# Predictions, role of interventions and implications of a national lockdown on the COVID-19 outbreak in India

COV-IND-19 Study Group

An interdisciplinary study group of data scientists

**Modeling COVID-19 Pandemic Resources, Methodology and Applications**

July 29, 2020

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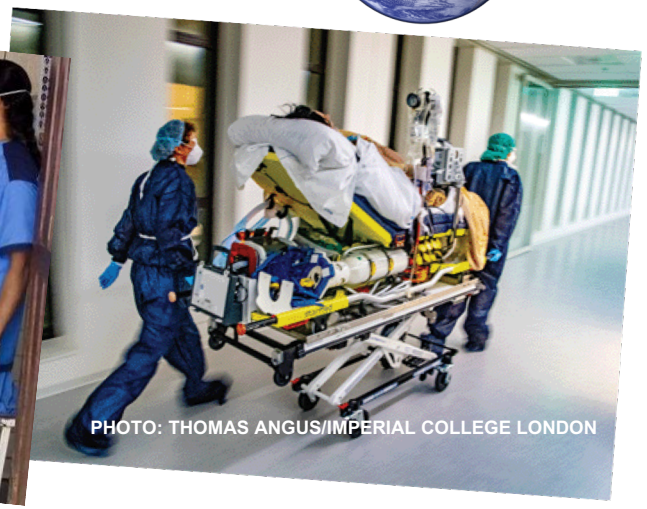
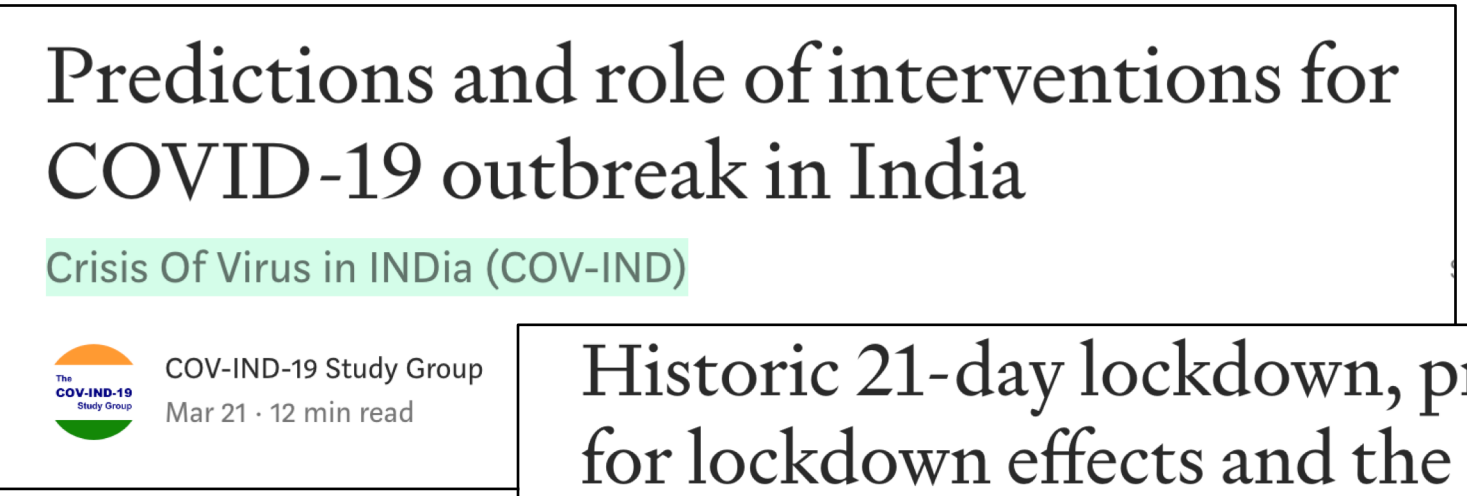
# COVID-19 Heroes

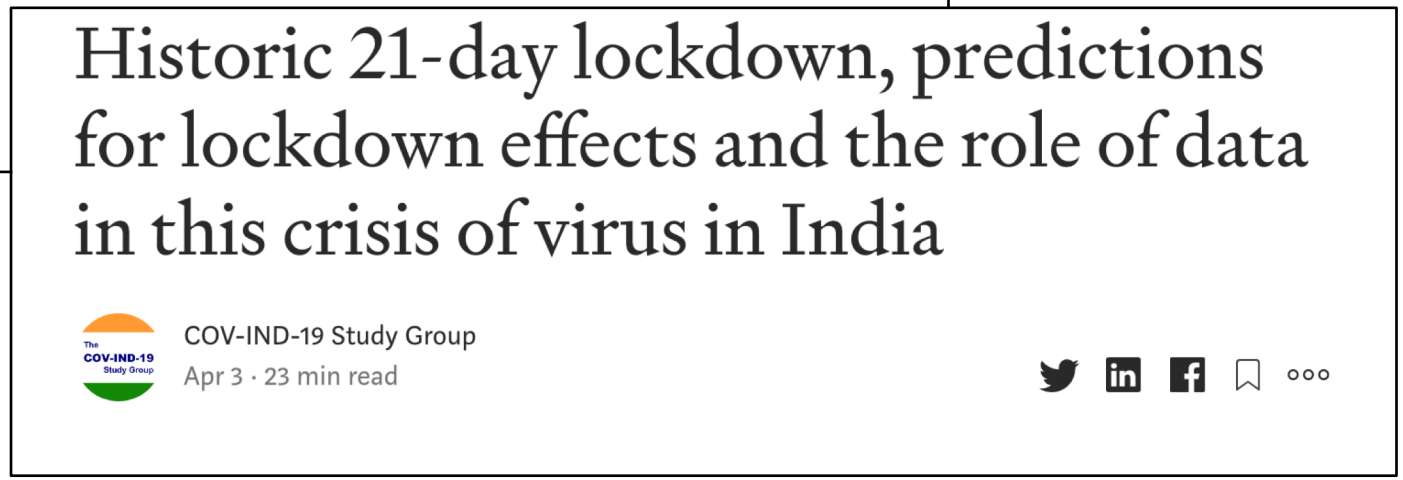
**Thanks to the first responders of COVID19 crisis around the world!**



# References to our work




[Medium Article on March 20]




[Medium Article April 3]

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

# Latest Updates

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

COV-IND-19 Study Group

Apr 24 · 15 min read

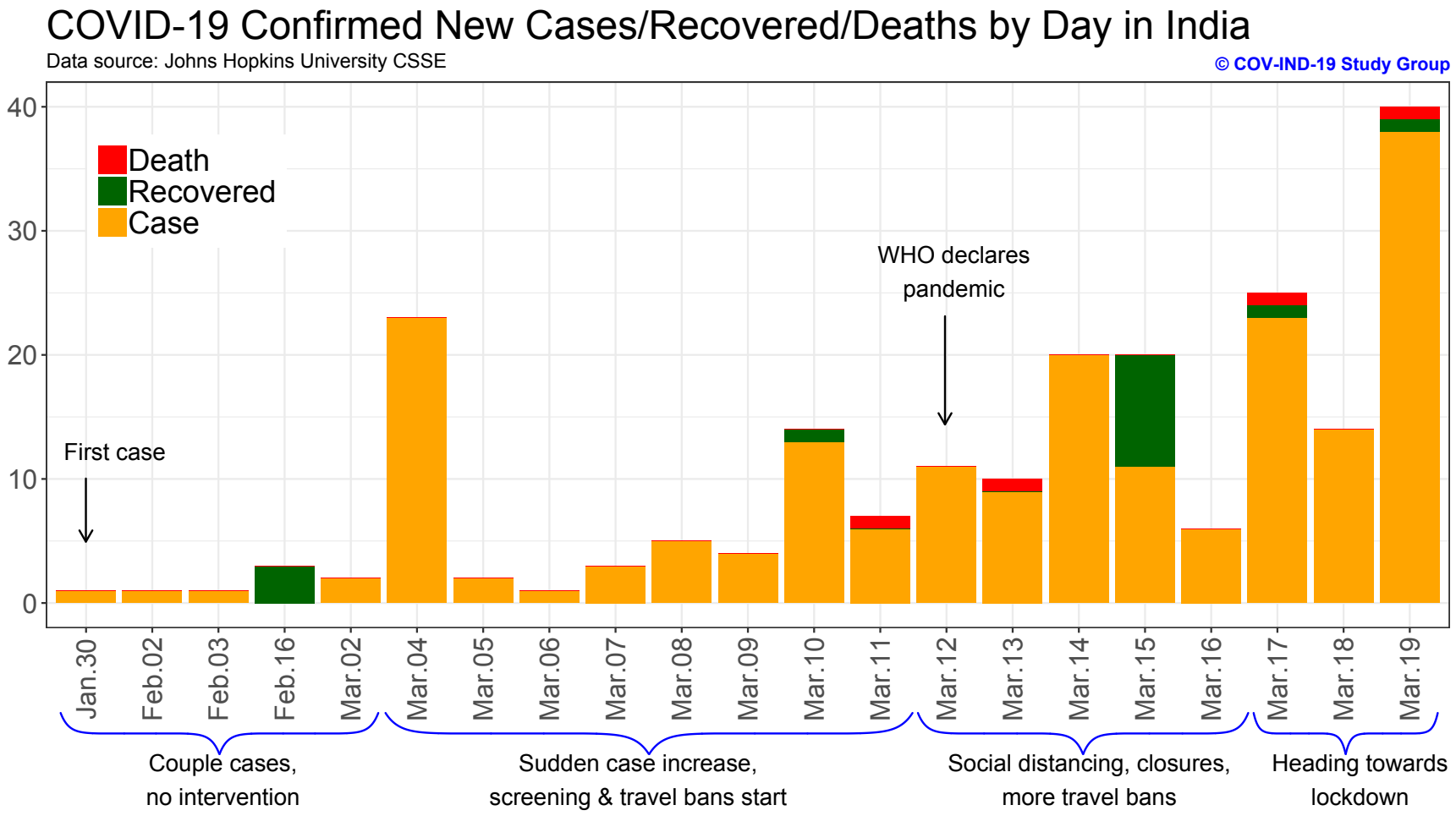
[Medium Article April 24]

[Manuscript in press, Harvard Data Science Review]

# Outline

- Pre-lockdown forecasting
- Post-lockdown analysis
- From  numerical forecasting to strategic vision

# When we started this work




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

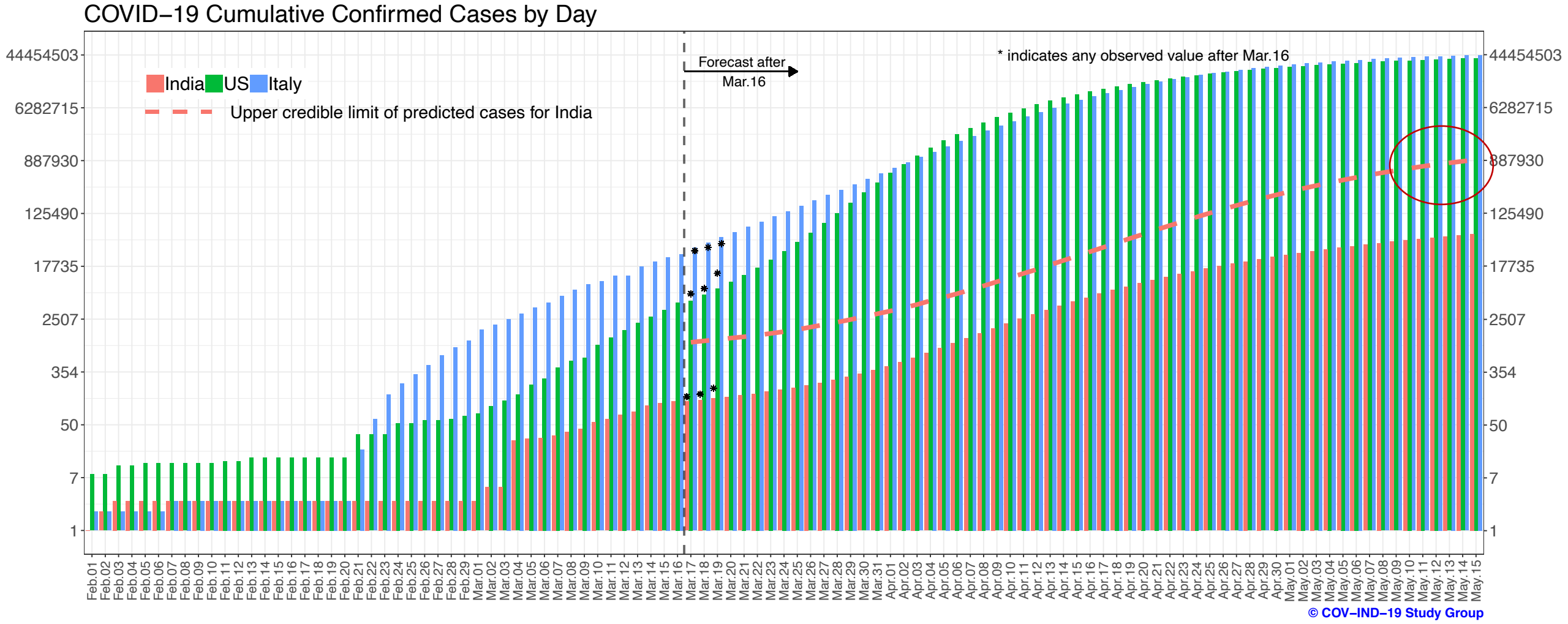
# Distribution of COVID-19 related risk factors

**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).

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)

# Lockdown simply buys us time

- To ramp up testing, disease surveillance, contact network tracing
- Prepare healthcare infrastructure
- Optimally deploy resources based on emerging hotspots
- Stop the virus: pause and then revive the economy
- Keeping the essential supply chain going and support the vulnerable
- Need long-term strategy: instead of discrete short-term tactics

