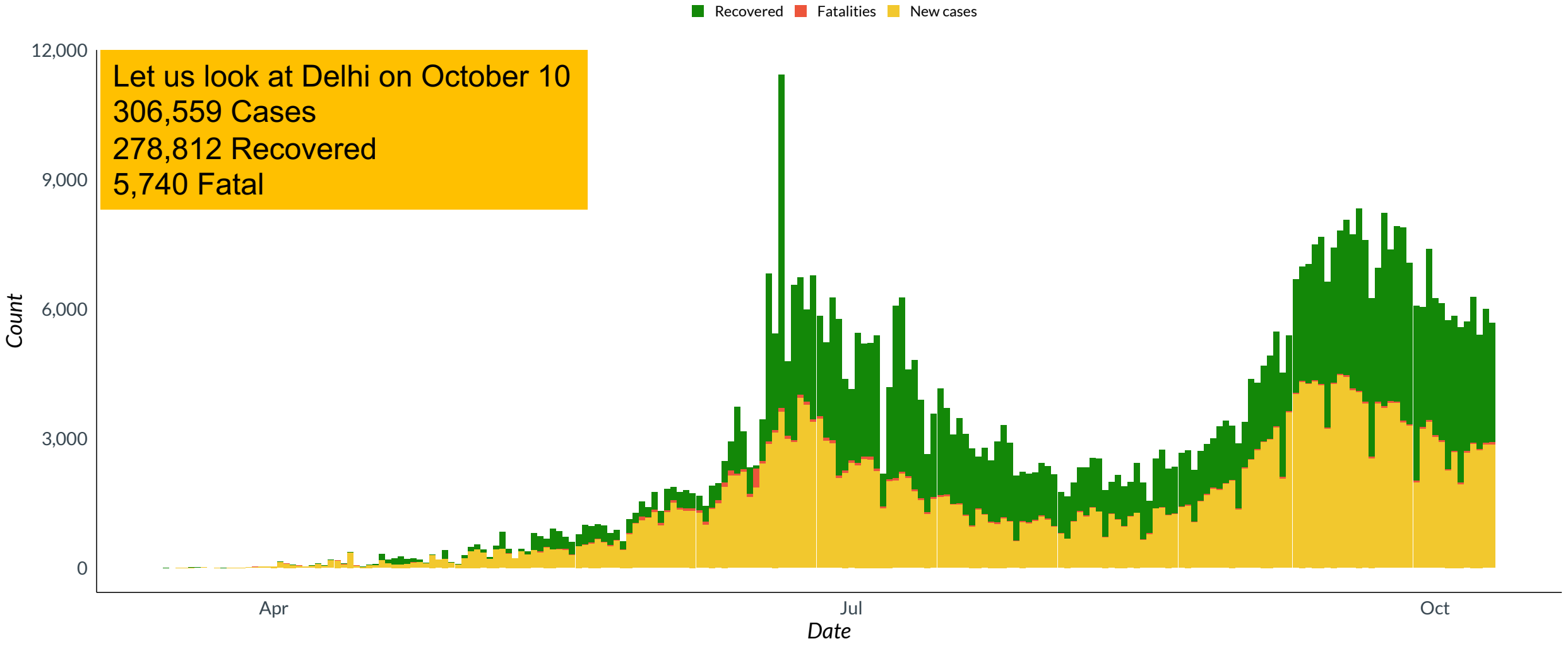
as of August 24



Source: covid19data.org

Daily number of COVID-19 cases, fatalities, and recovered in Delhi

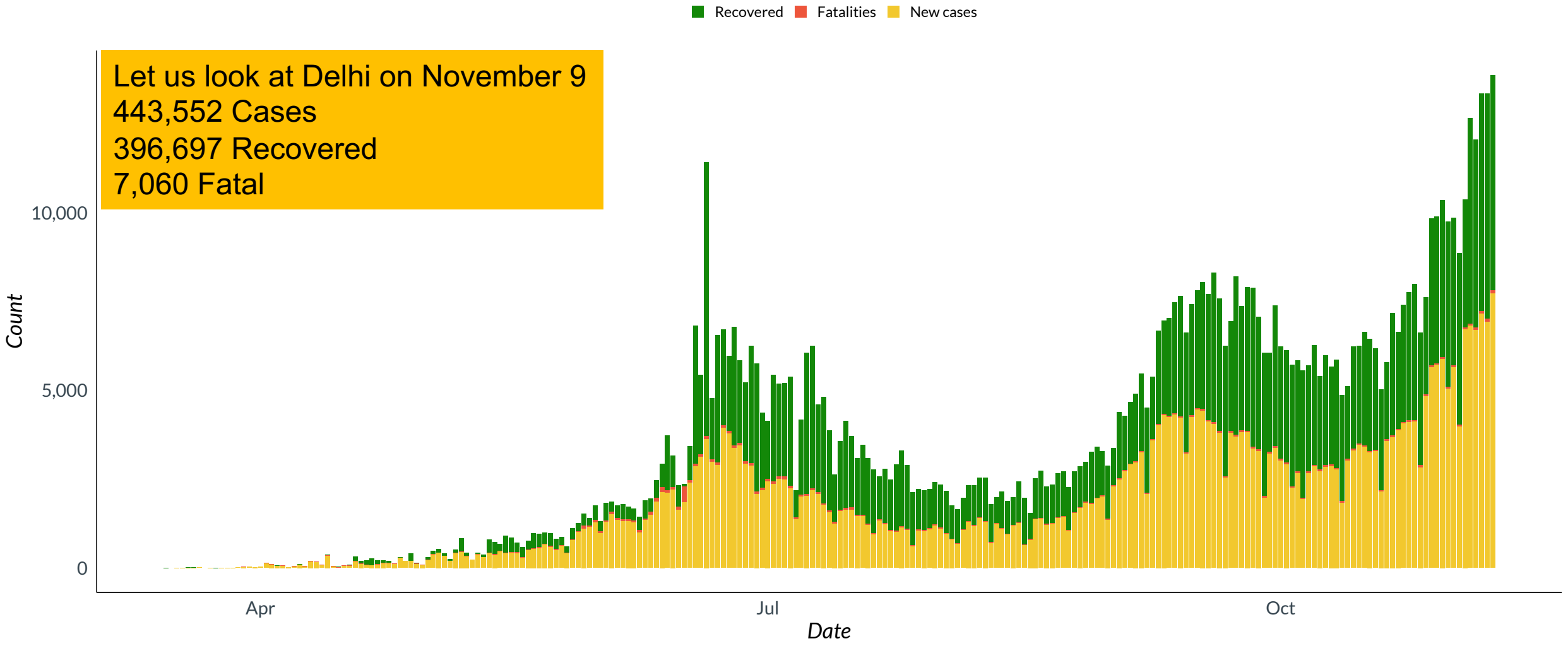
as of October 10



Source: covid19data.org

Daily number of COVID-19 cases, fatalities, and recovered in Delhi

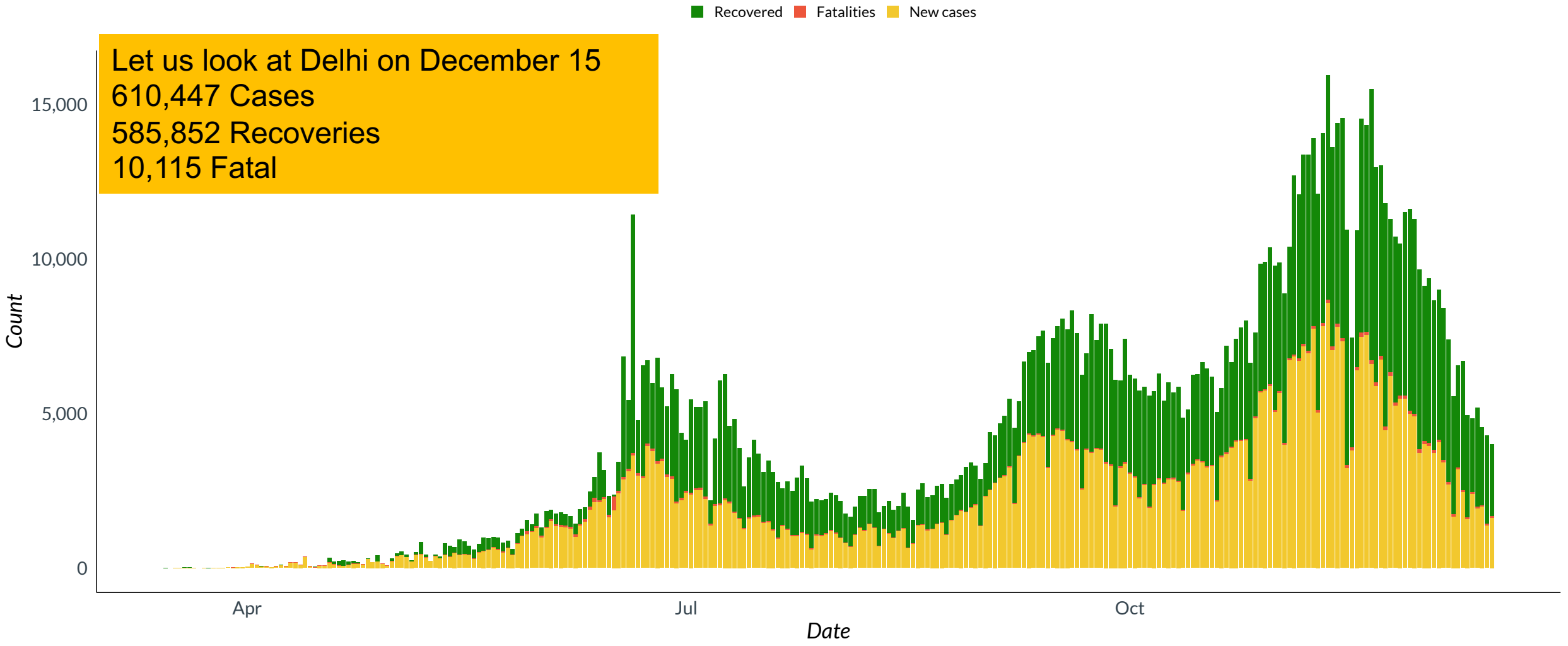
as of November 8



Source: covid19data.org

Daily number of COVID-19 cases, fatalities, and recovered in Delhi

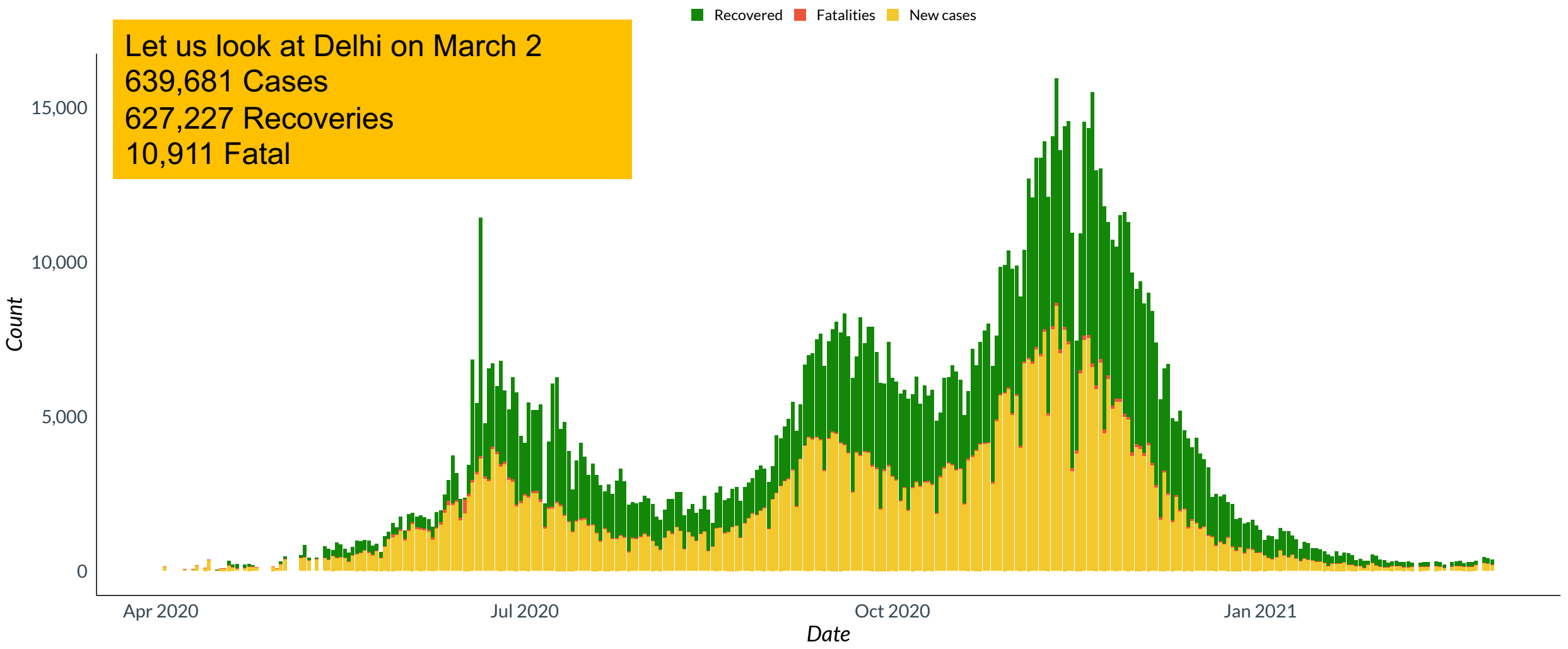
as of December 15