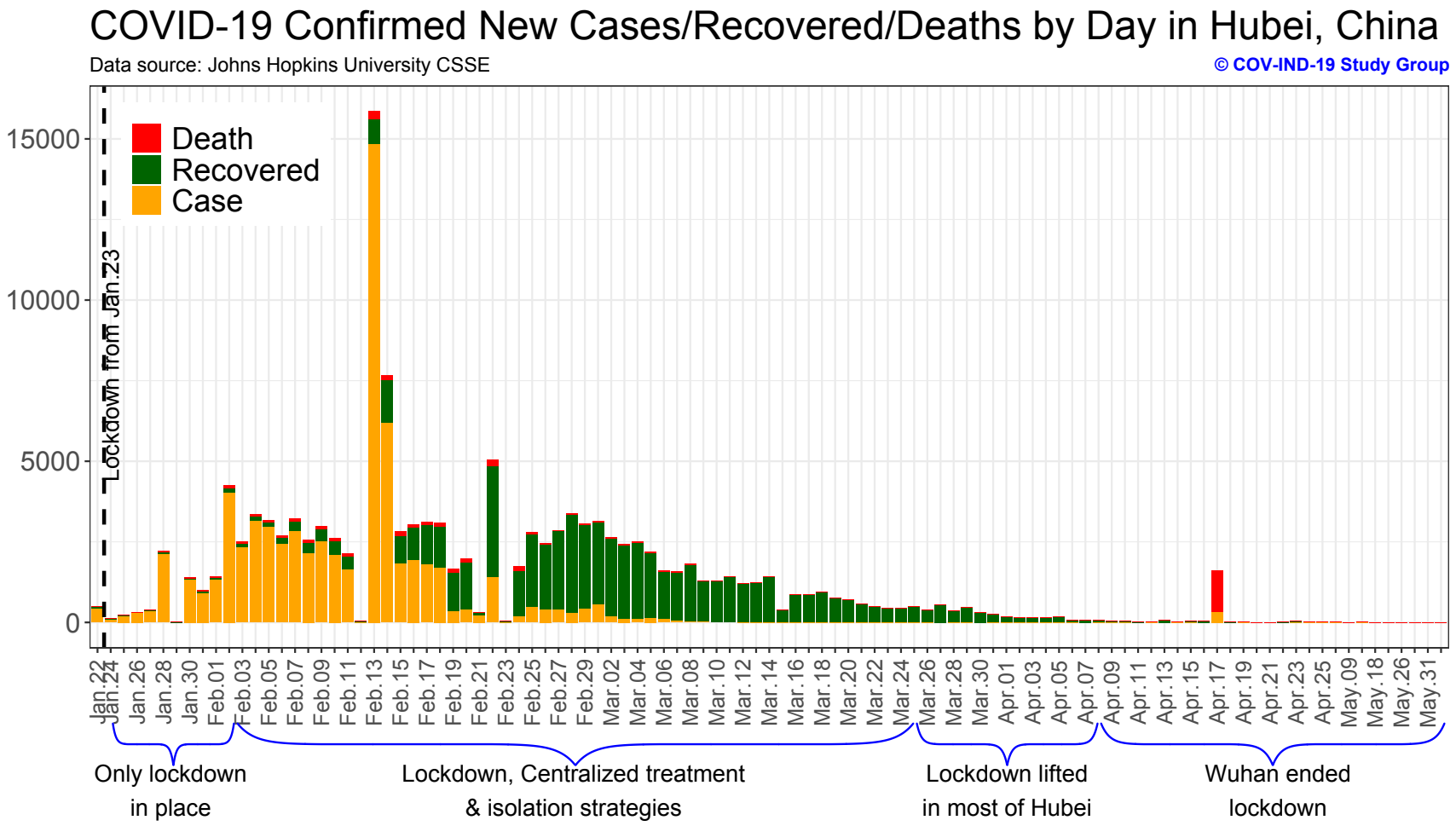
Had a picket fence

Need to build watch towers, dams, escape boats

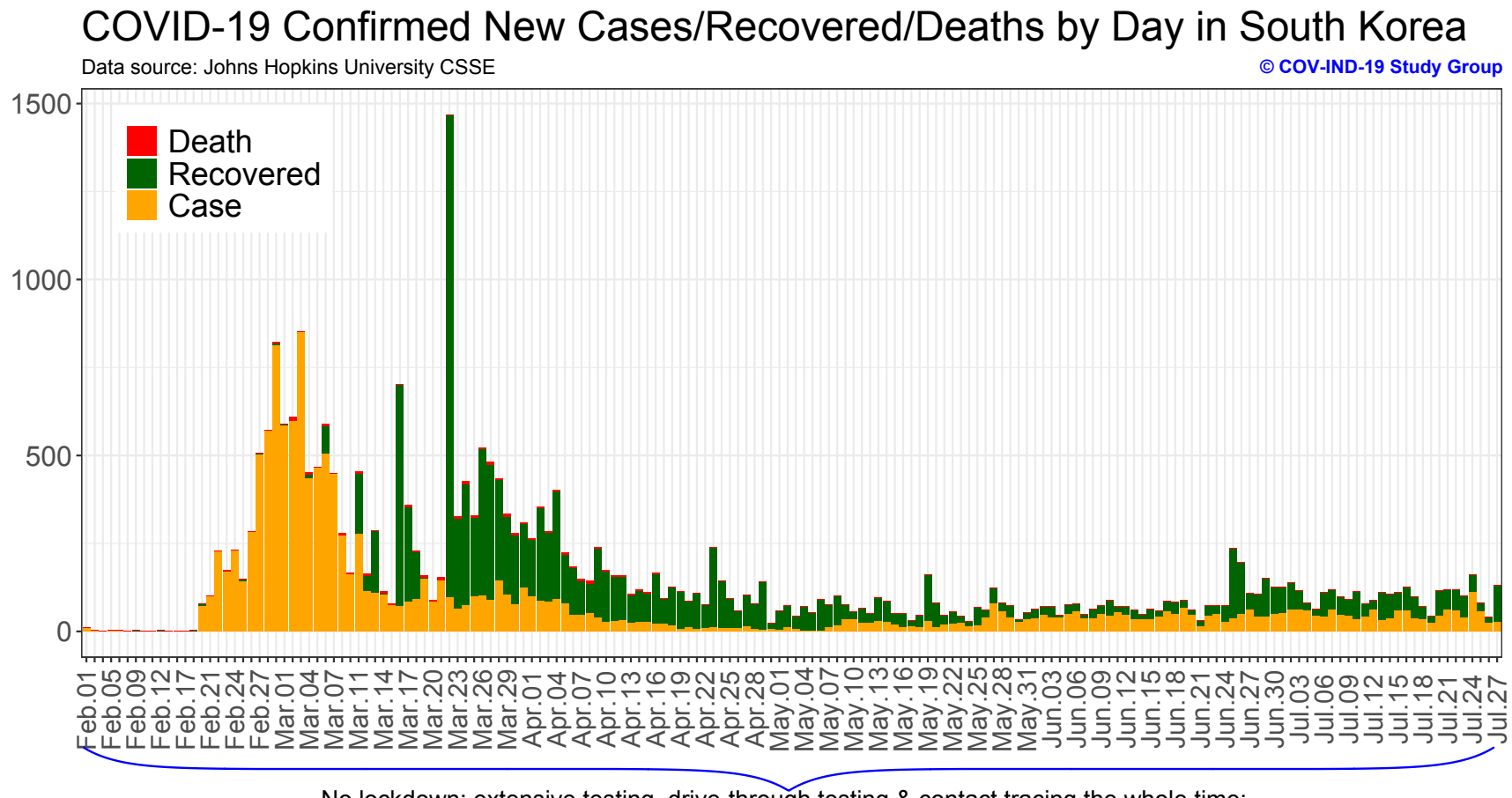
# Questions that one can pose

- How many cases do we expect to see post lockdown?
- When can we expect to see a decline in fatalities?
- What does a successful  lockdown look like?
- How should we return to normalcy from lockdown?

# Qualitative comparison - Hubei, China

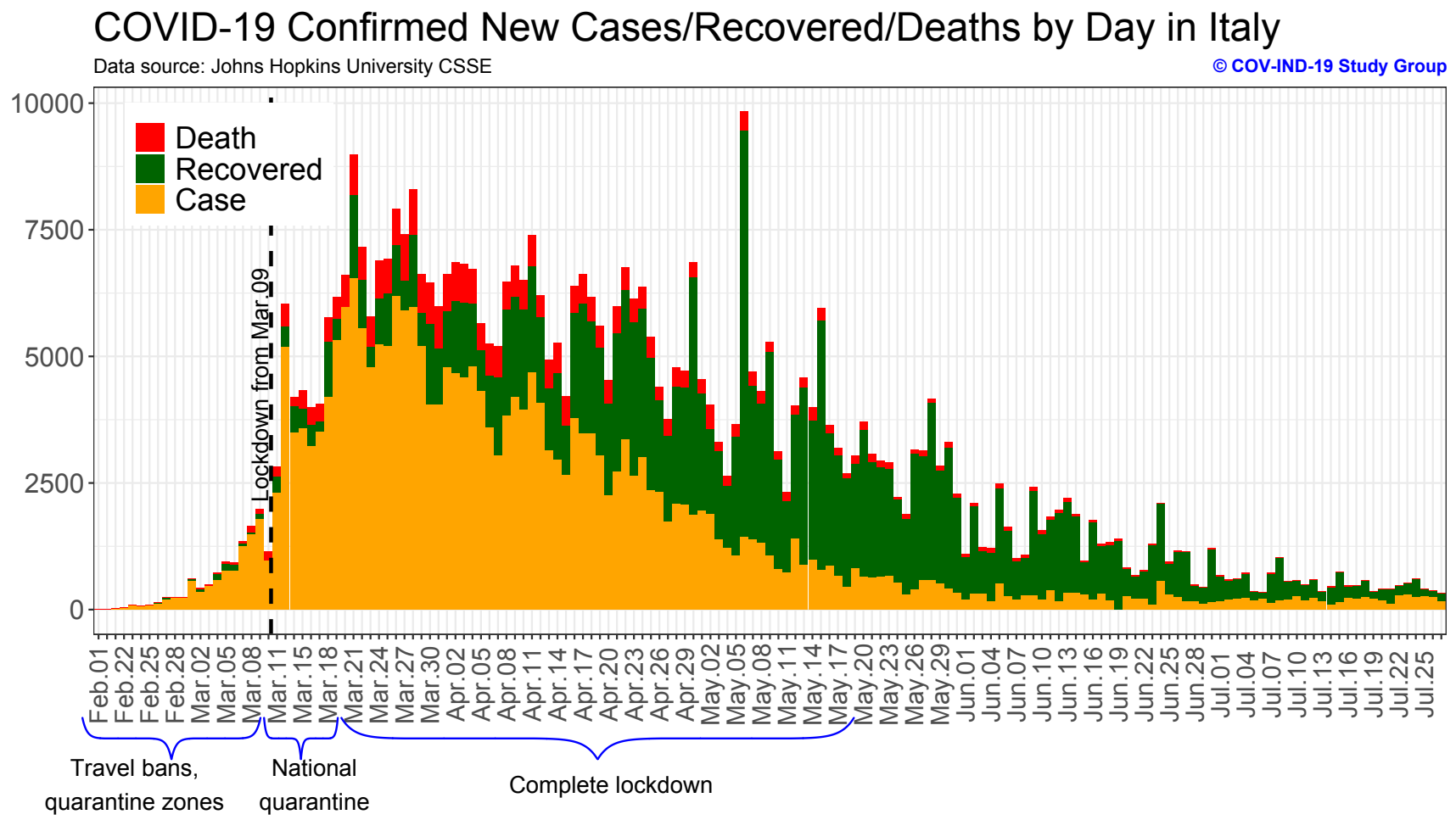


# Qualitative comparison - South Korea

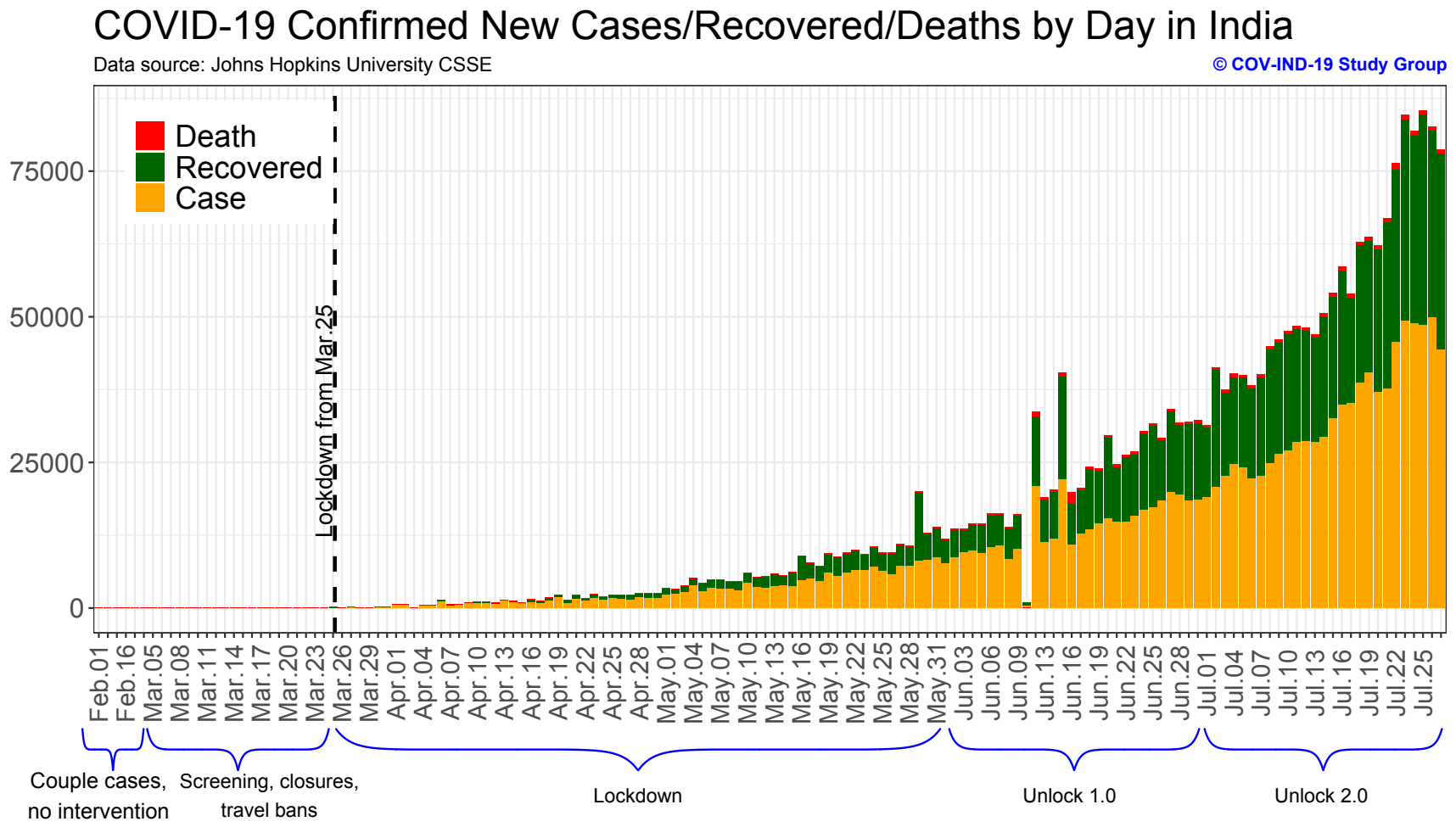



No lockdown; extensive testing, drive-through testing & contact tracing the whole time;
voluntary social distancing and self-quarantine recommended

# Qualitative comparison - Italy



# Qualitative comparison - India

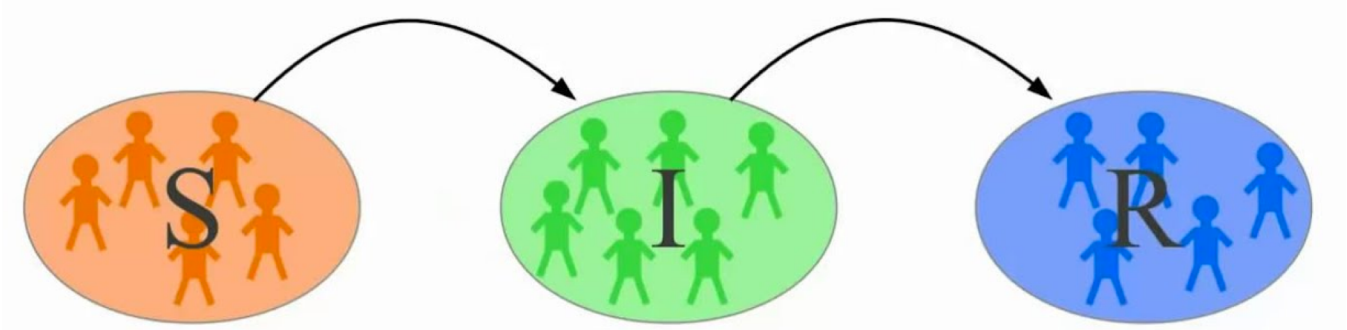


# Forecasting Models (India specific)

- ICMR
- Cambridge
- Armed Forces
- Sourish Das (CMI)
- Ohio State University
- INDSCISIM
- And many more in the last few weeks..

# SIR model: fundamentals

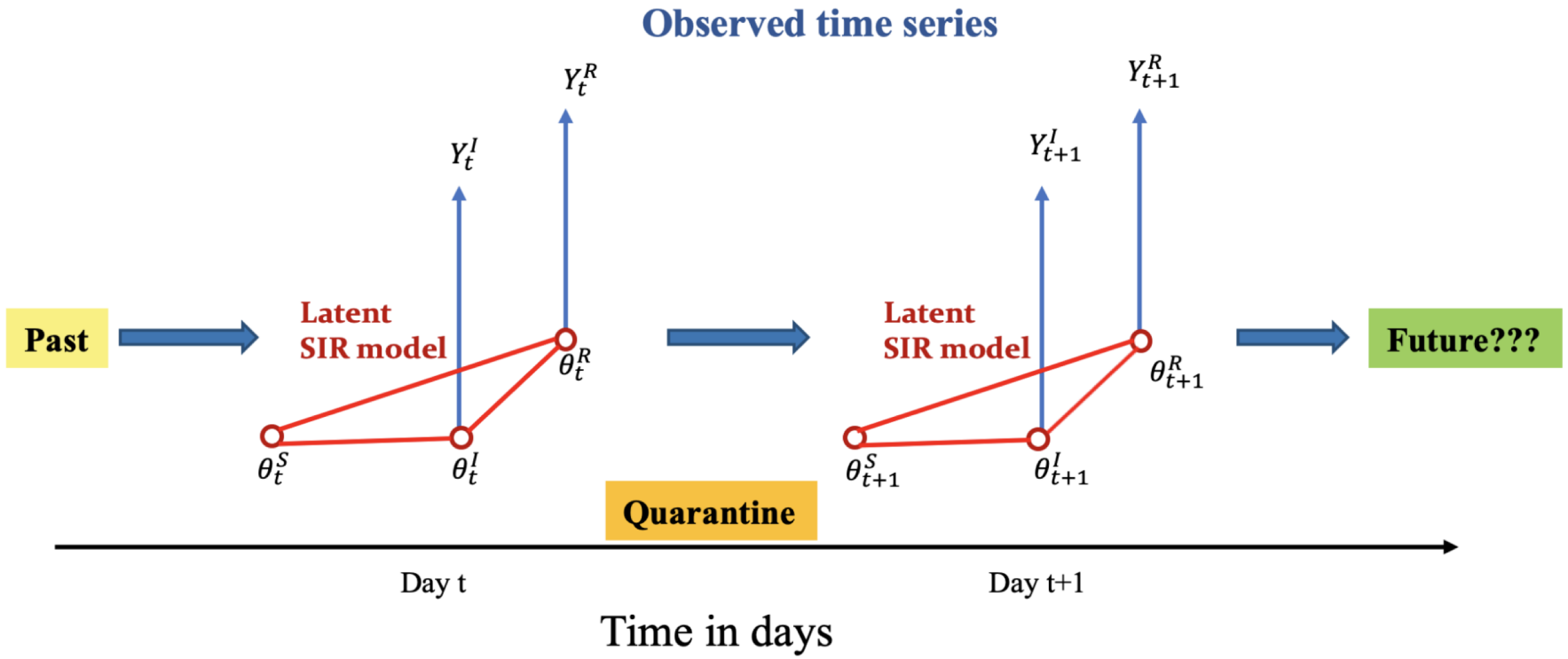
- **Structure:** Each person is in one of three ‘states’.