Source: covid19data.org

Daily number of COVID-19 cases, fatalities, and recovered in Delhi

as of March 2

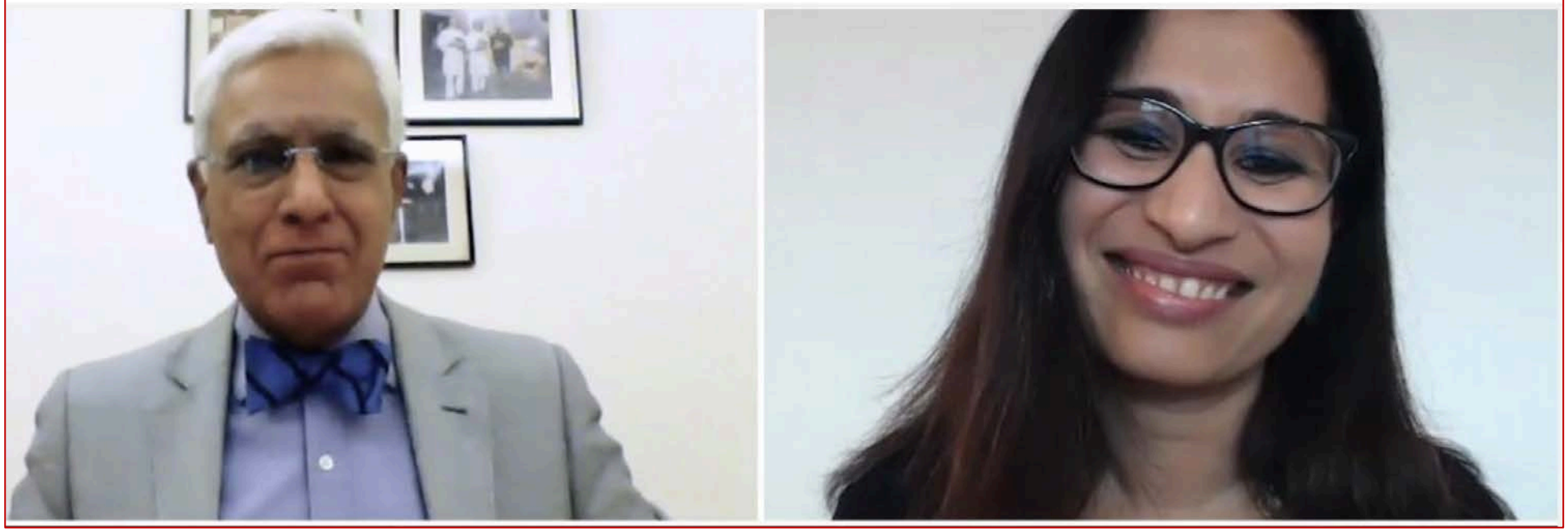


Source: covid19data.org

Phase 3: Seroprevalence surveys and underreporting

Watch | 'India Could Have 30 Million Undetected COVID-19 Cases Today; 100 Million in 6 Weeks'

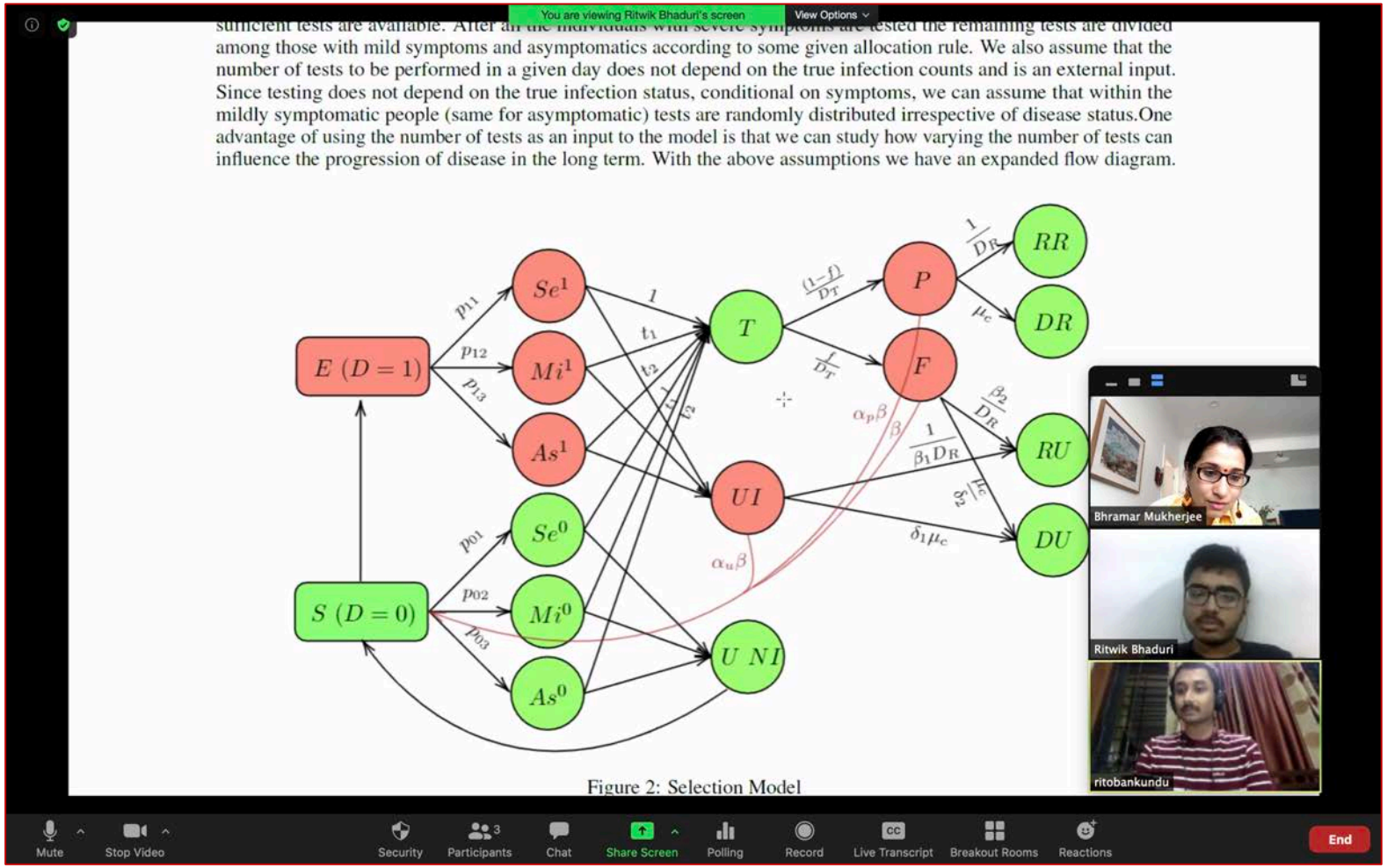
Bhramar Mukherjee, professor of epidemiology and head of the Department of Biostatistics at the University of Michigan, speaks to Karan Thapar on the future of the health crisis.



Mr Karan Thapar: India's Anderson Cooper for my generation

https://www.youtube.com/watch?v=gHakQGaEd9g

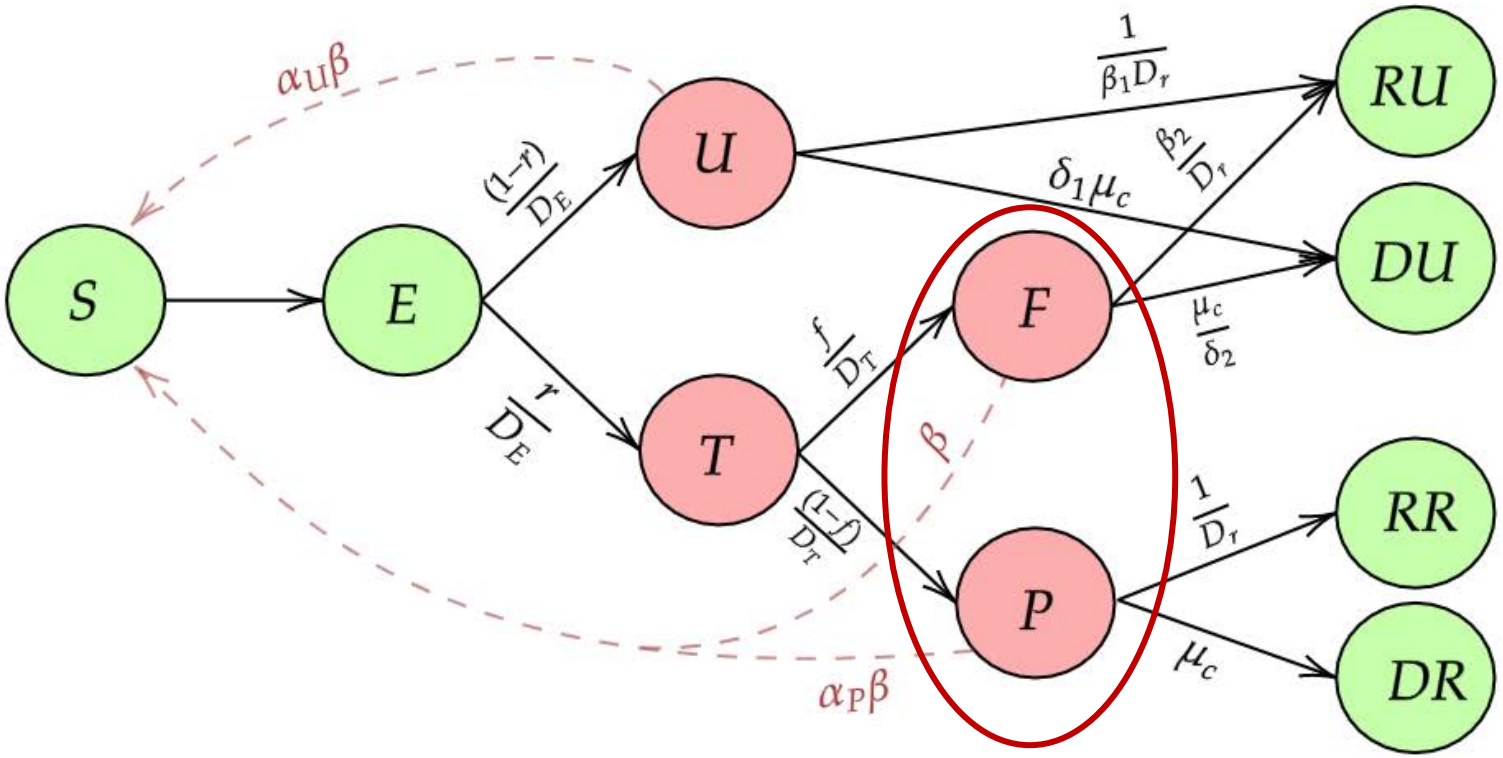
Summer Internship work of two students from ISI Kolkata: Handling false negatives in the tests and testing bias



Underreporting factor:

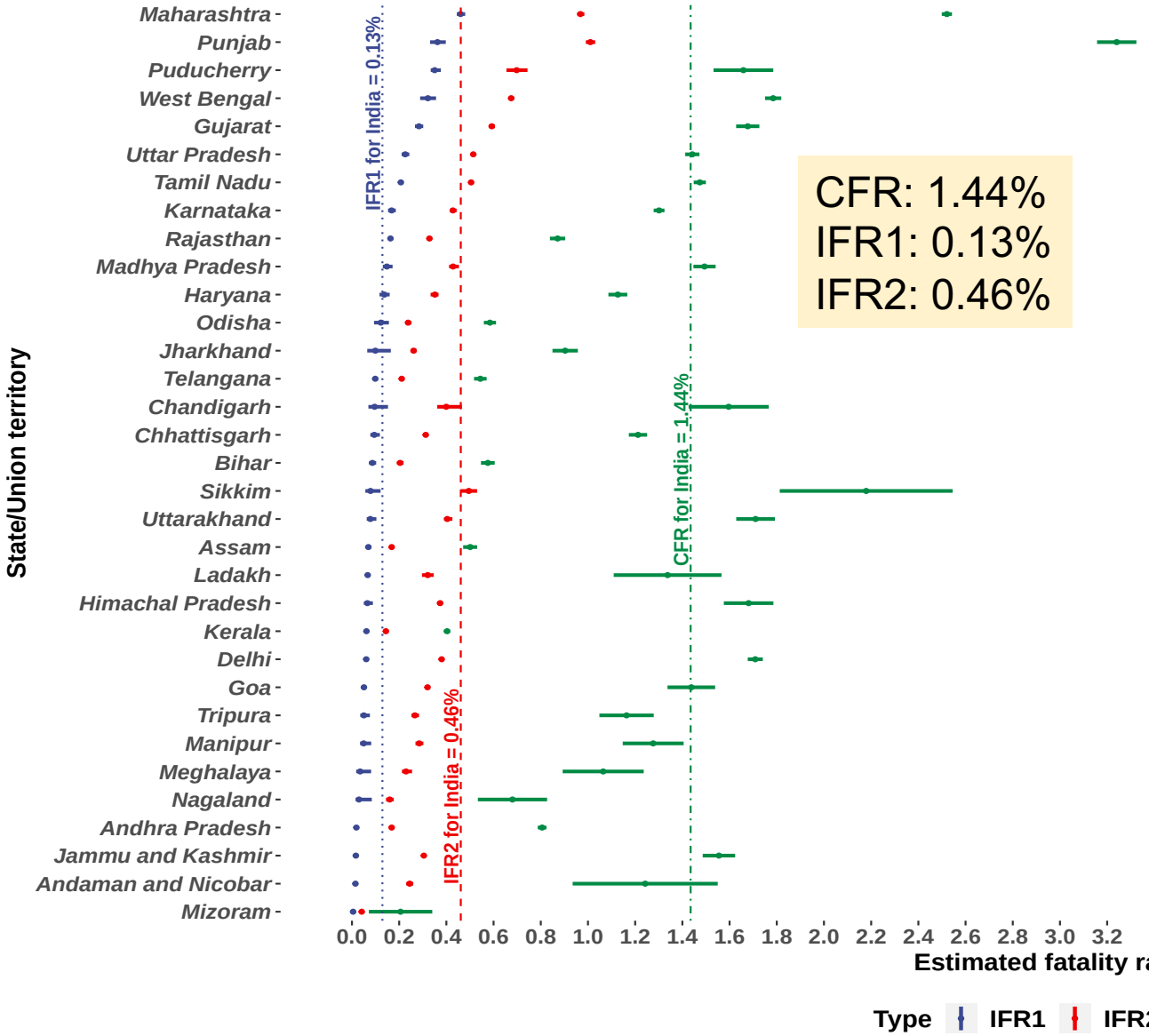
- For cases 10-20
- For deaths 2-5
- Infection Fatality Rate 0.1%-0.5%
- With 0.1% IFR If 50% of India gets the infection we will have 670,000 deaths

False negatives can give false security



$\alpha_u = \alpha_p = 0.5$
$\beta_1 = 0.6,\ \beta_2 = 0.7$
$\delta_1 = 0.3,\ \delta_2 = 0.7$
$f = 0.15$
$\mu_c = mCFR / 17.8$
$\mu = \lambda = 3.95 \times 10^{-5}$
$D_r = 17.8$
$D_E = 5.2$
$D_T \approx 0$
$\beta, r \rightarrow time\ varying$

Estimated fatality rates associated with SARS–CoV–2 for states in India as of 31 January 2021