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

# Facing the challenge: extended SIR

- **Idea:** Introduce a latent Markov 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

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

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

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.

# Prior specifications for Bayesian set-up

- **Latent proportions:** $\boldsymbol{\theta_0} \sim Dirichlet(1 - Y_1^I - Y_1^R, Y_1^I, Y_1^R)$, $\theta_0^S = 1 - \theta_0^I - \theta_0^R$.
- **Basic reproduction number:** $R_0 \sim logNormal(0.582, 0.223)$.
  - Prior mean and sd of $R_0$ are thus set at **2** and 1, respectively.
- **Removal rate:** $\gamma \sim logNormal(-2.955, 0.910)$.
  - Prior mean and sd of $\gamma$ are thus set at **0.082** and 0.1, respectively.
  - Prior average infectious period ($T_\gamma = \frac{1}{\gamma}$) is approx. **12 days**.
- Specifying priors on $\gamma$ and $R_0$ eliminates the need for specifying prior on $\beta$ separately.

# Markov chain Monte Carlo (MCMC) algorithm

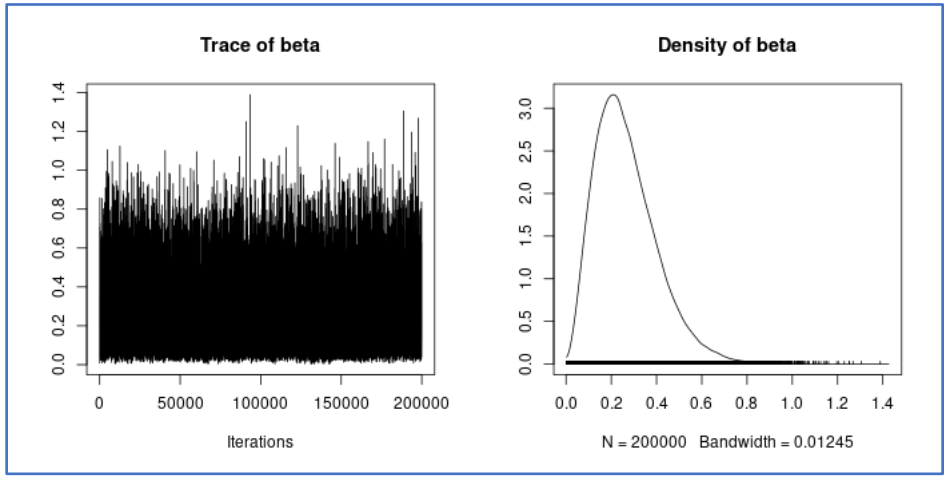
- Begin with large variances that can be tuned with more data coming in.

$$\kappa, \lambda^I, \lambda^R \sim Gamma(2, 0.0001)\ iid.$$

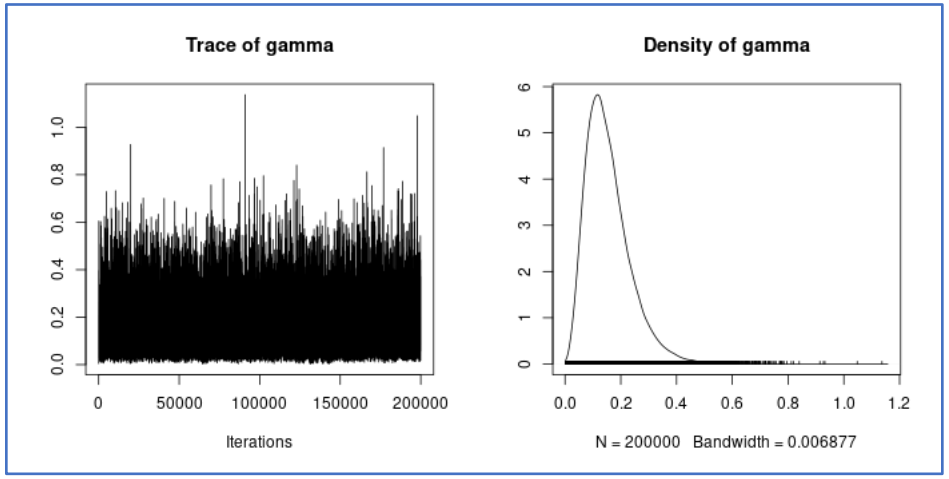
- $t_0$: last date of data availability; the forecast spans over the period $[t_0 + 1, T]$.
- **Algorithm:**
- 0. Take $\boldsymbol{M}$ **draws** from the posterior $[\boldsymbol{\theta_{1:t_0}}, \boldsymbol{\tau}|\boldsymbol{Y_{1:t_0}}]$.
- 1. For each solution path $m \in \{1, \dots, M\}$, iterate between the following two steps via MCMC.
  - i. Draw $\boldsymbol{\theta_t^{(m)}}$ from $\left[\boldsymbol{\theta_t}\middle|\boldsymbol{\theta_{t-1}^{(m-1)}}, \boldsymbol{\tau}^{(m)}\right], t \in \{t_0 + 1, \dots, T\}$.
  - ii. Draw $\boldsymbol{Y_t^{(m)}}$ from $\left[\boldsymbol{Y_t}\middle|\boldsymbol{\theta_t^{(m)}}, \boldsymbol{\tau}^{(m)}\right], t \in \{t_0 + 1, \dots, T\}$.

# Trace plots and posterior density plots

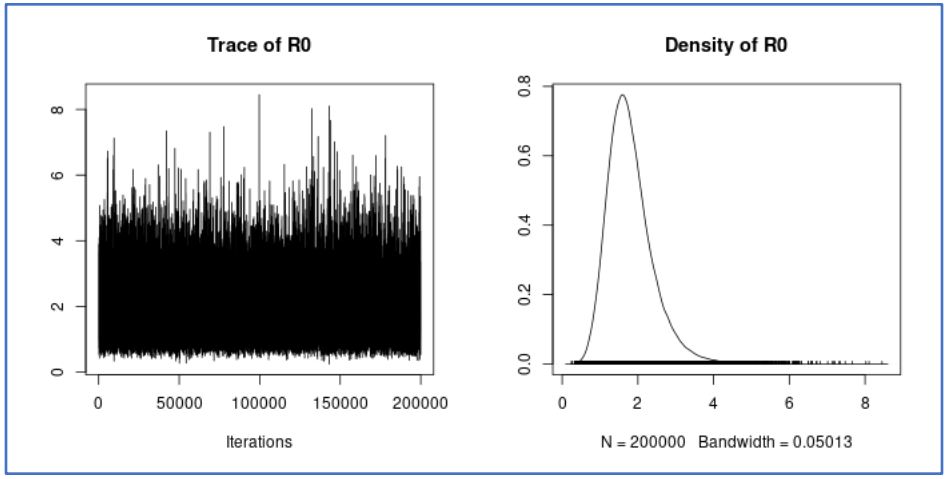
$\beta$



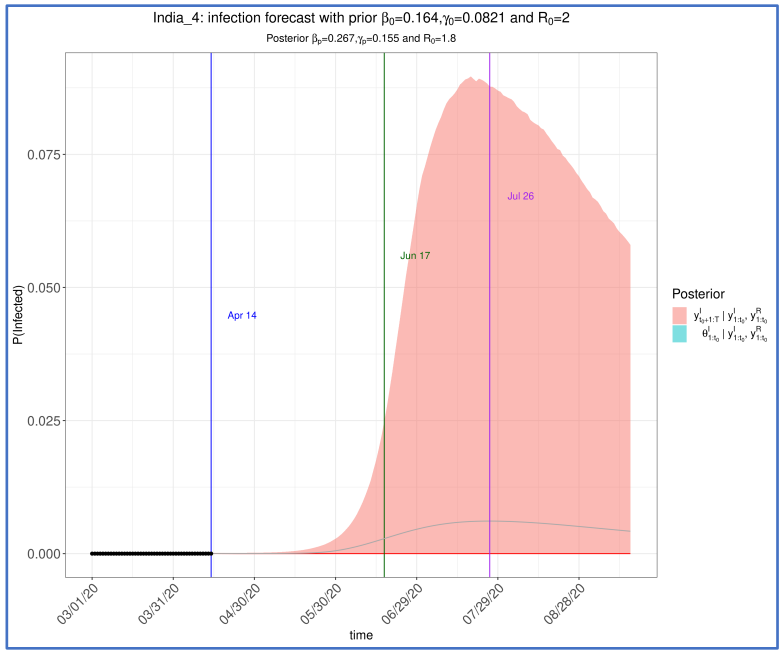

$\gamma$

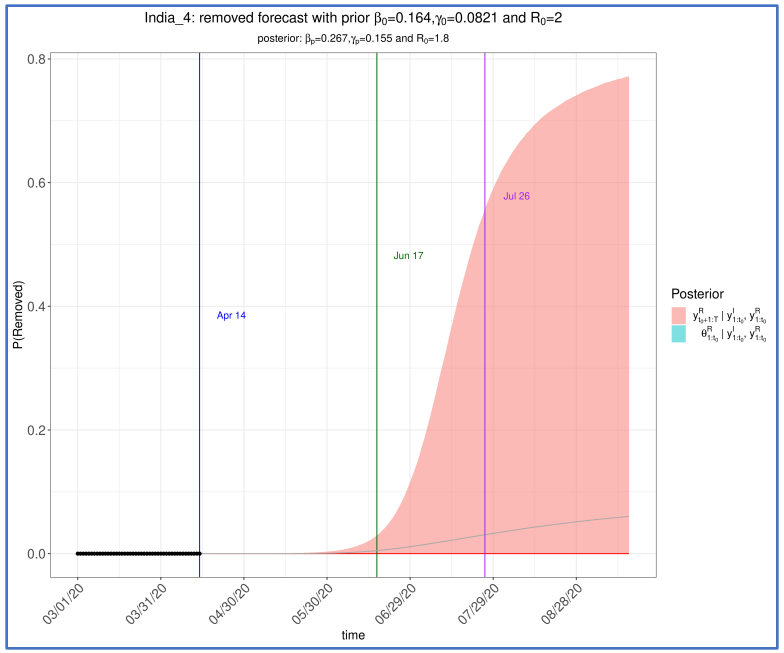


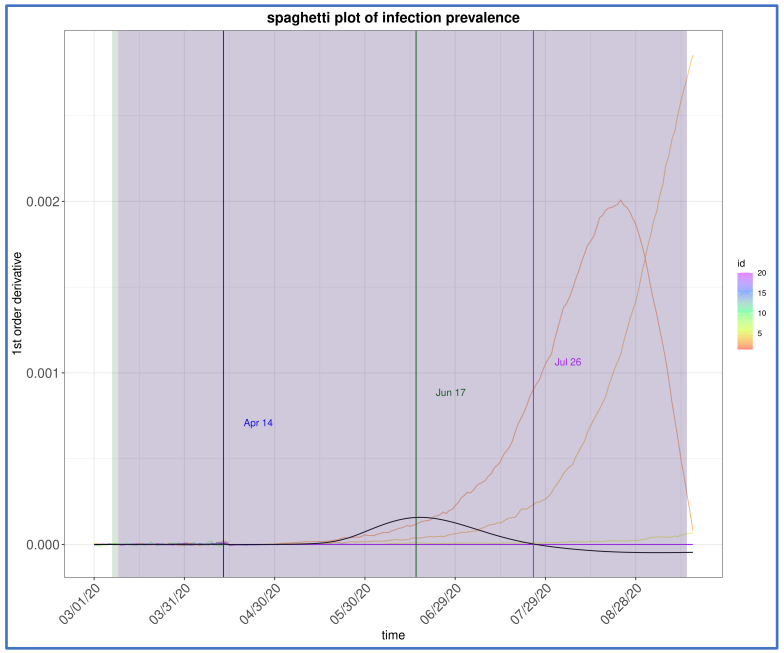

$R_0$



# Posterior distributions of *Y and* $\boldsymbol{\theta}$



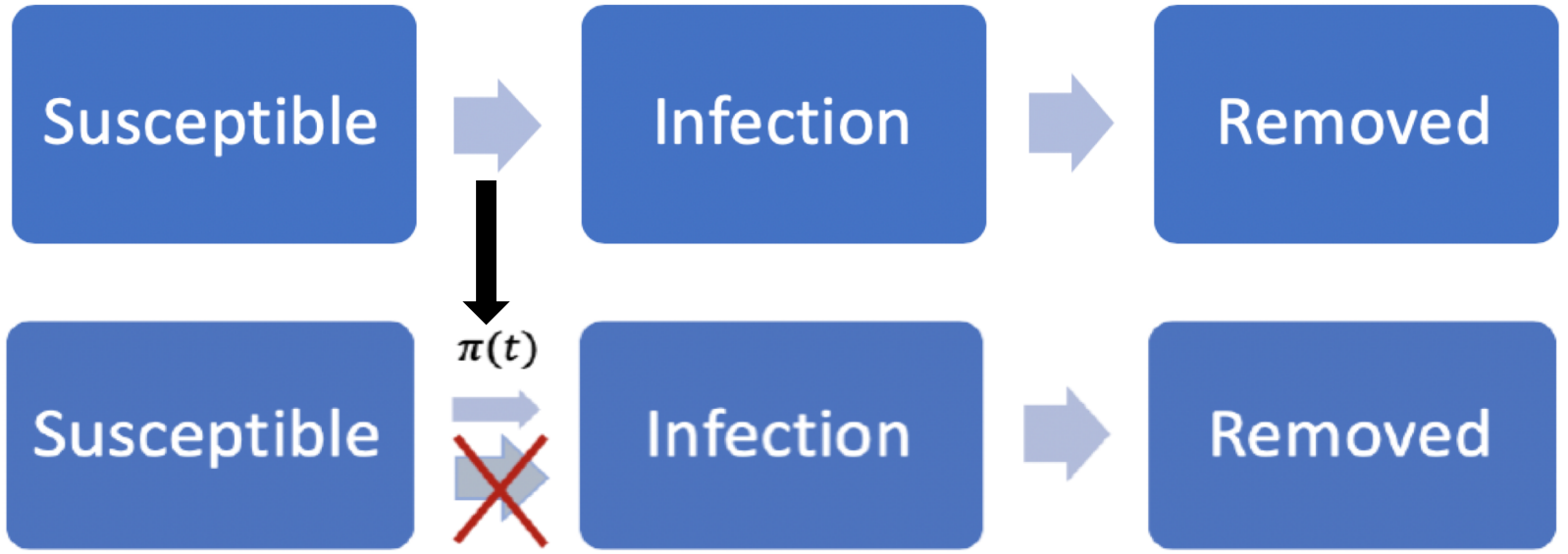




In compartment I

In compartment R

Daily Prevalence

# Modeling interventions




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

# Forecasting scenarios and assumptions

- No intervention
- Social distancing and travel ban (without lockdown)

Post-lockdown

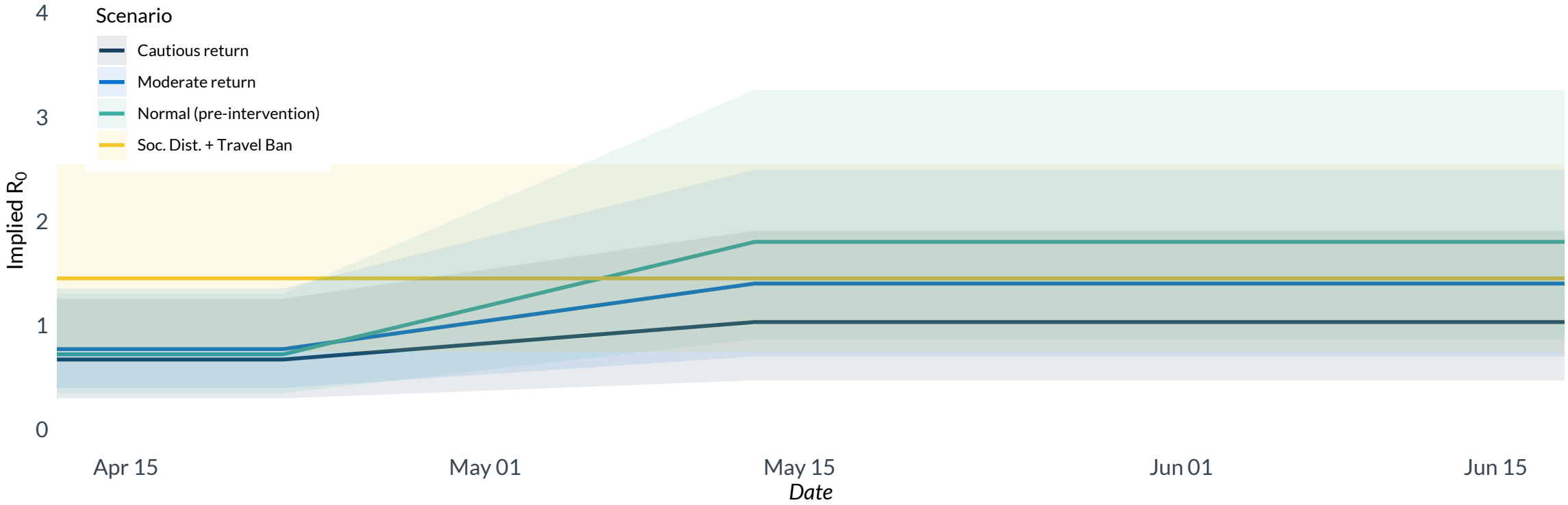
- 21-day lockdown with gradual resumption of activities at different levels:
  - Moderate
  - Cautious
  - Normal (pre-intervention)

-India has since extended the lockdown from 21- to 40- and then 55-days

# $R_0$ over time

## a. $R_0$ over time by scenario

as of 14 April 2020; quick adherence




**© COV-IND-19 Study Group**
**Note:** Bands indicate 95% credible limits. Some error added for visibility.

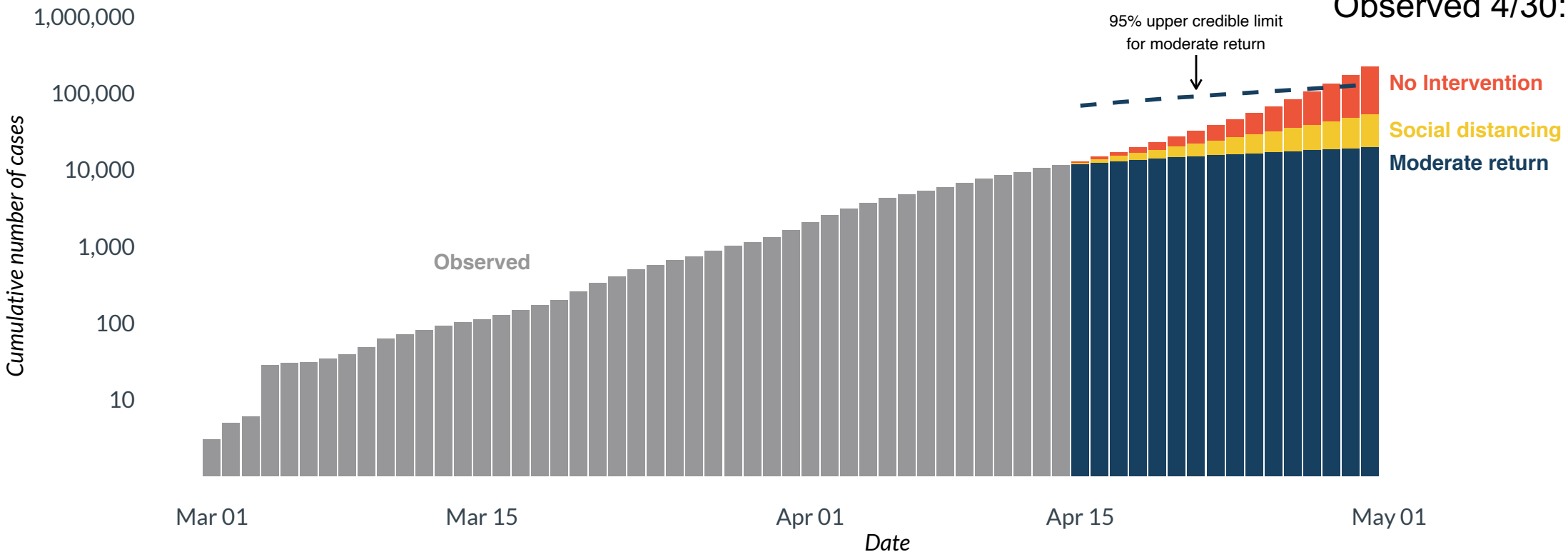
# Short term

| | April 30 estimate | Upper limit |
|---|---|---|
| No intervention | 221,977 | 1,432,841 |
| Social distancing | 52,972 | 328,718 |
| Lockdown (moderate) | 19,625 | 130,326 |

Observed 4/30: 34,866

**Cumulative COVID-19 cases by day in India**

as of 14 April 2020; quick adherence

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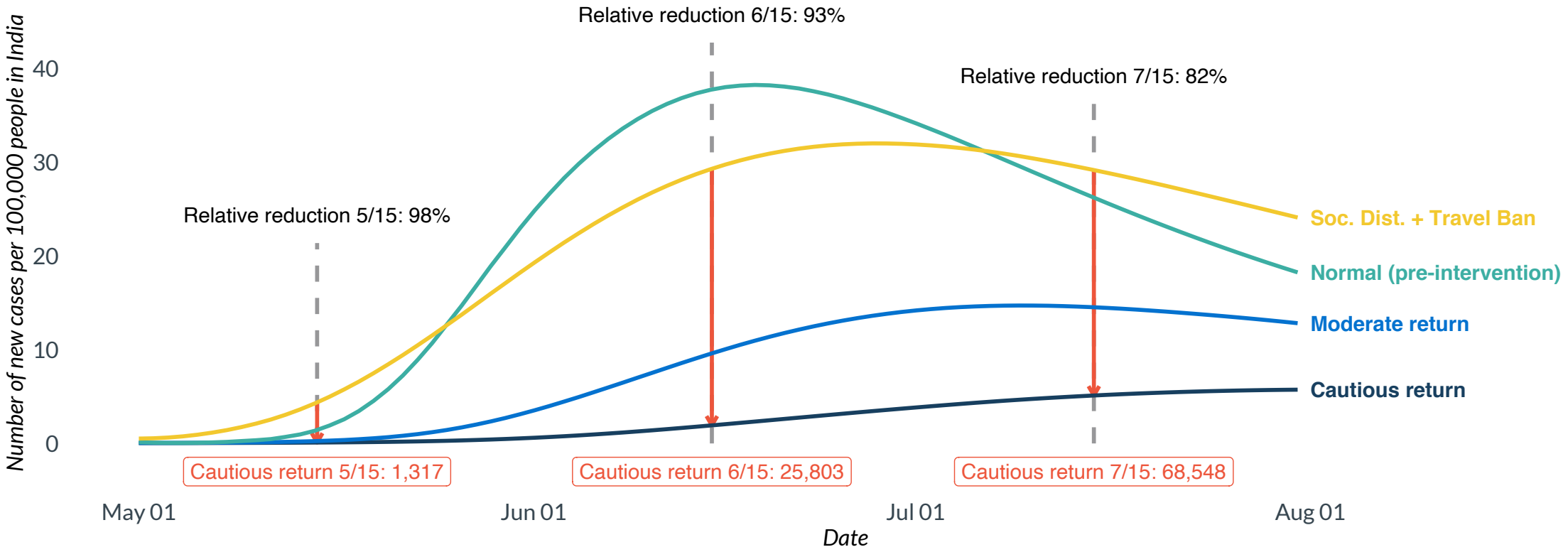
# Long term projection and forecasting scenarios

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

as of 14 April 2020; quick adherence

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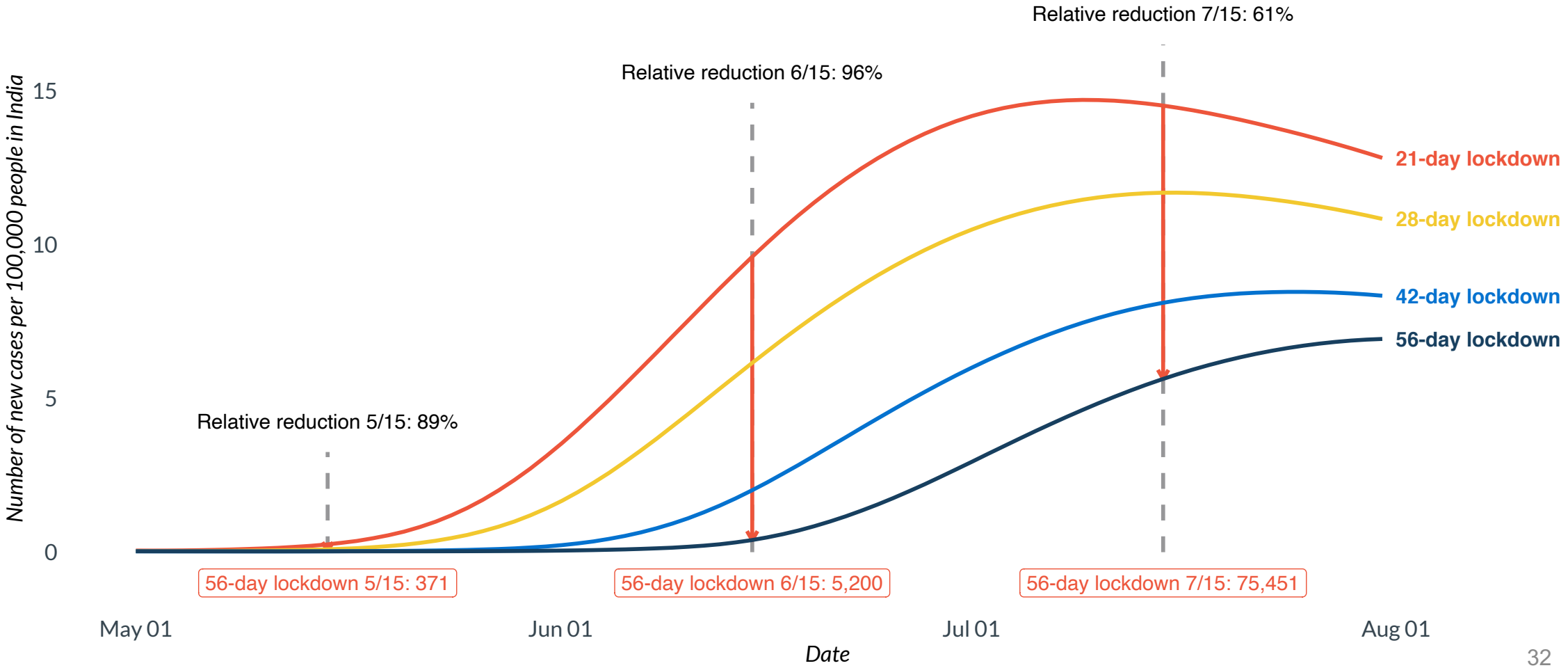
# Lockdown duration - incidence

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

as of 14 April, 2020; quick adherence




© COV-IND-19 Study Group

# Sensitivity analyses

- Under-reporting (10x number of observed cases)
- Case-clustering (use metro population instead of nationwide)
- Vary prior for $R_0$
  - Prior mean for $R_0 = 2$
  - Prior mean for $R_0 = 3$
  - Prior mean for $R_0 = 4$

# Sensitivity analyses

**Table 2**. Comparison of estimated projections and posterior estimates of model parameters across different sensitivity analysis scenarios under 21-day lockdown with moderate return, using observed data till April 14. Prior SD for $R_0$ is 1.0.

| **Sensitivity Analysis** | **Predictions** | | **Posterior Estimates** | | |
|---|---|---|---|---|---|
| **Scenario** | **May 1** | **May 15** | $R_0$ | $\beta$ | $\gamma$ |
| Under-reporting* | 25,248 [104,411] | 62,797 [343,465] | 2.28 [1.05, 4.20] | 0.20 [0.05, 0.39] | 0.09 [0.03, 0.19] |
| Case-clustering** | 24,818 [59,525] | 57,499 [189,010] | 2.81 [1.47, 4.70] | 0.16 [0.07, 0.26] | 0.06 [0.03, 0.10] |
| Prior mean for $R_0 = 2$ | 20,251 [135,034] | 42,252 [315,348] | 1.80 [0.87, 3.26] | 0.27 [0.06, 0.59] | 0.16 [0.04, 0.35] |
| Prior mean for $R_0 = 3$ | 25,757 [165,287] | 86,750 [638,770] | 2.43 [1.41, 4.07] | 0.30 [0.09, 0.60] | 0.13 [0.04, 0.30] |
| Prior mean for $R_0 = 4$ | 34,587 [213,556] | 253,935 [1,854,319] | 3.38 [2.09, 5.27] | 0.32 [0.10, 0.63] | 0.10 [0.03, 0.23] |

* Observed case-counts are multiplied by 10, Prior mean for $R_0 = 2$

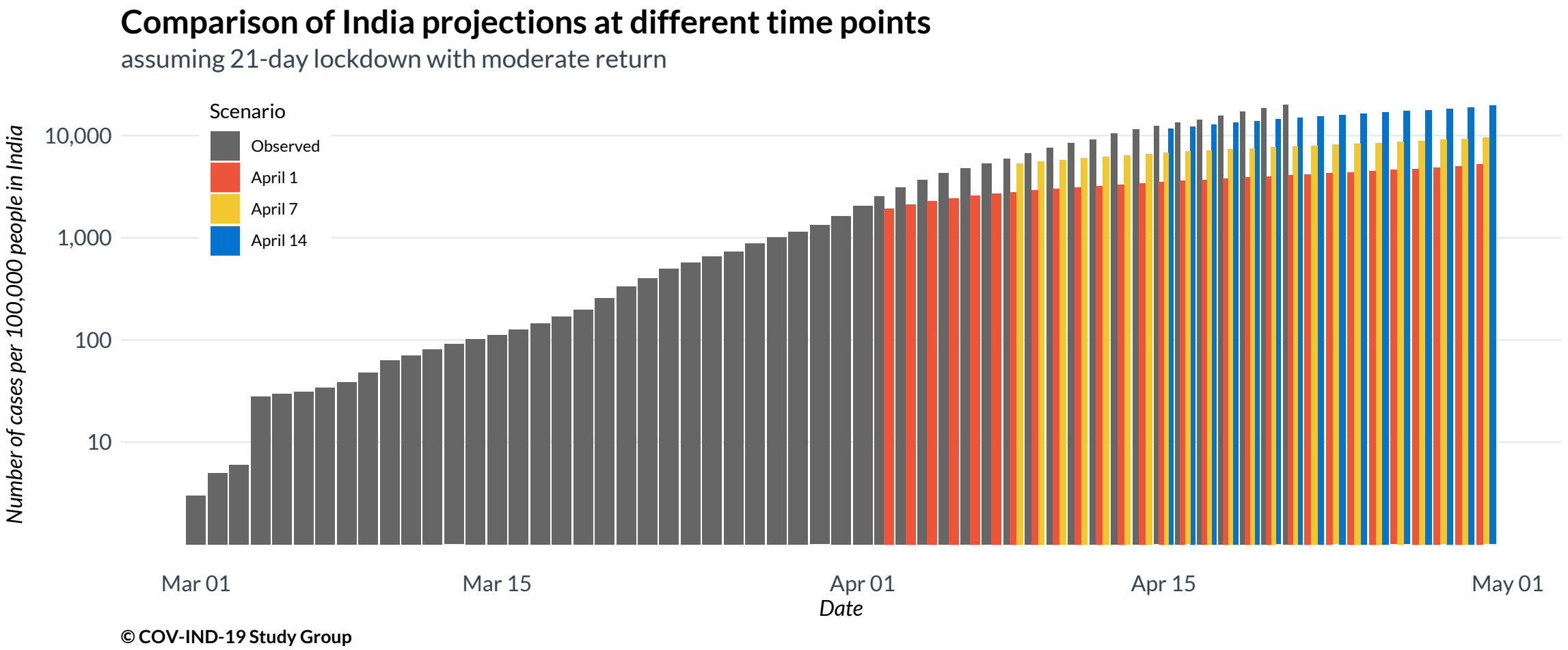
** Assume that the cases happen in metro hotspots, use population size $N$=32 million instead of national population 1.34 billion, Prior mean for $R_0 = 2$

# Updating projections

- How does observing new data impact our model projections?