CFR: 1.44%
IFR1: 0.13%
IFR2: 0.46%

IFR1: 0.46 (0.44–0.48)	IFR2: 0.97 (0.96–0.98)	CFR: 2.52 (2.50–2.54)
IFR1: 0.36 (0.33–0.40)	IFR2: 1.01 (0.99–1.03)	CFR: 3.24 (3.16–3.32)
IFR1: 0.35 (0.33–0.38)	IFR2: 0.70 (0.65–0.74)	CFR: 1.66 (1.53–1.79)
IFR1: 0.32 (0.29–0.36)	IFR2: 0.67 (0.66–0.69)	CFR: 1.78 (1.75–1.82)
IFR1: 0.28 (0.27–0.30)	IFR2: 0.59 (0.58–0.61)	CFR: 1.68 (1.63–1.73)
IFR1: 0.23 (0.21–0.24)	IFR2: 0.51 (0.50–0.52)	CFR: 1.44 (1.41–1.47)
IFR1: 0.21 (0.20–0.22)	IFR2: 0.50 (0.50–0.51)	CFR: 1.47 (1.45–1.50)
IFR1: 0.17 (0.15–0.19)	IFR2: 0.43 (0.41–0.44)	CFR: 1.30 (1.28–1.32)
IFR1: 0.16 (0.15–0.17)	IFR2: 0.33 (0.32–0.34)	CFR: 0.87 (0.84–0.90)
IFR1: 0.15 (0.13–0.17)	IFR2: 0.43 (0.41–0.45)	CFR: 1.49 (1.45–1.54)
IFR1: 0.14 (0.12–0.16)	IFR2: 0.35 (0.33–0.37)	CFR: 1.13 (1.09–1.17)
IFR1: 0.12 (0.09–0.16)	IFR2: 0.24 (0.23–0.25)	CFR: 0.58 (0.56–0.61)
IFR1: 0.10 (0.06–0.16)	IFR2: 0.26 (0.25–0.27)	CFR: 0.90 (0.85–0.96)
IFR1: 0.10 (0.09–0.11)	IFR2: 0.21 (0.20–0.22)	CFR: 0.54 (0.52–0.57)
IFR1: 0.10 (0.07–0.15)	IFR2: 0.40 (0.36–0.47)	CFR: 1.60 (1.43–1.77)
IFR1: 0.09 (0.08–0.12)	IFR2: 0.31 (0.30–0.32)	CFR: 1.21 (1.17–1.25)
IFR1: 0.09 (0.07–0.10)	IFR2: 0.20 (0.19–0.22)	CFR: 0.58 (0.55–0.60)
IFR1: 0.08 (0.06–0.12)	IFR2: 0.49 (0.46–0.53)	CFR: 2.18 (1.81–2.55)
IFR1: 0.08 (0.06–0.10)	IFR2: 0.40 (0.39–0.43)	CFR: 1.71 (1.63–1.79)
IFR1: 0.07 (0.06–0.08)	IFR2: 0.17 (0.16–0.18)	CFR: 0.50 (0.47–0.53)
IFR1: 0.07 (0.06–0.07)	IFR2: 0.32 (0.30–0.35)	CFR: 1.34 (1.11–1.57)
IFR1: 0.07 (0.05–0.09)	IFR2: 0.37 (0.36–0.38)	CFR: 1.68 (1.58–1.79)
IFR1: 0.06 (0.06–0.07)	IFR2: 0.14 (0.14–0.15)	CFR: 0.40 (0.39–0.42)
IFR1: 0.06 (0.06–0.06)	IFR2: 0.38 (0.38–0.38)	CFR: 1.71 (1.68–1.74)
IFR1: 0.05 (0.05–0.05)	IFR2: 0.32 (0.31–0.33)	CFR: 1.44 (1.34–1.54)
IFR1: 0.05 (0.04–0.08)	IFR2: 0.27 (0.25–0.28)	CFR: 1.16 (1.05–1.28)
IFR1: 0.05 (0.03–0.08)	IFR2: 0.28 (0.27–0.30)	CFR: 1.28 (1.15–1.41)
IFR1: 0.03 (0.02–0.08)	IFR2: 0.23 (0.21–0.25)	CFR: 1.06 (0.89–1.24)
IFR1: 0.03 (0.02–0.08)	IFR2: 0.16 (0.14–0.18)	CFR: 0.68 (0.53–0.83)
IFR1: 0.02 (0.02–0.02)	IFR2: 0.17 (0.17–0.17)	CFR: 0.81 (0.79–0.82)
IFR1: 0.02 (0.02–0.02)	IFR2: 0.30 (0.30–0.31)	CFR: 1.55 (1.49–1.62)
IFR1: 0.01 (0.01–0.01)	IFR2: 0.24 (0.23–0.26)	CFR: 1.24 (0.94–1.55)
IFR1: 0.00 (0.00–0.01)	IFR2: 0.04 (0.03–0.05)	CFR: 0.21 (0.07–0.34)

$$\text{IFR}_1 = \frac{\text{Observed total deaths}}{\text{Estimated total cases}}$$

$$\text{IFR}_2 = \frac{\text{Estimated total deaths}}{\text{Estimated total cases}}$$

$$\text{CFR} = \frac{\text{Observed total deaths}}{\text{Observed total cases}}$$

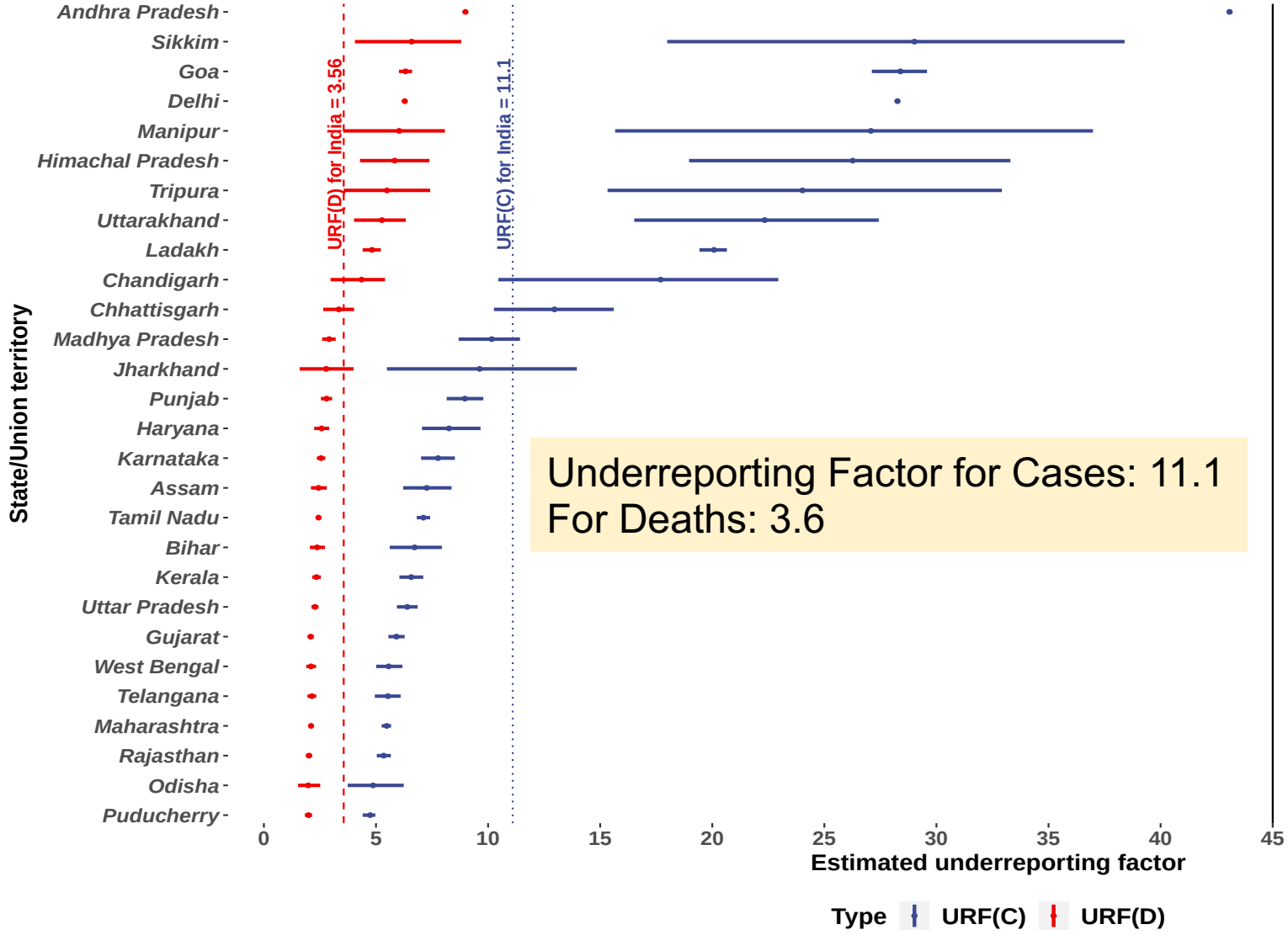
Estimated count

= Observed count
+ Unreported count

Source: covid19india.org
Note:
– Owing to lack of sufficient data, estimates from Arunachal Pradesh and Dadra and Nagar Haveli have not been included.
– Coloured blue for IFR1, red for IFR2 and green for CFR values.