- Use observed counts up until
  - April 1
  - April 7
  - April 14

# Updating projections



# Updating projections: Always Underestimating

**Table 3.** Comparison of model projections using observed data up to different dates assuming a 21-day lockdown with moderate return.

| | Projected Counts [Upper Credible Interval] | | Posterior Estimates [95% CrI] | | |
|---|---|---|---|---|---|
| **Observed/Projection** | **April 15** | **May 1** | $R_0$ | $\beta$ | $\gamma$ |
| Observed | 12,370 | 37,262 | - | - | - |
| Use Data up to April 1 | 1,944 [14,178] | 3,807 [28,777] | 1.85 [0.84, 3.47] | 0.28 [0.05, 0.70] | 0.16 [0.03, 0.40] |
| Use Data up to April 7 | 5,344 [36,222] | 8,330 [61,270] | 1.74 [0.80, 3.22] | 0.22 [0.05, 0.52] | 0.14 [0.03, 0.32] |
| Use Data up to April 14 | 11,736 [68,836] | 20,251 [135,034] | 1.80 [0.87, 3.26] | 0.27 [0.04, 0.35] | 0.16 [0.04, 0.35] |

Note: All prediction scenarios assume a prior mean of $R_0 = 2$

# COVIND19.org
(Please check it out!)

Our contribution and service as data scientists

COVID-19 Outbreak in India | National Observed | National Forecast | Testing | State Forecasts

## COV-IND-19 Study Group

The COV-IND-19 Study Group

Welcome to the COV-IND-19 shiny app. We aim to provide a resource to describe the COVID-19 outbreak in India to date as well as prediction models under various hypothetical scenarios. The figure and forecasting models update as new data becomes available (i.e., at least daily). You may download PNG files of each figure by clicking on the camera icon when you are hovering within each plot. Please cite our medium article and this website in any publication that you use this resource for.

The COV-IND-19 study group is comprised of: Maxwell Salvatore, Alexander Rix, Michael Kleinsasser, Daniel Barker, Lili Wang, Rupam Bhattacharyya, Soumik Purkayastha, Debashree Ray, Shariq Mohammed, Aritra Halder, Debraj Bose, Peter Song, Mousumi Banerjee, Veera Baladandayuthapani, and Parikshit Ghosh. Led by PI Bhramar Mukherjee.

Please direct inquiries to Maxwell Salvatore, Alexander Rix, Michael Kleinsasser, and Bhramar Mukherjee

### References

Read the study: Ray et al. 2020

Read the report: COV-IND-19 Report (this is a direct download link, check your downloads folder)

Read our Medium trilogy: pre-lockdown (March 21), studying lockdown (April 3), and unlocking the lockdown (April 24)

Source code: COV-IND-19 GitHub

### Sources

Non-India country-level data source: JHU CSSE COVID-19 GitHub

India National and State / Union Territory data source: covid19india.org

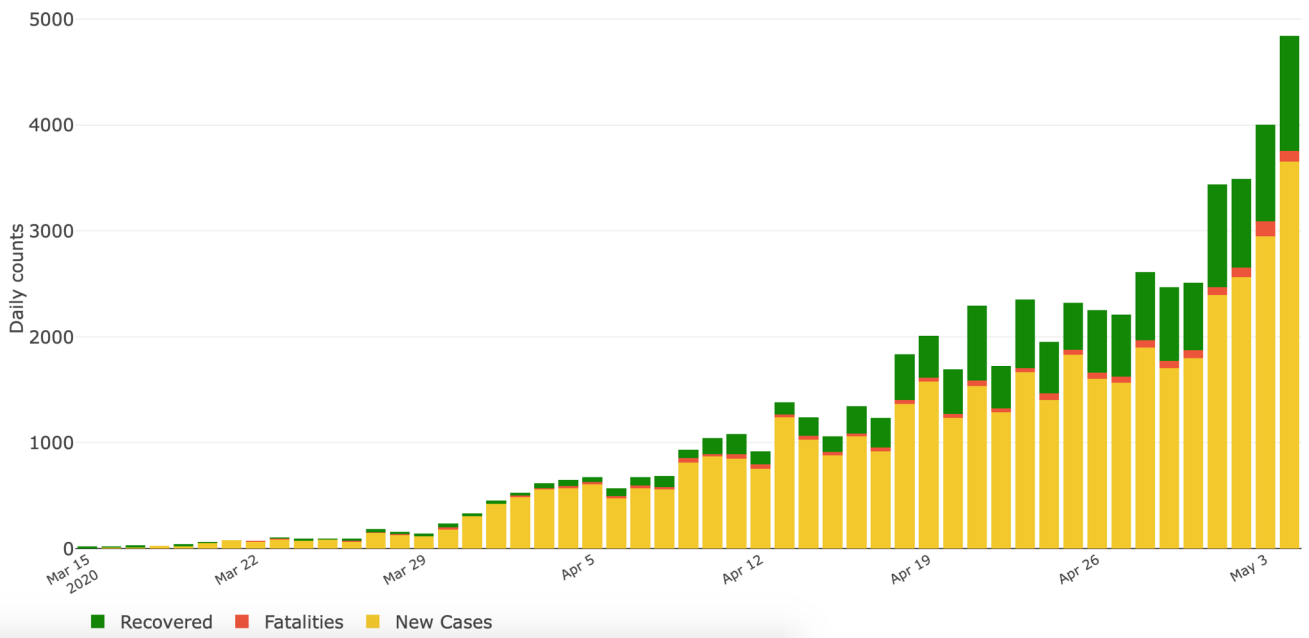
R modeling package: eSIR R package

**(Please wait a few seconds for the figures to load)**

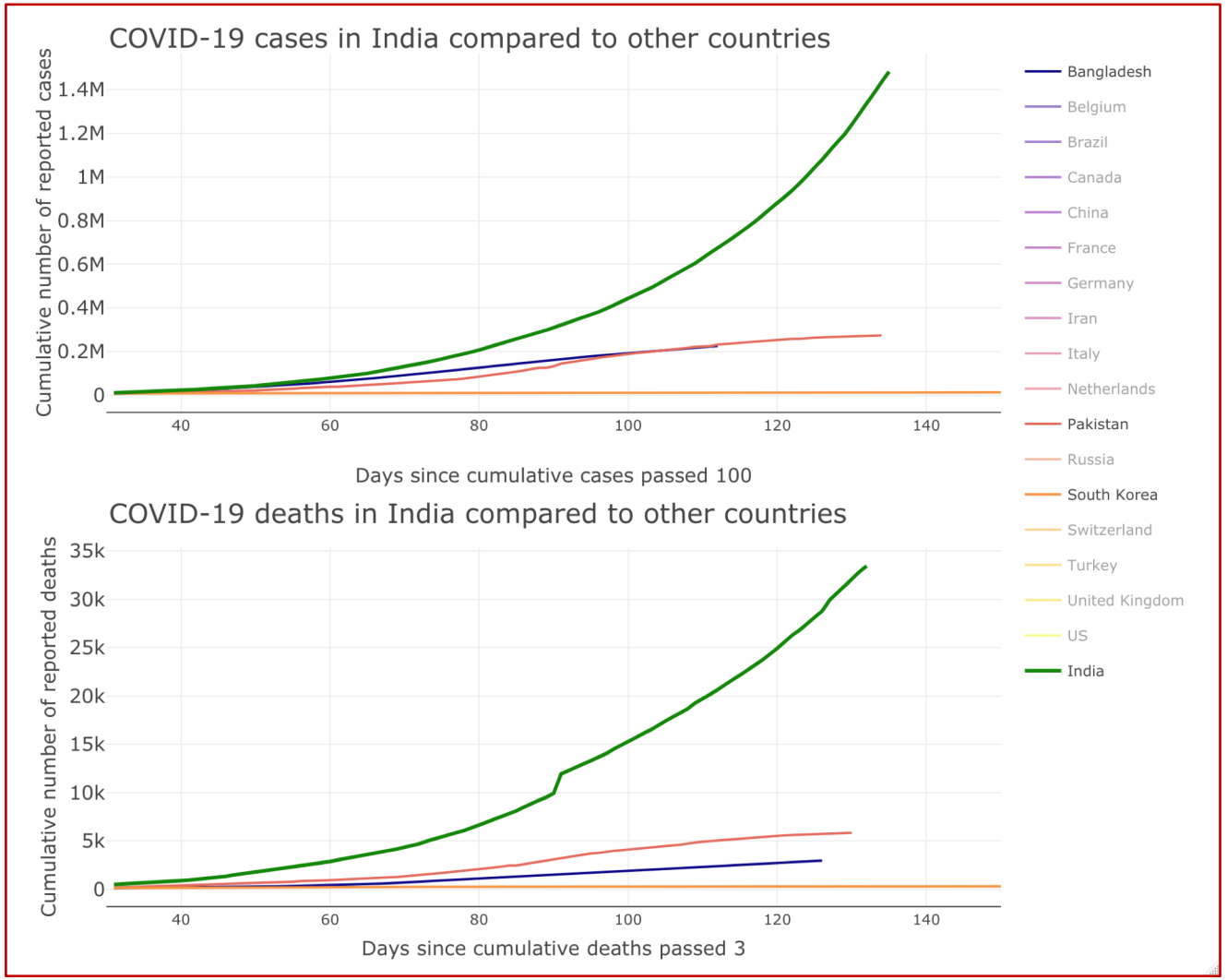
**Data last updated May 05**

### Daily number of new COVID-19 cases, fatalities and recovered in India

This figure provides the number of COVID-19 new cases (yellow), fatalities (red), and recovered cases (green) in India. You can hover your cursor over the bar to see the exact numerical counts.

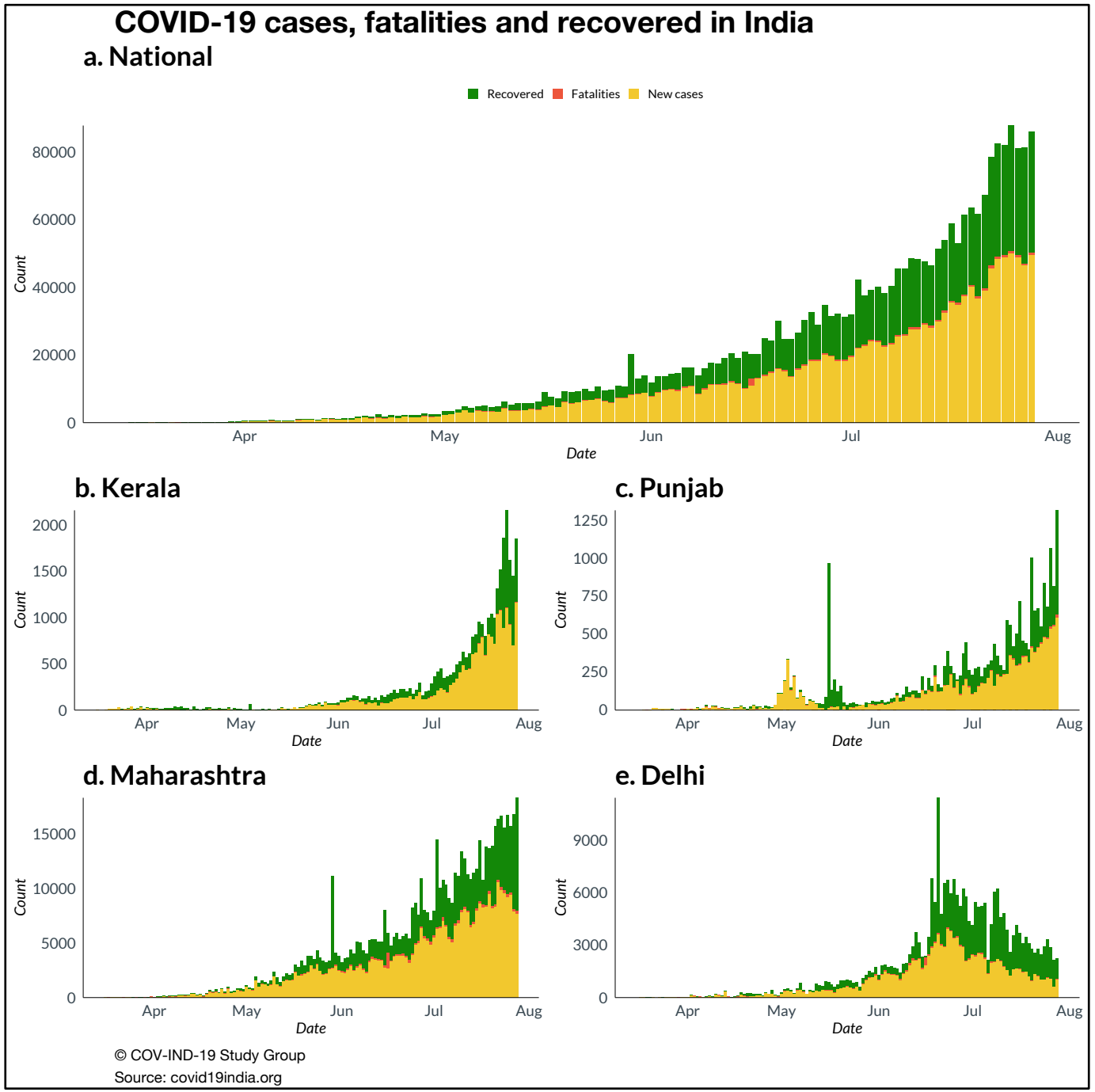


# Where is India Now?



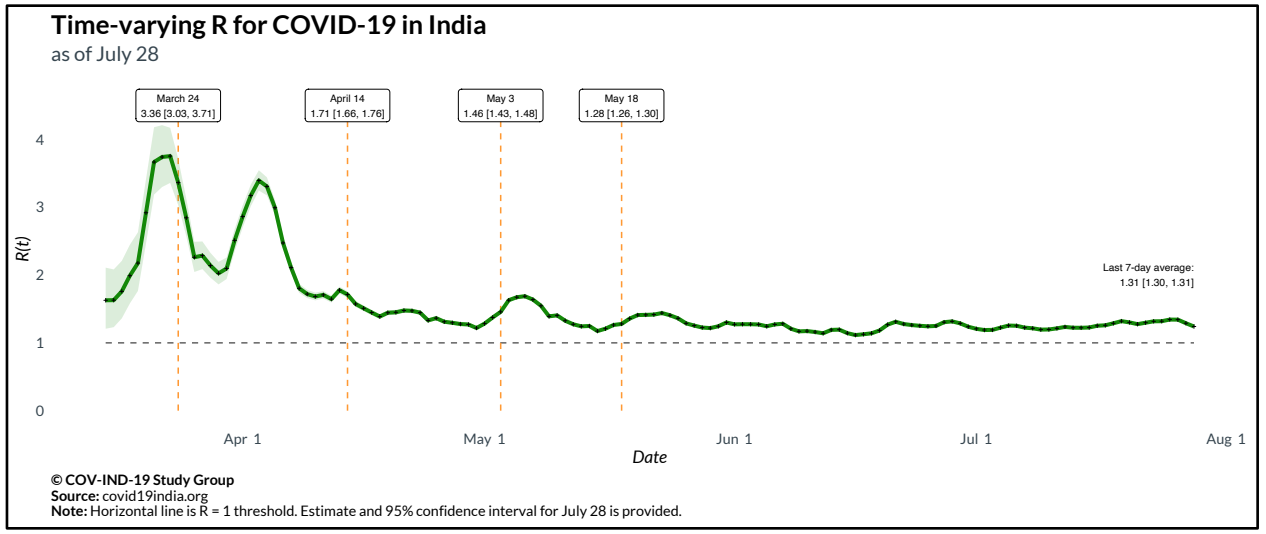

527,273 Cases
35,000 Deaths
17.7 million tests done
6% test positive rate
Case Fatality Rate: 2.2%