Estimated underreporting factors associated with SARS–CoV–2 for states in India

as of 31 January 2021



Underreporting Factor for Cases: 11.1
For Deaths: 3.6

URF(D): 9.0 (8.9– 9.1)	URF(C): 43.1 (43.0–43.2)
URF(D): 6.6 (4.1– 8.8)	URF(C): 29.0 (18.0–38.4)
URF(D): 6.3 (6.0– 6.6)	URF(C): 28.4 (27.1–29.6)
URF(D): 6.3 (6.2– 6.3)	URF(C): 28.3 (28.2–28.4)
URF(D): 6.0 (3.5– 8.1)	URF(C): 27.1 (15.7–37.0)
URF(D): 5.8 (4.3– 7.4)	URF(C): 26.3 (19.0–33.3)
URF(D): 5.5 (3.6– 7.4)	URF(C): 24.0 (15.3–32.9)
URF(D): 5.3 (4.0– 6.3)	URF(C): 22.3 (16.5–27.4)
URF(D): 4.8 (4.4– 5.2)	URF(C): 20.1 (19.4–20.7)
URF(D): 4.4 (3.0– 5.4)	URF(C): 17.7 (10.5–22.9)
URF(D): 3.3 (2.6– 4.0)	URF(C): 13.0 (10.3–15.6)
URF(D): 2.9 (2.6– 3.2)	URF(C): 10.2 (8.7–11.4)
URF(D): 2.8 (1.6– 4.0)	URF(C): 9.6 (5.5–14.0)
URF(D): 2.8 (2.5– 3.0)	URF(C): 9.0 (8.2– 9.8)
URF(D): 2.6 (2.2– 2.9)	URF(C): 8.3 (7.1– 9.7)
URF(D): 2.6 (2.4– 2.7)	URF(C): 7.8 (7.0– 8.5)
URF(D): 2.4 (2.1– 2.8)	URF(C): 7.3 (6.2– 8.4)
URF(D): 2.4 (2.3– 2.5)	URF(C): 7.1 (6.8– 7.4)
URF(D): 2.4 (2.0– 2.7)	URF(C): 6.7 (5.6– 7.9)
URF(D): 2.3 (2.2– 2.5)	URF(C): 6.6 (6.0– 7.1)
URF(D): 2.3 (2.1– 2.4)	URF(C): 6.4 (5.9– 6.9)
URF(D): 2.1 (2.0– 2.2)	URF(C): 5.9 (5.6– 6.3)
URF(D): 2.1 (1.9– 2.3)	URF(C): 5.6 (5.0– 6.2)
URF(D): 2.1 (1.9– 2.3)	URF(C): 5.5 (4.9– 6.1)
URF(D): 2.1 (2.0– 2.2)	URF(C): 5.5 (5.3– 5.7)
URF(D): 2.0 (1.9– 2.1)	URF(C): 5.3 (5.0– 5.7)
URF(D): 2.0 (1.5– 2.5)	URF(C): 4.9 (3.7– 6.2)
URF(D): 2.0 (1.8– 2.1)	URF(C): 4.7 (4.4– 5.0)

$$\mathrm{URF_D} = \frac{\text{Observed total deaths}}{\text{Estimated total deaths}}$$

$$\mathrm{URF_C} = \frac{\text{Observed total cases}}{\text{Estimated total cases}}$$

Estimated count
= Observed count
+ Unreported count

Source: covid19india.org
Note:
– Owing to lack of sufficient data, estimates from Jammu and Kashmir, Dadra and Nagar Haveli, Arunachal Pradesh, Mizoram, Nagaland, Meghalaya and Andaman and Nicobar have not been included.
– Coloured blue for URF(C) and red for URF(D) values.

Summary of various serological surveys conducted in India during 2020-21.

Part B: Results from some other serological surveys conducted in India in 2020-21.

Region	*Study setting*	*Study period*	*# of people tested*	*% of positive samples*
Delhi (Round 3)	Urban	September 1-5, 2020	17,409	**25.1**
Delhi (Round 4)	Urban	January 11-22, 2021	28,840	**58.0**
Tamil Nadu	Rural and Urban	October-November, 2020	26,640	**26.9 (rural areas)** **36.9 (urban areas)**
Mumbai	Urban	Last half of August, 2020	3,024 (slum areas) 2,176 (non-slum areas)	**45.2 (slum areas)** **17.1 (non-slum areas)**
Pune	Urban	July 20 – August 5, 2020	1,664	**51.5**
Chennai (Round 1)	Urban	July 17 – 28, 2020	12,405	**18.4**
Chennai (Round 2)	Urban	October 8 – 15, 2020	6,366	**30.1**
Indore	Urban	August 11 – 23, 2020	7,100	**7.75**
Karnataka	Rural and urban	June 15 – August 29, 2020	15,624	**44.1 (rural areas)** **53.8 (urban areas)**
Jammu and Kashmir	Rural and urban	October, 2020	6,230	**38.8**

Latest National Serosurvey: "The 3rd sero-survey was done from Dec 17, 2020 to Jan 8, 2021. A general population of 28,589 individuals were included & another group of 7,171 healthcare workers were also included. Above the age of 18 years the sero-prevalance was 21.4%."

If you believe the data then there are 175M infections In India. Qualitatively agrees with the model estimates (120-125M)

Methodological Advances

- SEIR-FanSy: Extension to SEIR model under false negatives
- Comparison of five different epidemiologic models
- Optimal test allocation strategies

Dangers of rapid science

The New York Times

Opinion

How to Identify Flawed Research Before It Becomes Dangerous

Scientists and journalists need to establish a
research that's publicized before it is peer rev

By Michael B. Eisen and Robert Tibshirani

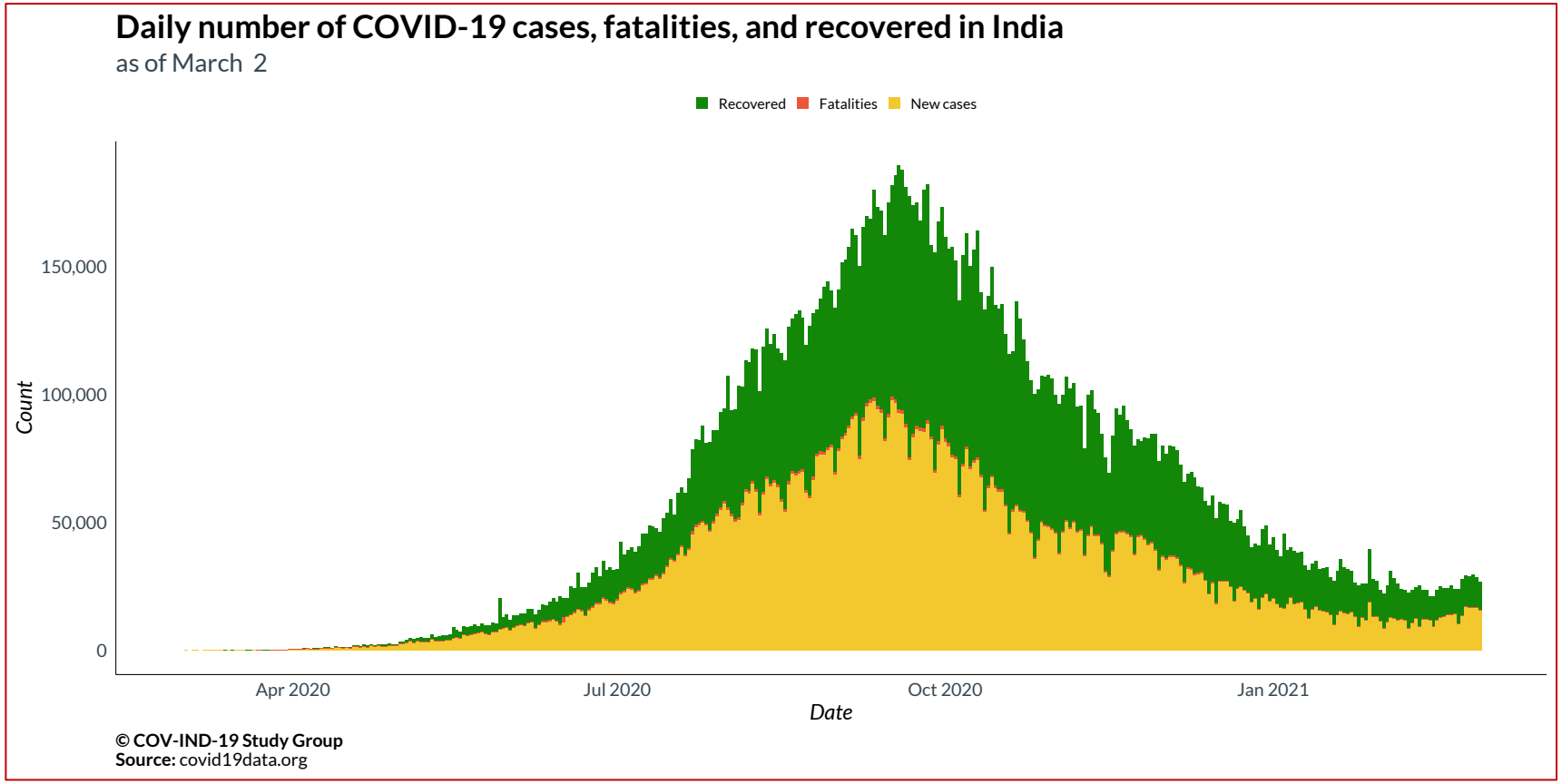
Mr. Eisen is a biologist at the University of California, Berkeley. Mr. Tibshirani is a statistician at Stanford University.

July 20, 2020

We are thrilled that researchers have embraced preprints, which are making new ideas, data and discoveries about the pandemic available to scientists and the public in almost real time. An example is the work of Bhramar Mukherjee and her team at the University of Michigan, whose research modeling the Covid-19 outbreak in India helped guide that government's lockdown policies.