New Paper on Medrxiv

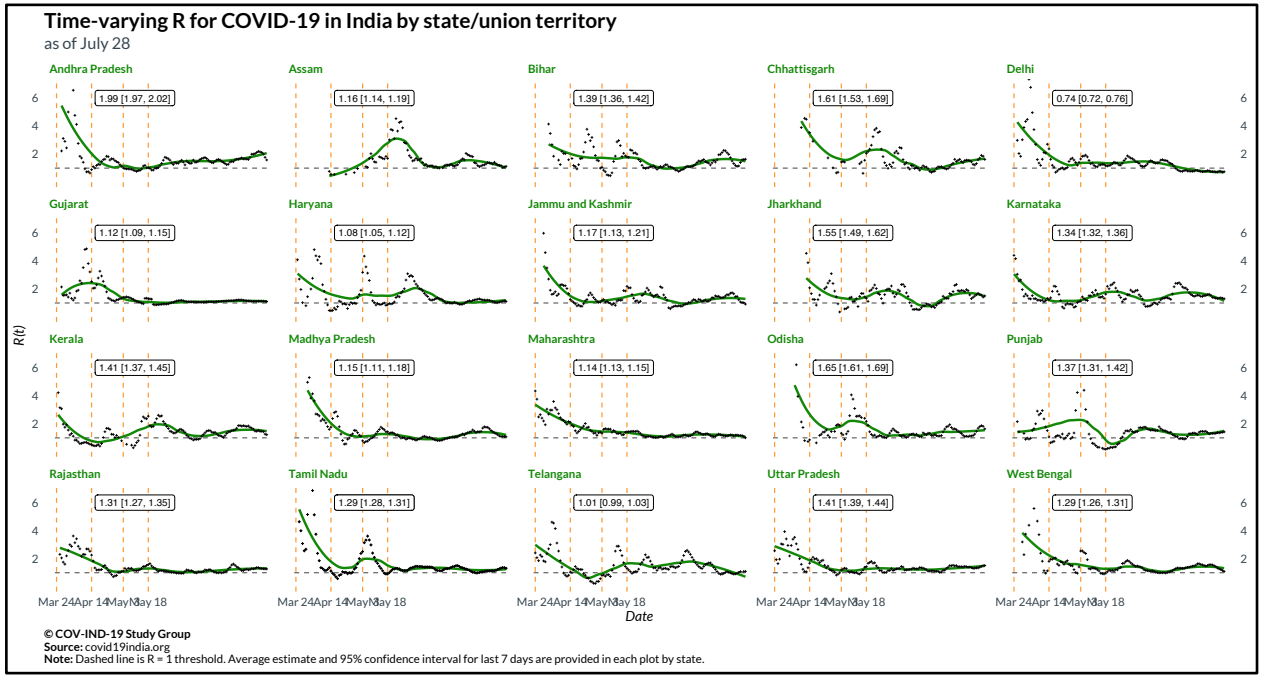



National Data Masking
State Level Variations

# Other metrics: Effective R

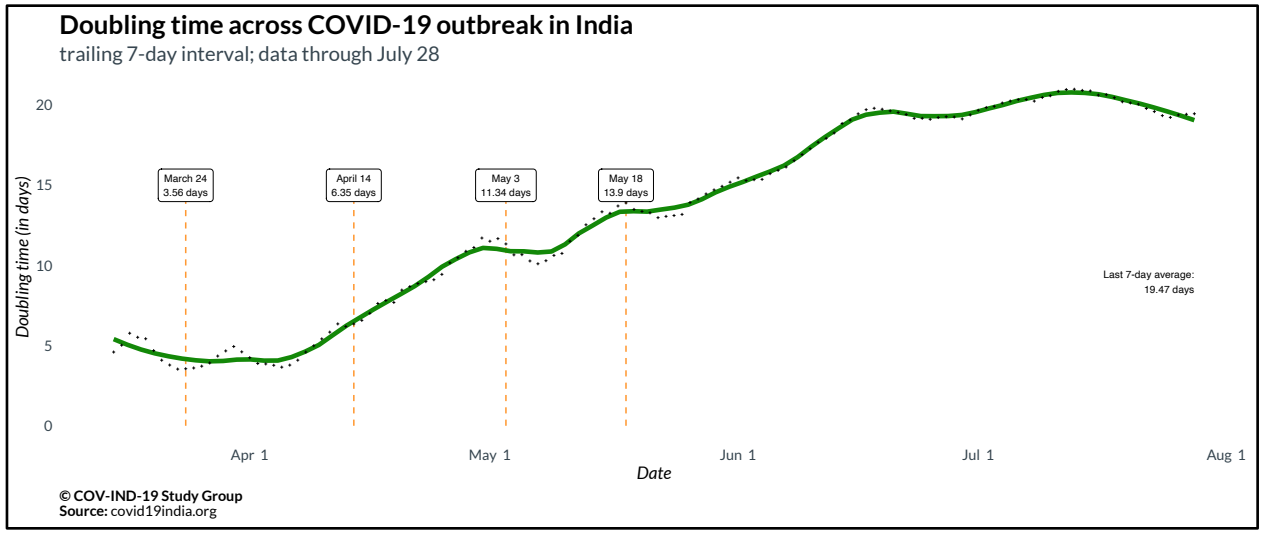



National Data

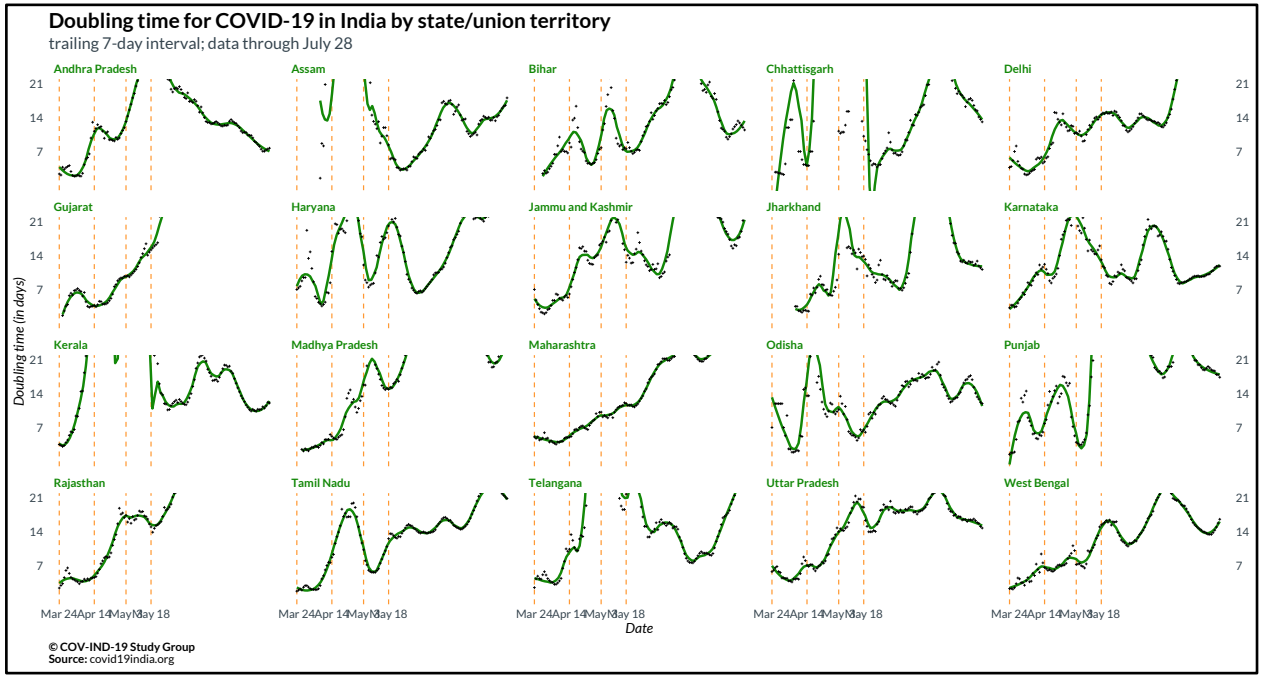



State Data

# Other metrics: doubling time

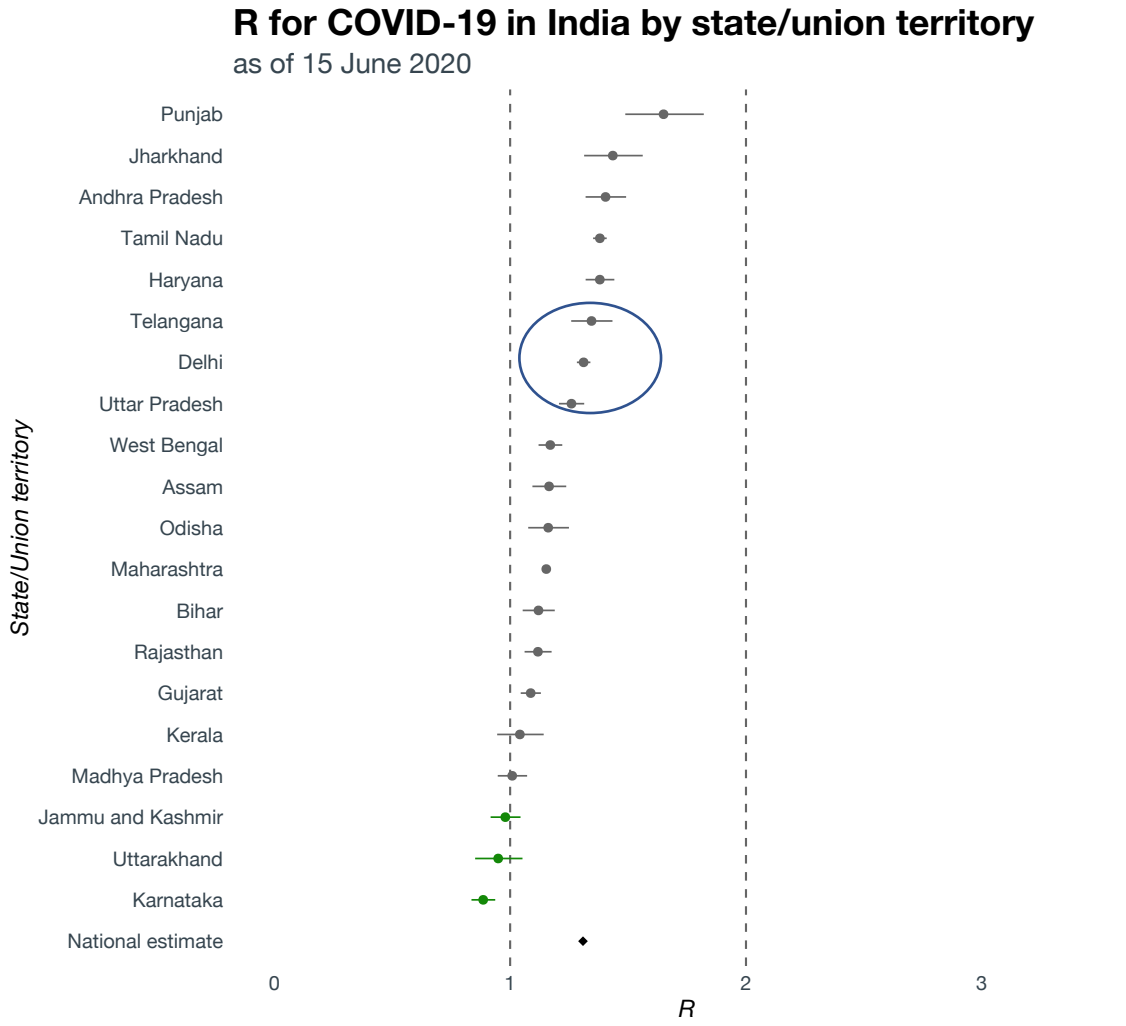



National Data

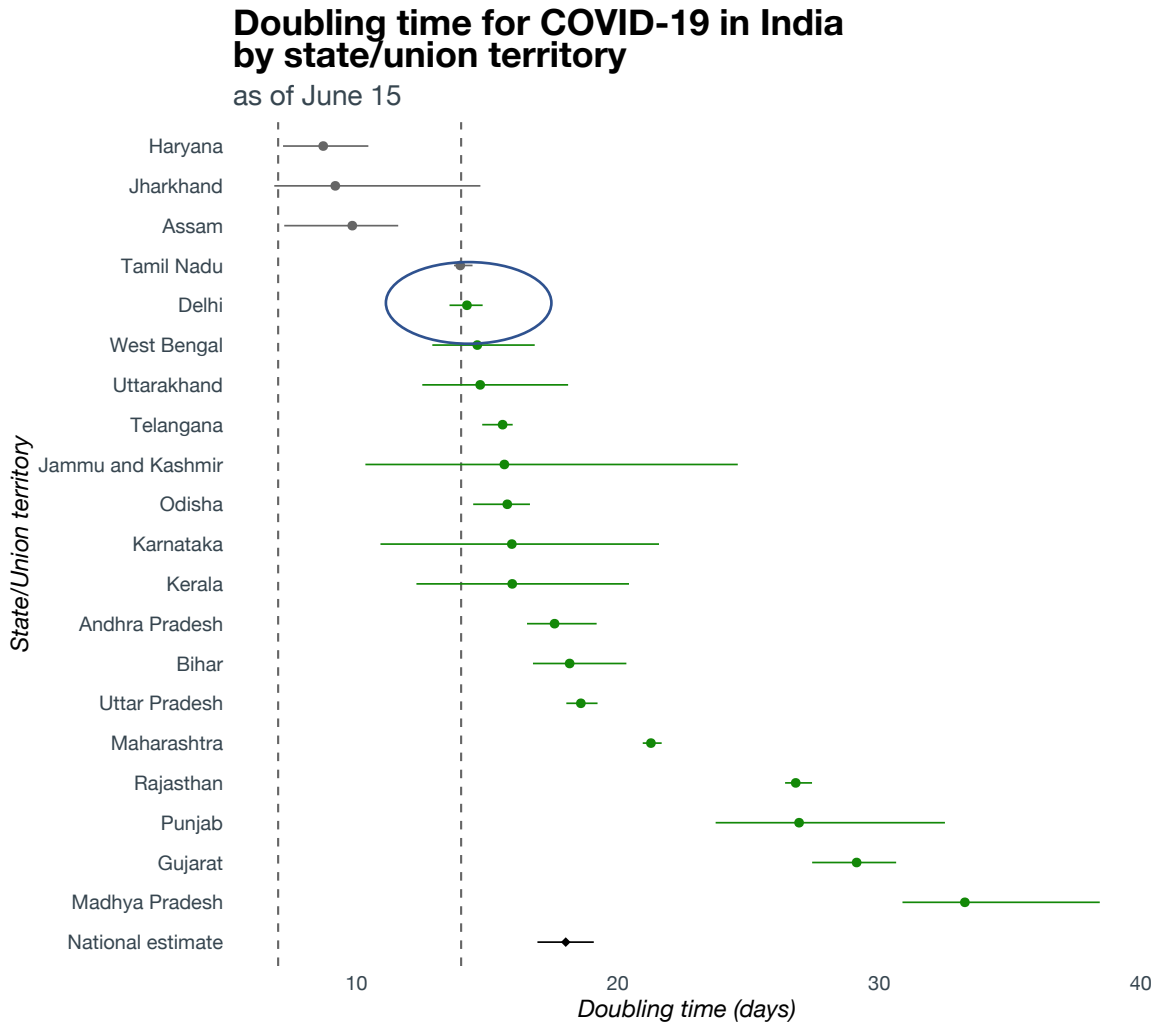



State Data

# Forest plots: Policymaker's public health dashboard (June 15)



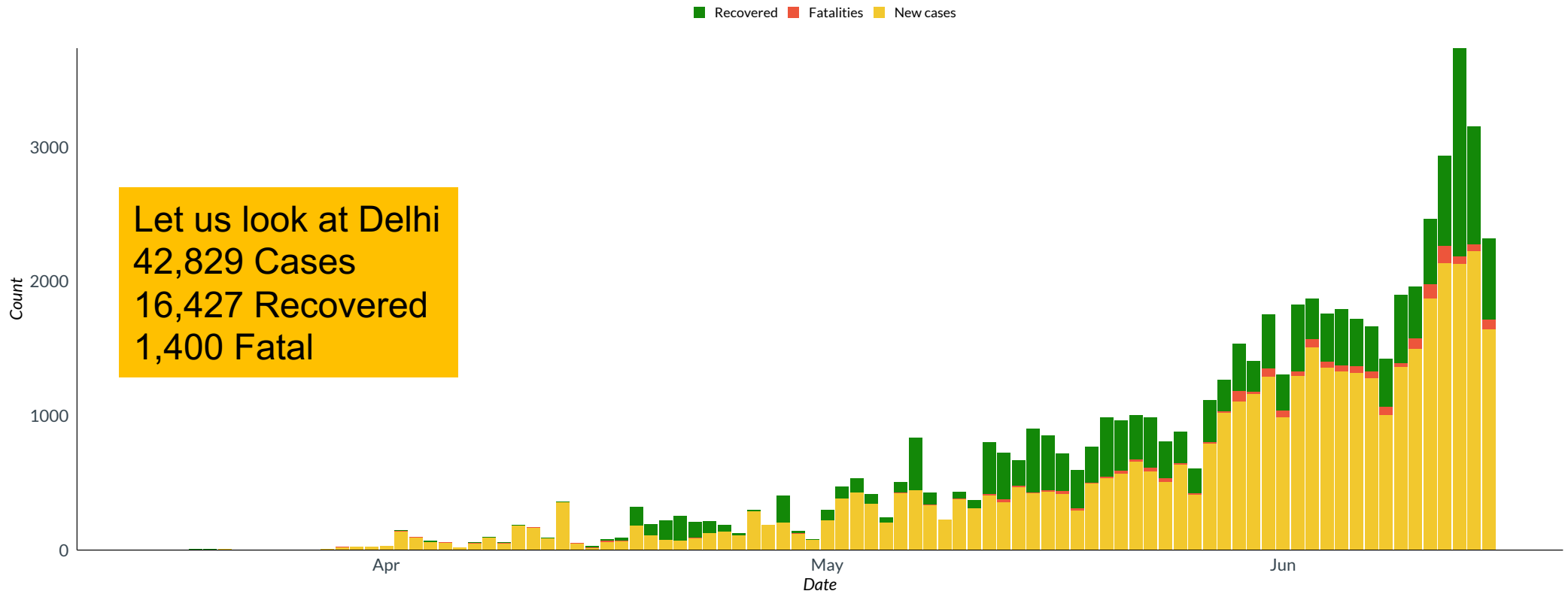

**© COV-IND-19 Study Group**
**Source:** covid19india.org
**Note:**
- Average estimate and 95% confidence interval for last 7 days are provided in each plot by state.
- Colored red if estimate is above 2 and green if below 1.




**© COV-IND-19 Study Group**
**Source:** covid19india.org
**Note:**
- Colored red if estimate is below 7 and green if above 14.
- Intervals represent the range of doubling times over the last 7 days.

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

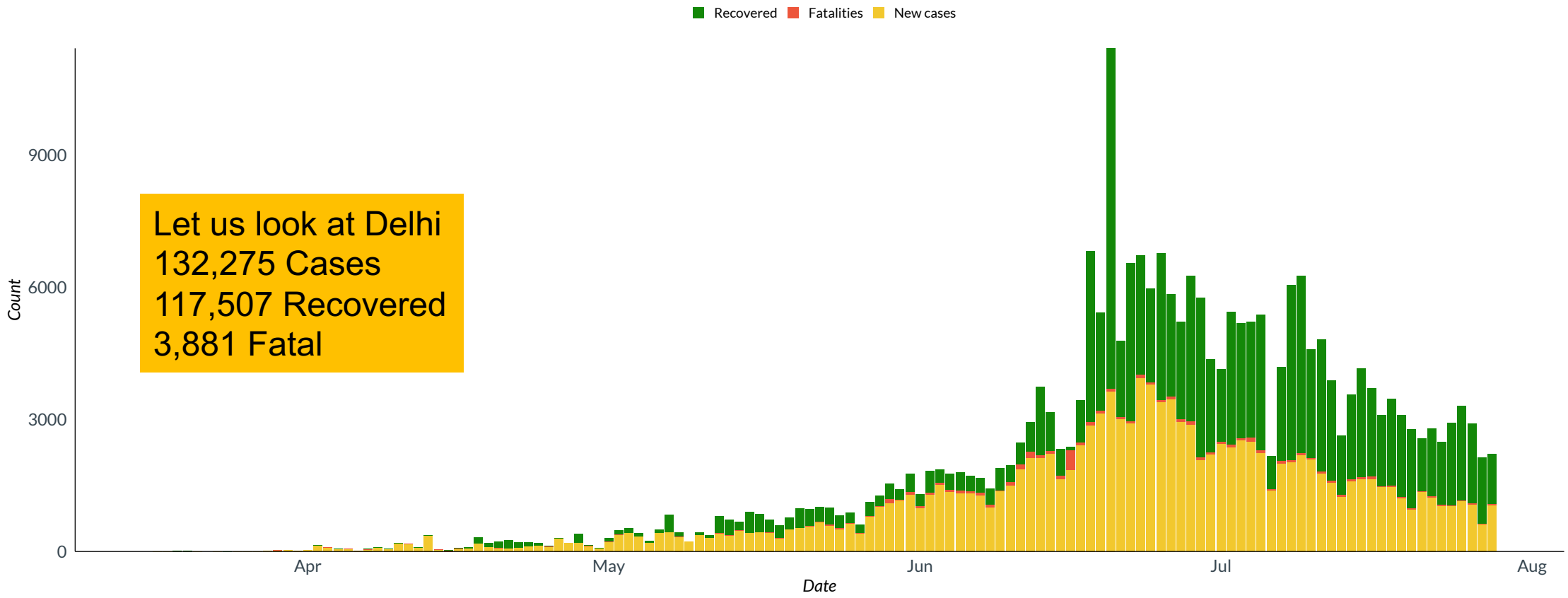
as of June 15



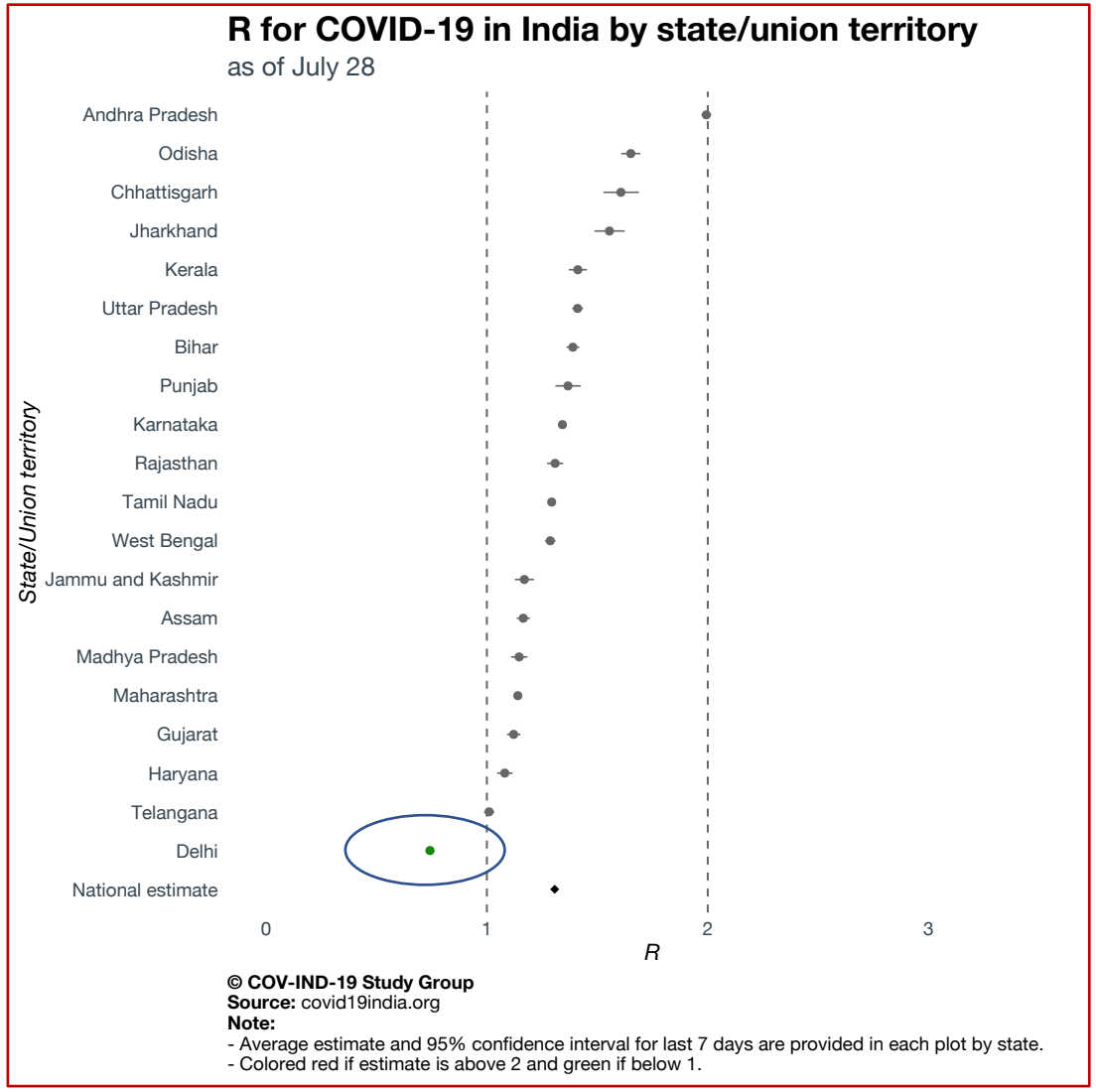

**© COV-IND-19 Study Group**
**Source:** covid19data.org

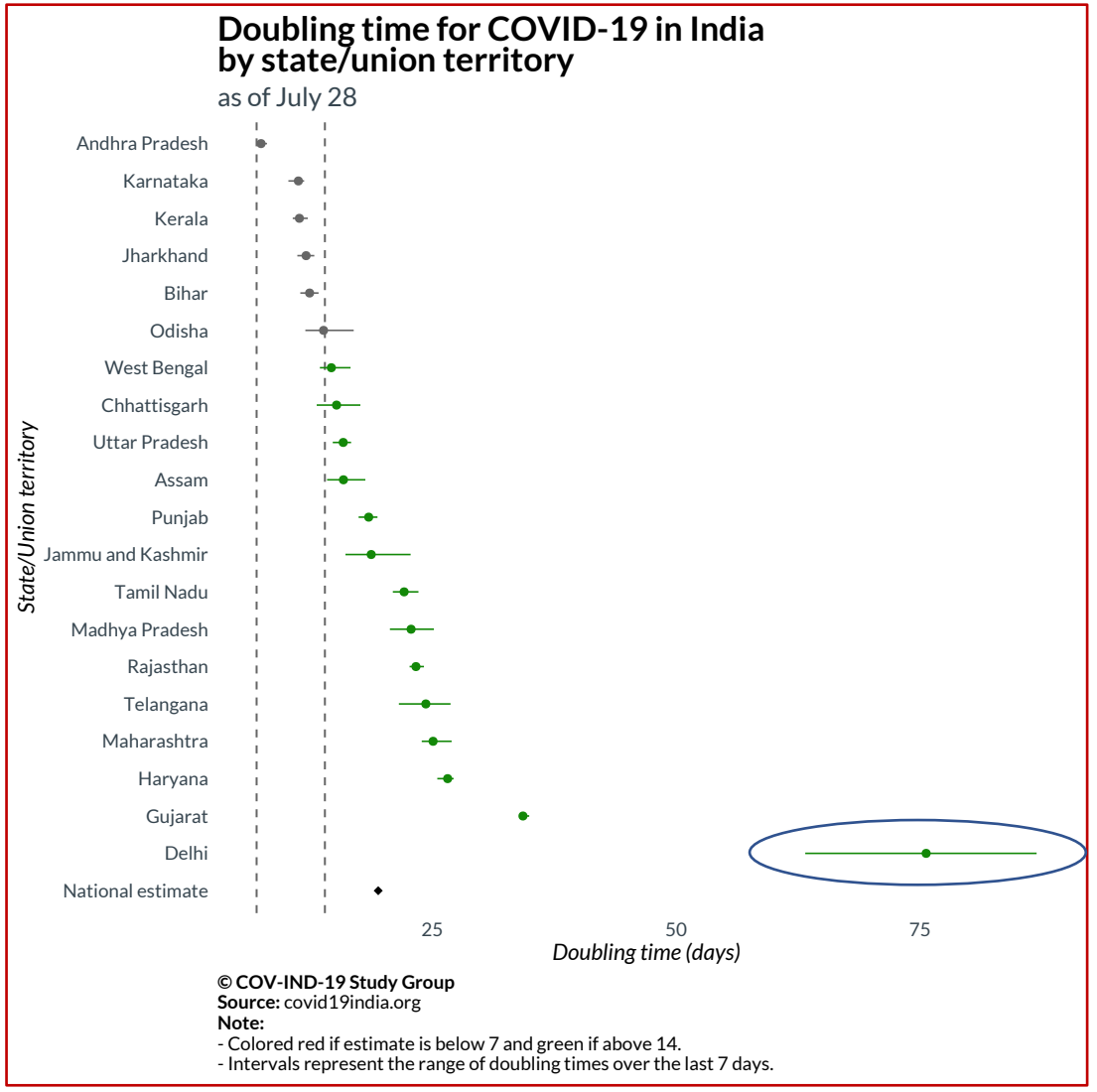
## Daily number of COVID-19 cases, fatalities, and recovered in Delhi

as of July 28




© COV-IND-19 Study Group
**Source:** covid19data.org


R for COVID-19 in India by state/union territory
as of July 28
Andhra Pradesh
Odisha
Chhattisgarh
Jharkhand
Kerala
Uttar Pradesh
Bihar
Punjab
Karnataka
Rajasthan
Tamil Nadu
West Bengal
Jammu and Kashmir
Assam
Madhya Pradesh
Maharashtra
Gujarat
Haryana
Telangana
Delhi
National estimate
State/Union territory
0
1
2
3
R
© COV-IND-19 Study Group
Source: covid19india.org
Note:
- Average estimate and 95% confidence interval for last 7 days are provided in each plot by state.
- Colored red if estimate is above 2 and green if below 1.


Doubling time for COVID-19 in India
by state/union territory
as of July 28
Andhra Pradesh
Karnataka
Kerala
Jharkhand
Bihar
Odisha
West Bengal
Chhattisgarh
Uttar Pradesh
Assam
Punjab
Jammu and Kashmir
Tamil Nadu
Madhya Pradesh
Rajasthan
Telangana
Maharashtra
Haryana
Gujarat
Delhi
National estimate
State/Union territory
25
50
75
Doubling time (days)
© COV-IND-19 Study Group
Source: covid19india.org
Note:
- Colored red if estimate is below 7 and green if above 14.
- Intervals represent the range of doubling times over the last 7 days.

FiveThirtyEight

Politics Sports **Science & Health** Economics Culture

APR. 4, 2020, AT 1:11 PM

# Coronavirus Case Counts Are Meaningless*

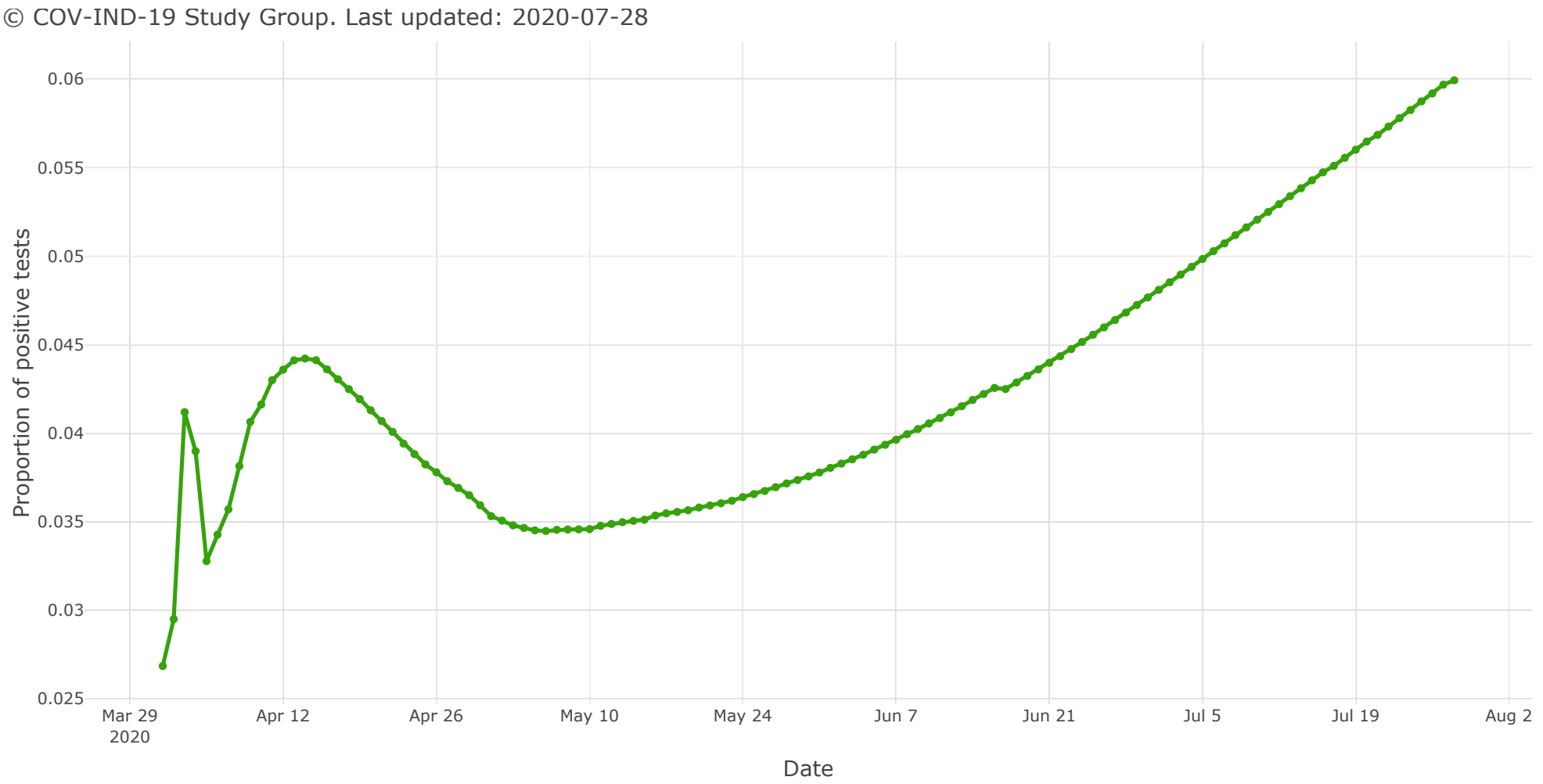
*Unless you know something about testing. And even then, it gets complicated.