https://www.nytimes.com/2020/07/20/opinion/coronavirus-preprints.html

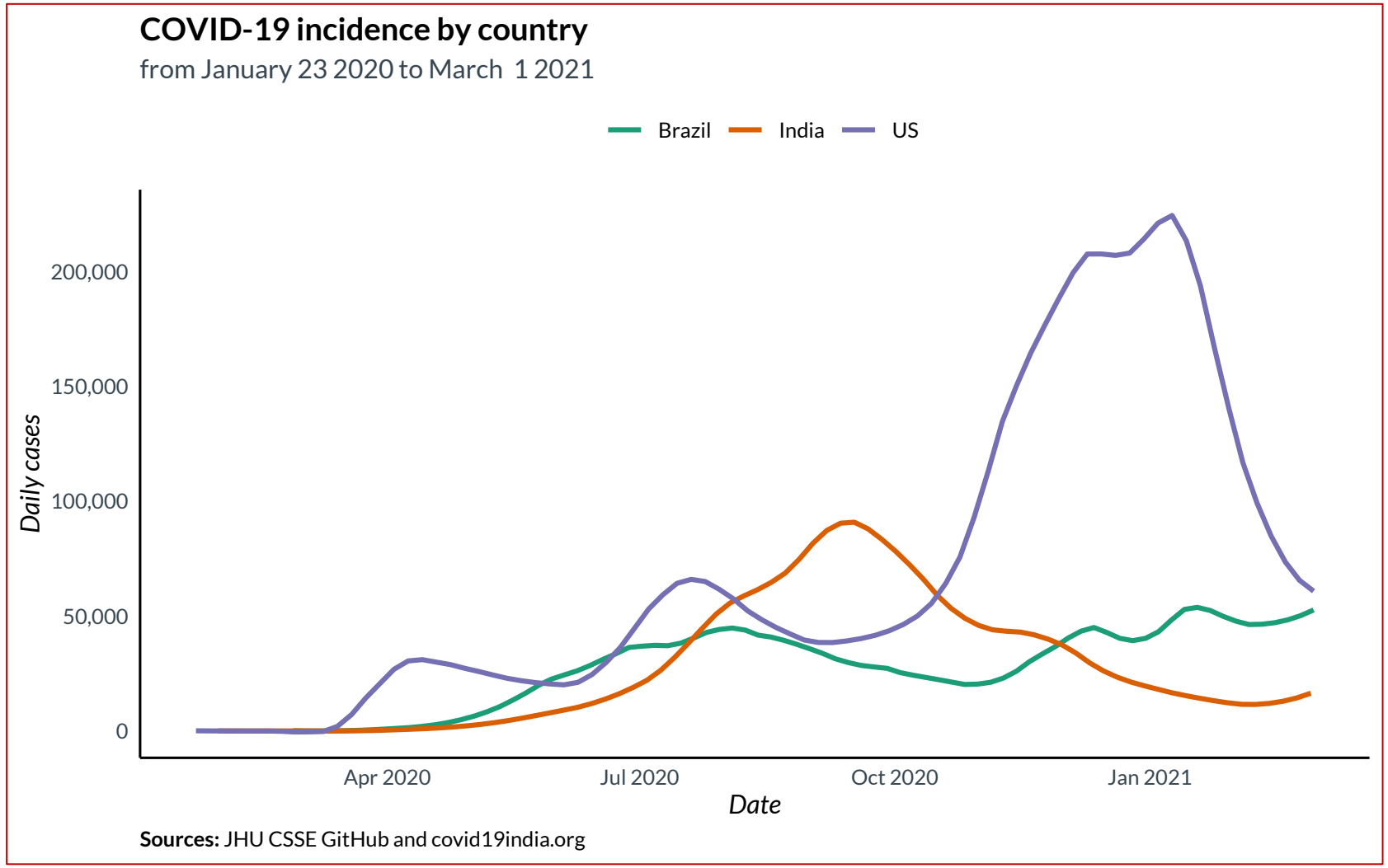
India Recently



Summary as of March 2:

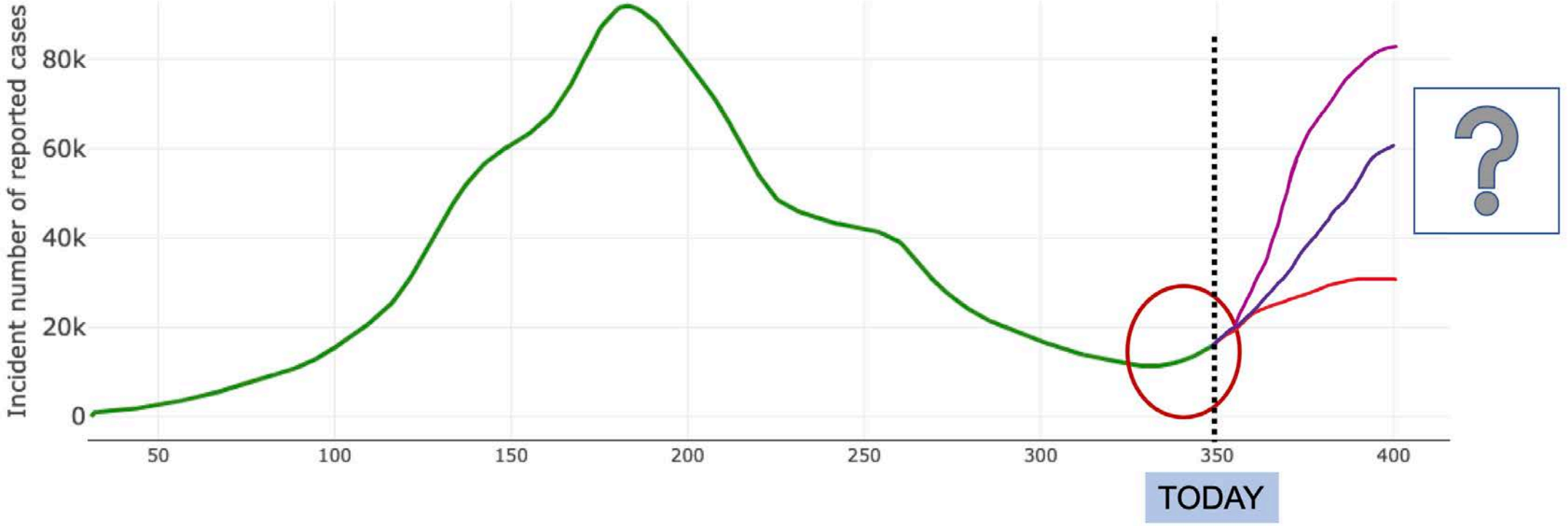
11. 6 M total cases
167 K Active Cases
157 K Deaths
218 M tests done
16% population tested
5.1% cumulative test positivity rate
2.5% daily test positive rate
Case Fatality Rate: 1.4%

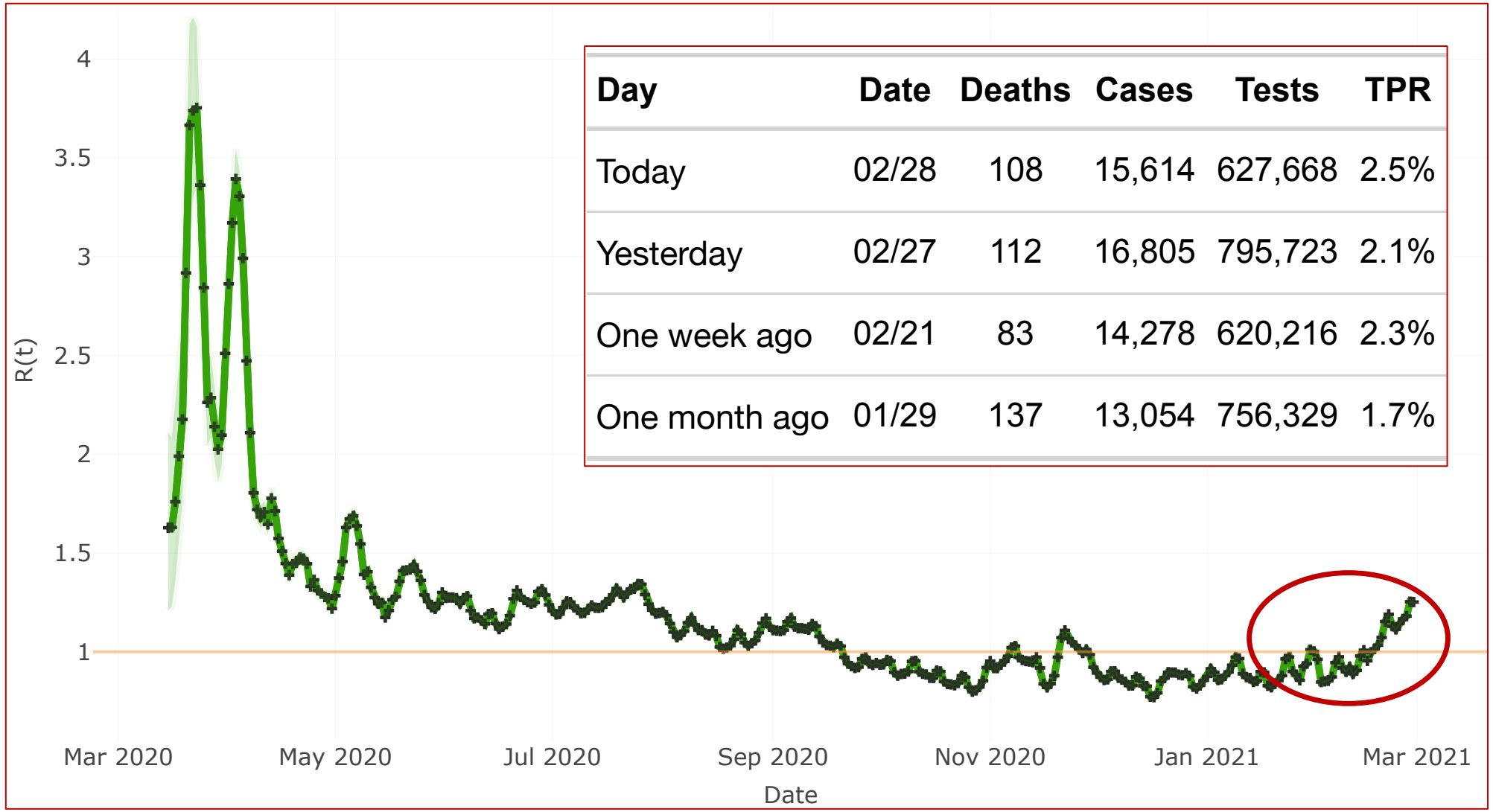
India vs US


COVID-19 incidence by country
from January 23 2020 to March 1 2021
Brazil
India
US
200,000
150,000
100,000
50,000
0
Daily cases
Apr 2020
Jul 2020
Oct 2020
Jan 2021
Date
Sources: JHU CSSE GitHub and covid19india.org

Predictions for second wave depend on assumptions

- Are people with AB getting reinfected?
- What fraction will be vaccinated?
- Damped Oscillations is our forecast not a huge second peak





Day	Date	Deaths	Cases	Tests	TPR
Today	02/28	108	15,614	627,668	2.5%
Yesterday	02/27	112	16,805	795,723	2.1%
One week ago	02/21	83	14,278	620,216	2.3%
One month ago	01/29	137	13,054	756,329	1.7%

Effective R over time for India

Assessing COVID-19 in India

as of March 1

LOCATION	METRICS R	CFR	TEST-POSITIVE RATE	TOTAL TESTED	PPT (%)	TESTING SHORTFALL	PREDICTED CASES (03/22) NO INTERVENTION
National estimate	1.18	0.014	0.051	216,231,106	16.22	339,367,794	11,405,226
Maharashtra	1.55	0.024	0.132	16,284,612	13.33	91,468,888	2,270,688
Kerala	0.83	0.004	0.092	11,476,284	32.67	41,493,916	1,121,973
Karnataka	1.02	0.013	0.051	18,796,775	28.57	28,765,775	962,043
Andhra Pradesh	1.23	0.008	0.064	13,954,131	26.72	30,541,669	893,512
Tamil Nadu	0.99	0.015	0.049	17,479,572	23.09	25,097,528	861,007
Delhi	1.27	0.017	0.052	12,380,699	62.48	19,583,751	641,648
Uttar Pradesh	1.15	0.014	0.019	31,287,226	13.91	0	612,733
West Bengal	1.08	0.018	0.067	8,563,278	8.84	20,192,622	583,352
Odisha	1.02	0.006	0.041	8,321,641	19.06	8,537,909	340,198
Rajasthan	1.07	0.009	0.051	6,304,465	8.16	9,712,335	324,113
Chhattisgarh	0.94	0.012	0.065	4,812,273	16.75	10,815,727	316,458
Telangana	1.28	0.005	0.034	8,700,651	23.38	6,214,199	301,470
Gujarat	1.27	0.016	0.023	11,739,846	17.28	1,754,554	275,185
Haryana	1.36	0.011	0.048	5,669,984	19.78	7,869,216	274,082
Madhya Pradesh	1.31	0.015	0.045	5,786,018	7.04	7,302,282	268,796
Bihar	1.03	0.006	0.012	22,434,044	18.77	0	266,754
Assam	1.48	0.005	0.032	6,850,204	19.98	4,021,546	221,057
Punjab	1.53	0.032	0.036	4,999,390	16.74	4,109,410	194,690
Jammu and Kashmir	1.13	0.015	0.024	5,201,665	39.40	1,120,385	128,259
Jharkhand	1.13	0.009	0.022	5,528,514	14.78	467,686	122,730

Source data: covid19india.org
Notes: Cells highlighted in green indicates good performance for given metric while red indicates need for improvement. Predicted cases are for March 22 based on data through March 1. Only states/union territories with the highest cumulative case counts as of March 1 are shown. National Commission on Population 2019 projections used to calculate PPT.
Abbrev: CFR, Case-fatality rate; PPT, Proportion of population tested

EVERYDAY
~10-17,000 new cases
~100 deaths

Updated daily
Under the metrics Tab at covind19.org

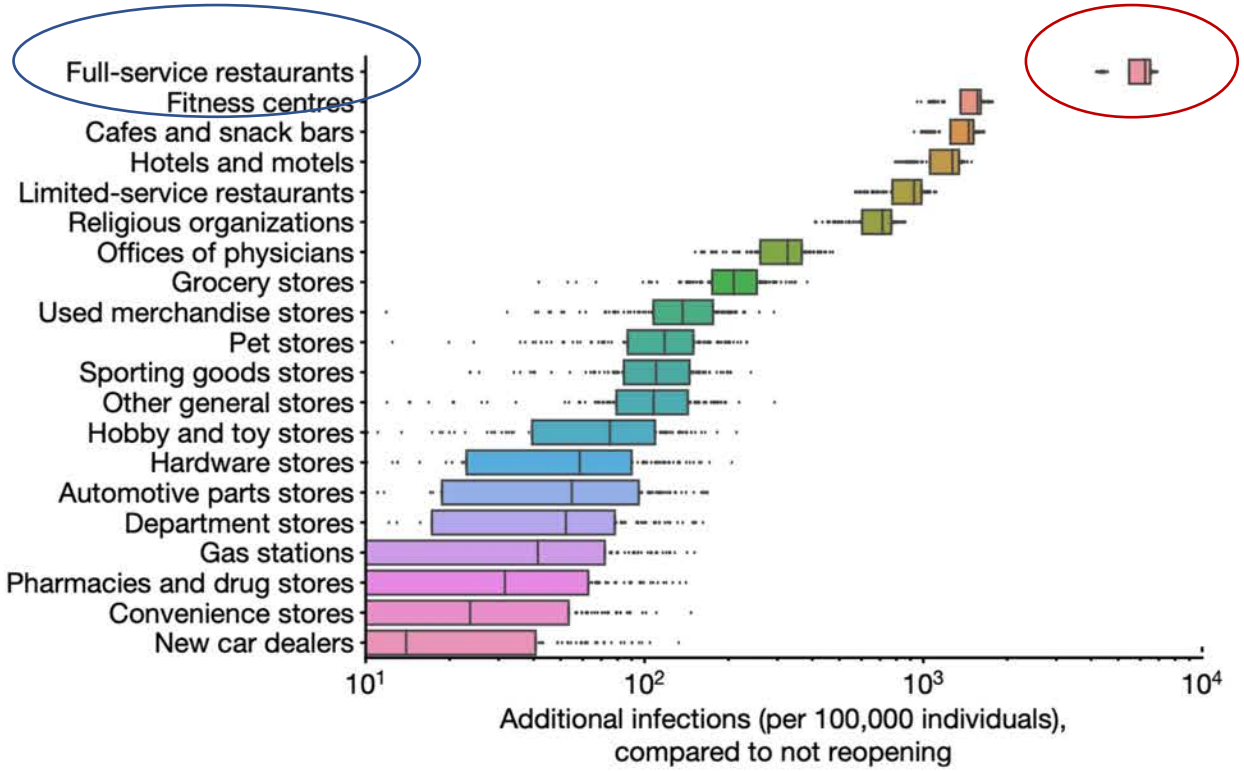
Moving Forward…

- There is no “the” model, ensembling is a better alternative
- Need a transparent vaccine dissemination plan: public-private partnership
- Need an evaluation of the disruption the pandemic caused to healthcare, nutrition programs, immunization, education
- Need population-based periodic serosurveys (with serial follow-up to track seroconversions).
- Genomic surveillance to track variants.
- Nimble policymaking (pause, push and drive) in a data adaptive way.
- Track daily death and admissions data and compare to historical trends.
- A national follow up cohort of recovered patients (already underway)

- Public has a serious role in public health. We need to manage risk in our daily lives.

Mobility network models of COVID-19 explain inequities and inform reopening

nature

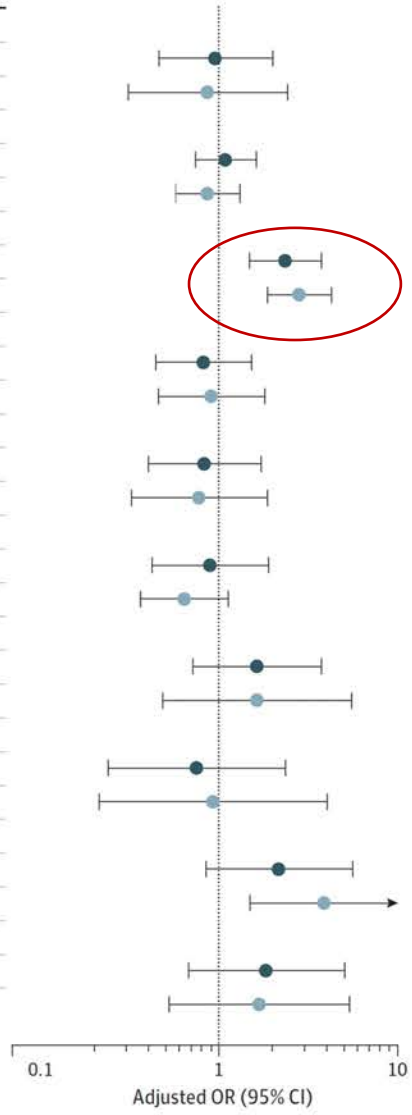


Managing Risk in Our Daily Lives!

Identifying COVID-19 Risk Through Observational Studies to Inform Control Measures

JAMA
The Journal of the American Medical Association

	Adjusted OR (95% CI)
Shopping	
Close COVID-19 contact	0.96 (0.46-2.00)
No close COVID-19 contact	0.87 (0.31-2.43)
Home, ≤10 persons	
Close COVID-19 contact	1.09 (0.74-1.63)
No close COVID-19 contact	0.87 (0.57-1.32)
Restaurant	
Close COVID-19 contact	2.37 (1.49-3.76)
No close COVID-19 contact	2.82 (1.86-4.26)
Office setting	
Close COVID-19 contact	0.82 (0.45-1.52)
No close COVID-19 contact	0.91 (0.46-1.80)
Salon	
Close COVID-19 contact	0.83 (0.40-1.71)
No close COVID-19 contact	0.78 (0.32-1.86)
Home, >10 persons	
Close COVID-19 contact	0.89 (0.42-1.89)
No close COVID-19 contact	0.64 (0.37-1.13)
Gym	
Close COVID-19 contact	1.64 (0.71-3.76)
No close COVID-19 contact	1.64 (0.49-5.53)
Public transportation	
Close COVID-19 contact	0.75 (0.24-2.35)
No close COVID-19 contact	0.93 (0.21-4.05)
Bar or coffee shop	
Close COVID-19 contact	2.18 (0.85-5.61)
No close COVID-19 contact	3.88 (1.49-10.05)
Church or religious gathering	
Close COVID-19 contact	1.84 (0.67-5.02)
No close COVID-19 contact	1.68 (0.53-5.38)



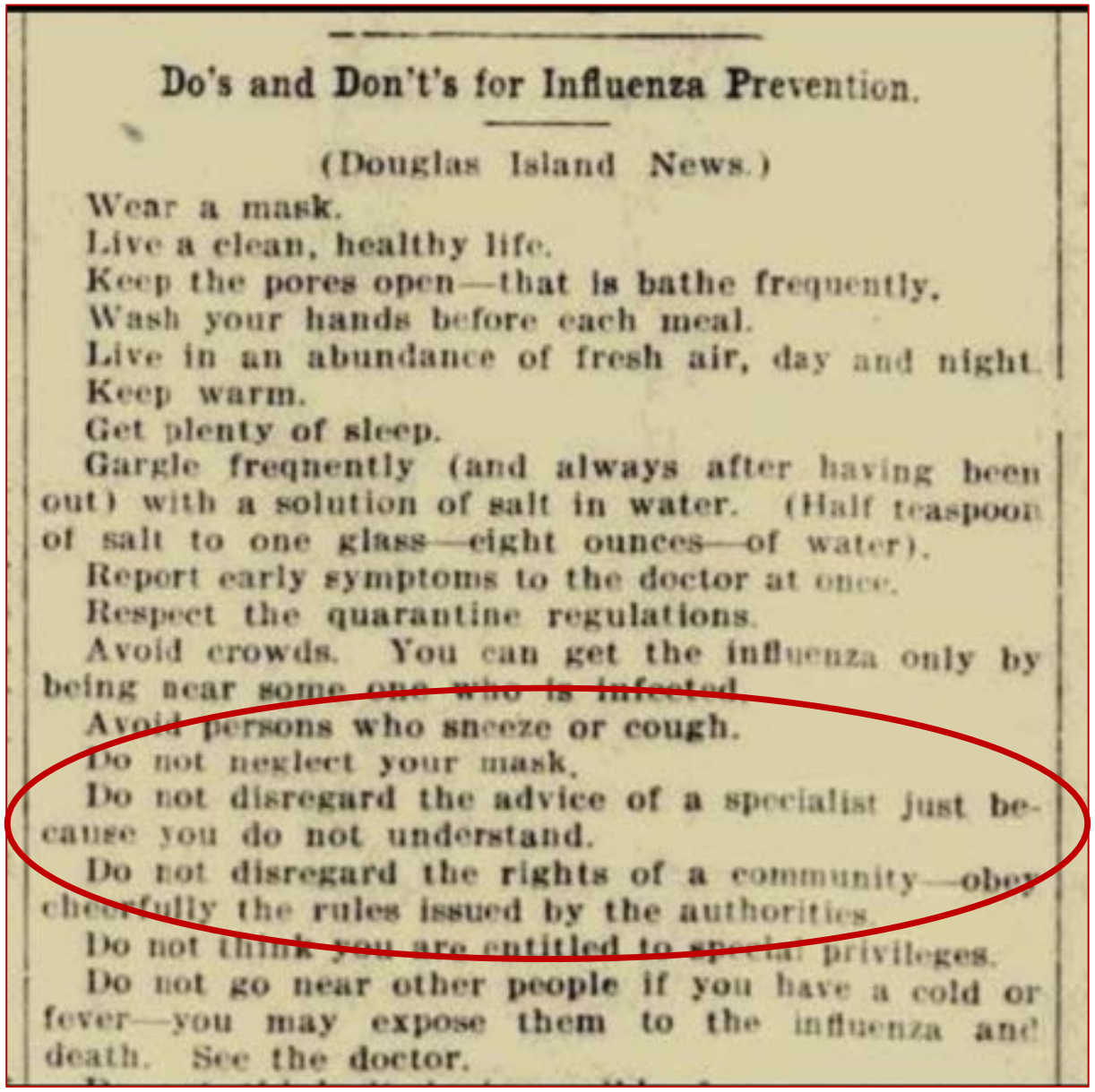
An antique cartoon from 1920

The 2020 String Quartet

- The. Government
- The Public
- The Scientists
- The Corporations
- Conductor: The Virus

Not always in harmony

Closing Remarks: The Humanitarian Component



Do's and Don't's for Influenza Prevention.

(Douglas Island News.)

Wear a mask.
Live a clean, healthy life.
Keep the pores open—that is bathe frequently.
Wash your hands before each meal.
Live in an abundance of fresh air, day and night.
Keep warm.
Get plenty of sleep.
Gargle frequently (and always after having been out) with a solution of salt in water. (Half teaspoon of salt to one glass—eight ounces—of water).
Report early symptoms to the doctor at once.
Respect the quarantine regulations.
Avoid crowds. You can get the influenza only by being near some one who is infected.
Avoid persons who sneeze or cough.
Do not neglect your mask.
Do not disregard the advice of a specialist just because you do not understand.
Do not disregard the rights of a community—obey cheerfully the rules issued by the authorities.
Do not think you are entitled to special privileges.
Do not go near other people if you have a cold or fever—you may expose them to the influenza and death. See the doctor.

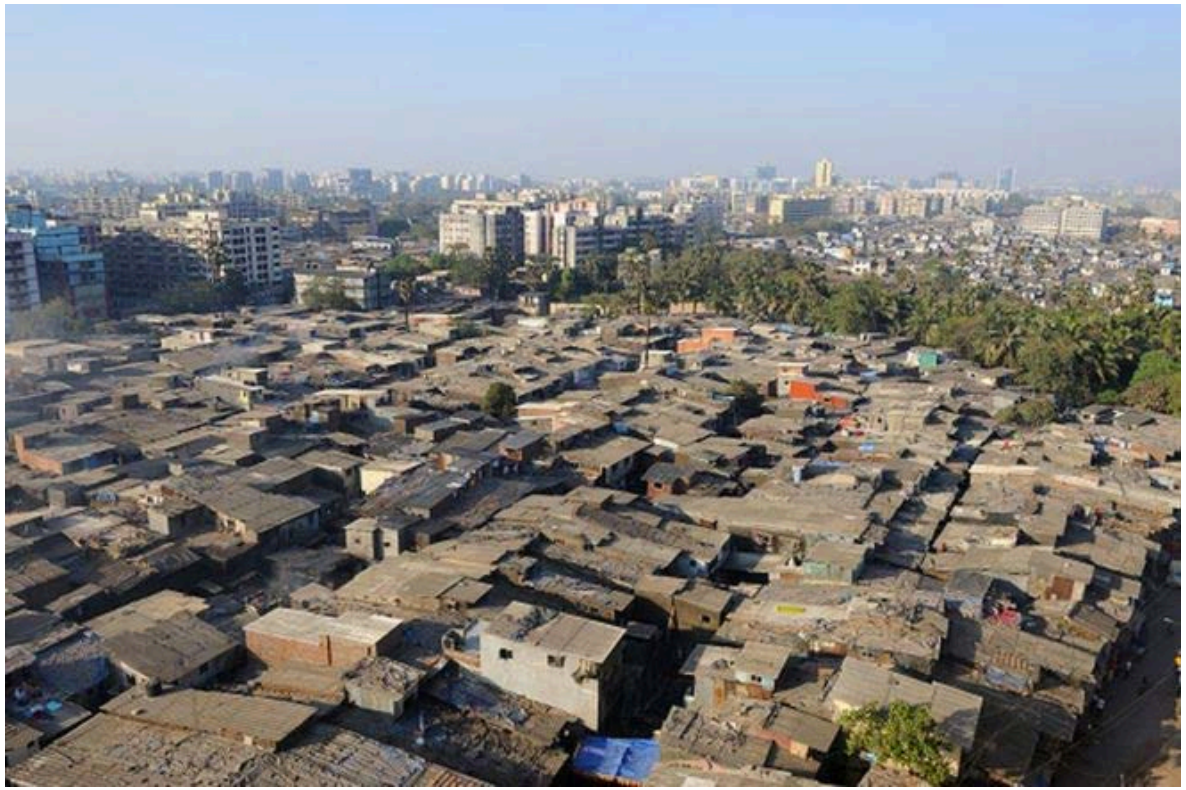
- It is a long haul, we are tired.
- Some recommendations are eternal
- Mental health and humanitarian aspects need to have more focus in our discussions
- Morbidity and mortality due to delay in care and from other causes need to be quantified

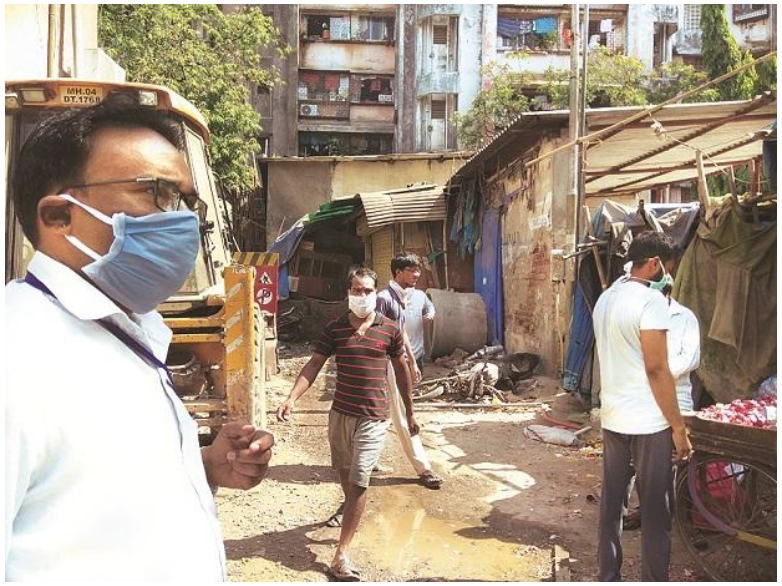
On being human in the face of a pandemic

Nature Cancer (2020) | Cite this article

30 Altmetric | Metrics

As the COVID-19 pandemic sweeps through the world, we must reassess the principles that guide our individual and collective responses and the way we operate in society. In the face of crisis, we must lead with science and humanity.





Dharavi, Mumbai

Asia’s Largest Slum

Austrian Poet Rainer Maria Rilke said, “Let everything happen to you. The beauty and the terror. Just keep going. No feeling is final.”

We have to manage our personal risks!

My desk in Ann Arbor

I flew back to India on November 1

Happy Reunion

Thank you so much for listening!