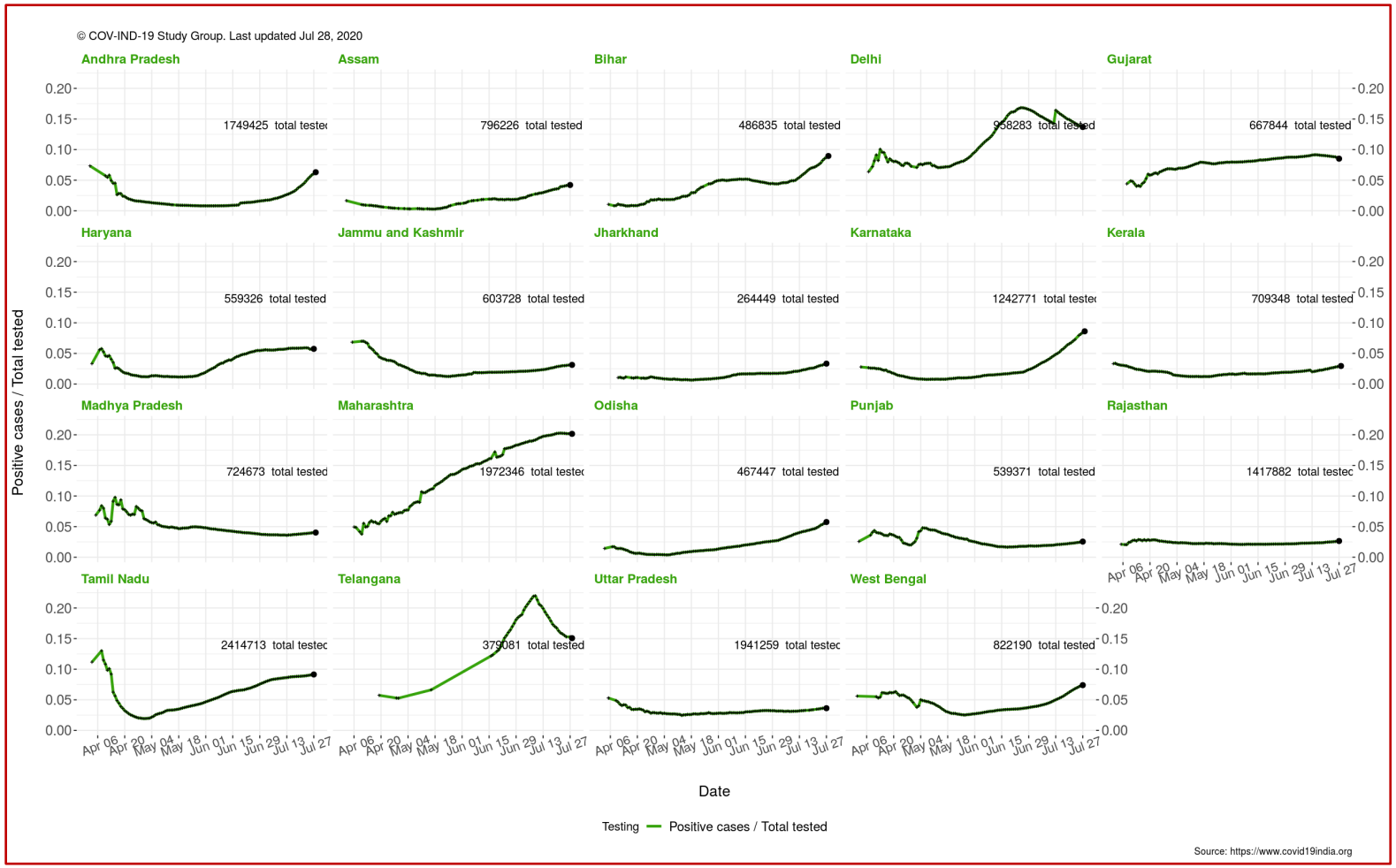
By Nate Silver

Filed under Coronavirus

Source: https://fivethirtyeight.com/features/coronavirus-case-counts-are-meaningless/

# Test Positive Rate

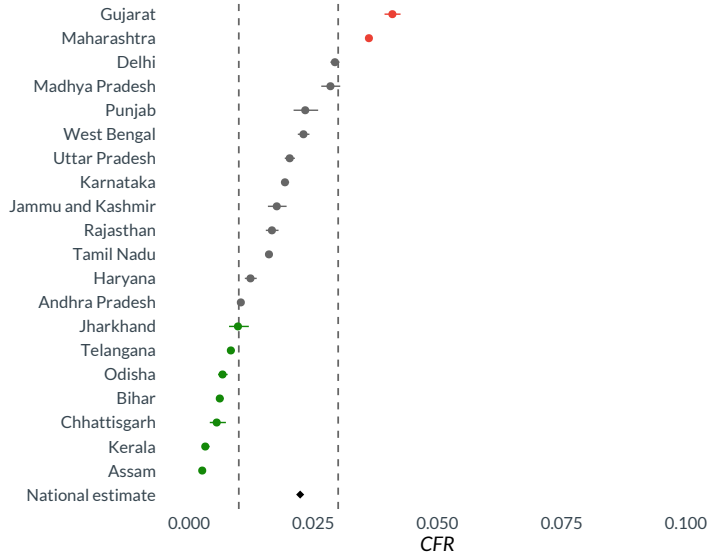





# Variation in TPR across States

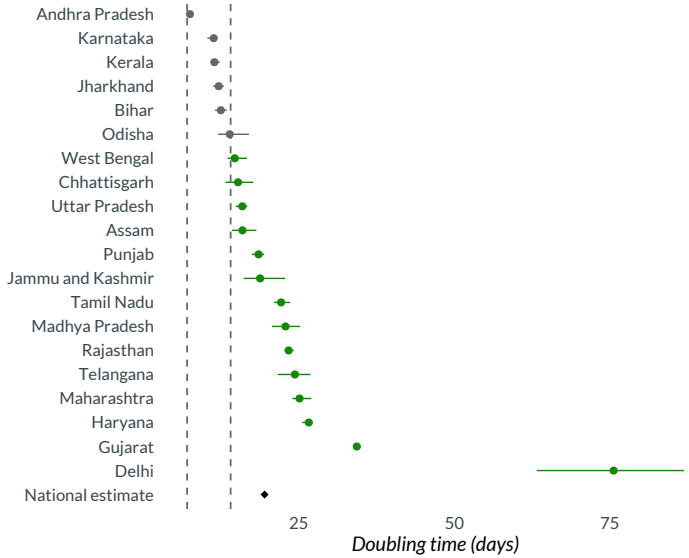
# COVID-19 in India Dashboard

## a. Case-fatality rate (CFR1)



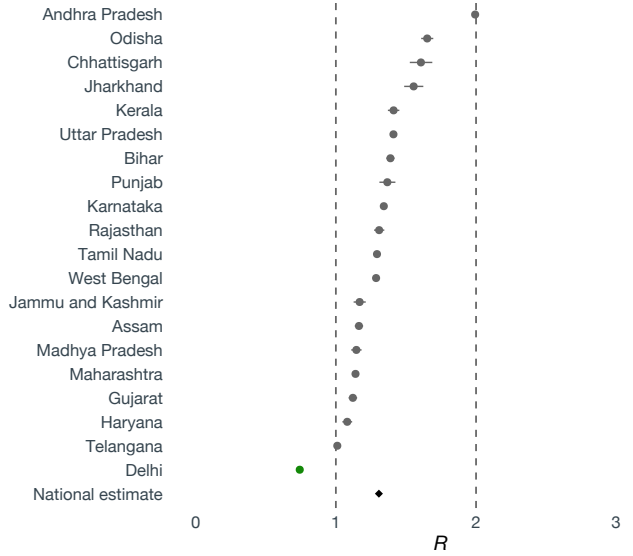

**Notes:**
- 7-day average estimate with 95% confidence interval shown.
- Colored red if estimate is above 0.03 and green if below 0.01.

## b. Doubling time



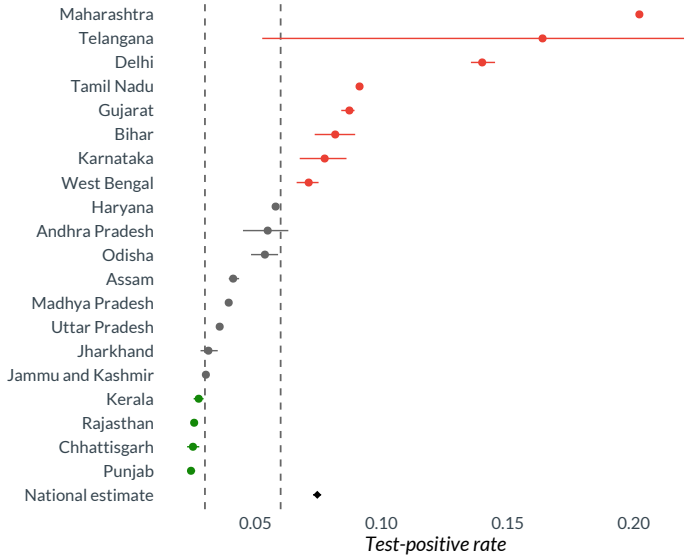

**Notes:**
- 7-day average estimate with range shown.
- Colored red if estimate is below 7 and green if above 14.

## c. Effective reproduction number




**Notes:**
- 7-day average estimate with 95% confidence interval shown.
- Colored red if estimate is above 2 and green if below 1.

## d. Test-positive rate




**Notes:**
- 7-day average estimate with range shown.
- Colored red if estimate is above 0.06 and green if below 0.03.

© COV-IND-19 Study Group

Source: covid19india.org (data through July 28)

Updated daily
Under the metrics Tab
at covind19.org

# Assessing COVID-19 in India

as of July 28

| | METRICS | | | | | | | PREDICTED CASES (08/18) | |
|---|---|---|---|---|---|---|---|---|---|
| LOCATION | R | DOUBLING TIME (DAYS) | CFR | TEST-POSITIVE RATE | TOTAL TESTED | PPT (%) | TESTING SHORTFALL | CAUTIOUS RETURN | MODERATE RETURN |
| **National estimate** | 1.26 | 19.5 | 0.022 | 0.075 | 20,255,683 | 1.52 | 56,647,617 | 2,093,102 | 2,368,184 |
| **Maharashtra** | 1.14 | 25.1 | 0.036 | 0.202 | 1,928,333 | 1.58 | 17,573,476 | 523,634 | 575,700 |
| **Tamil Nadu** | 1.29 | 22.1 | 0.016 | 0.091 | 2,414,713 | 3.19 | 8,470,434 | 282,033 | 307,762 |
| **Andhra Pradesh** | 1.99 | 7.5 | 0.010 | 0.055 | 1,686,446 | 3.23 | 2,825,340 | 241,342 | 326,387 |
| **Karnataka** | 1.34 | 11.3 | 0.019 | 0.077 | 1,205,051 | 1.83 | 3,374,620 | 233,210 | 303,190 |
| **Delhi** | 0.74 | 75.6 | 0.029 | 0.140 | 958,283 | 4.84 | 5,779,224 | 140,656 | 144,185 |
| **Uttar Pradesh** | 1.41 | 15.9 | 0.020 | 0.036 | 1,941,259 | 0.86 | 1,529,169 | 125,346 | 161,696 |
| **West Bengal** | 1.29 | 14.7 | 0.023 | 0.071 | 822,190 | 0.85 | 2,074,285 | 97,023 | 117,871 |
| **Bihar** | 1.39 | 12.4 | 0.006 | 0.082 | 470,560 | 0.39 | 1,419,034 | 74,939 | 101,040 |
| **Telangana** | 1.01 | 24.3 | 0.008 | NA | 363,242 | 0.98 | 2,485,362 | 74,454 | 83,426 |
| **Gujarat** | 1.12 | 34.3 | 0.041 | 0.087 | 667,844 | 0.98 | 2,263,635 | 70,631 | 76,560 |
| **Rajasthan** | 1.31 | 23.3 | 0.017 | 0.026 | 1,417,882 | 1.84 | 394,259 | 52,291 | 60,358 |
| **Assam** | 1.16 | 15.9 | 0.003 | 0.041 | 796,226 | 2.32 | 827,581 | 48,807 | 57,876 |
| **Odisha** | 1.65 | 13.9 | 0.007 | 0.054 | 467,447 | 1.07 | 768,822 | 45,813 | 57,647 |
| **Madhya Pradesh** | 1.15 | 22.8 | 0.028 | 0.039 | 711,982 | 0.87 | 685,888 | 40,588 | 47,069 |
| **Haryana** | 1.08 | 26.6 | 0.012 | 0.058 | 559,326 | 1.95 | 1,064,669 | 40,087 | 43,760 |
| **Kerala** | 1.41 | 11.4 | 0.003 | 0.028 | 688,163 | 1.96 | 247,838 | 39,428 | 53,337 |
| **Jammu and Kashmir** | 1.17 | 18.7 | 0.018 | 0.030 | 592,482 | 4.49 | 302,749 | 26,770 | 30,160 |
| **Punjab** | 1.37 | 18.5 | 0.023 | 0.024 | 539,371 | 1.81 | 113,349 | 21,615 | 26,356 |
| **Jharkhand** | 1.55 | 12.1 | 0.010 | 0.031 | 264,449 | 0.71 | 142,267 | 21,228 | 30,265 |
| **Chhattisgarh** | 1.61 | 15.2 | 0.006 | 0.025 | 292,627 | 1.02 | 70,729 | 14,772 | 19,764 |

**© COV-IND-19 Study Group**

**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 August 18 based on data through July 28. Only states/union territories with the highest cumulative case counts as of July 28 are shown. National Commission on Population 2019 projections used to calculate PPT.

**Abbrev:** CFR, Case-fatality rate; PPT, Proportion of population tested

# Predictions and upper CI (As of July 28)

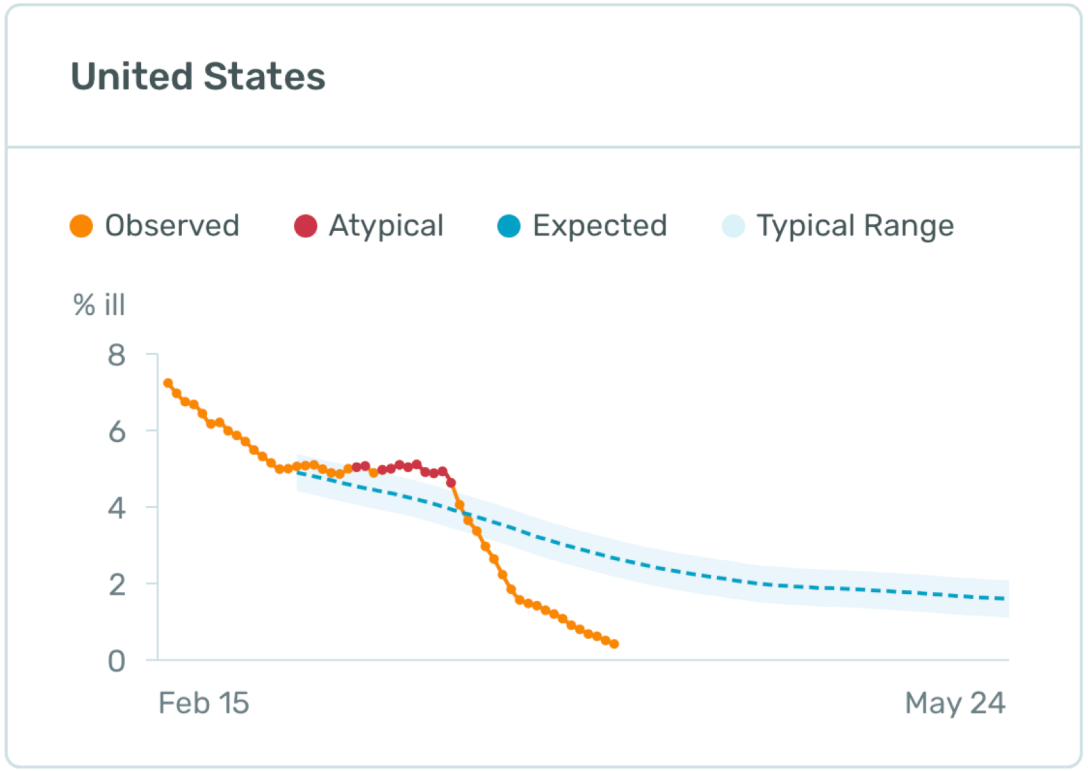
| State | August 8 | August 27 |
|---|---|---|
| Maharashtra | 462-666 thousand | 578-974 thousand |
| Delhi | 137-175 thousand | 142-200 thousand |
| Gujarat | 64-118 thousand | 76-178 thousand |
| Tamil Nadu | 256-372 thousand | 302-512 thousand |
| India | 1.8-3.2 million | 2.3-5.2 million |

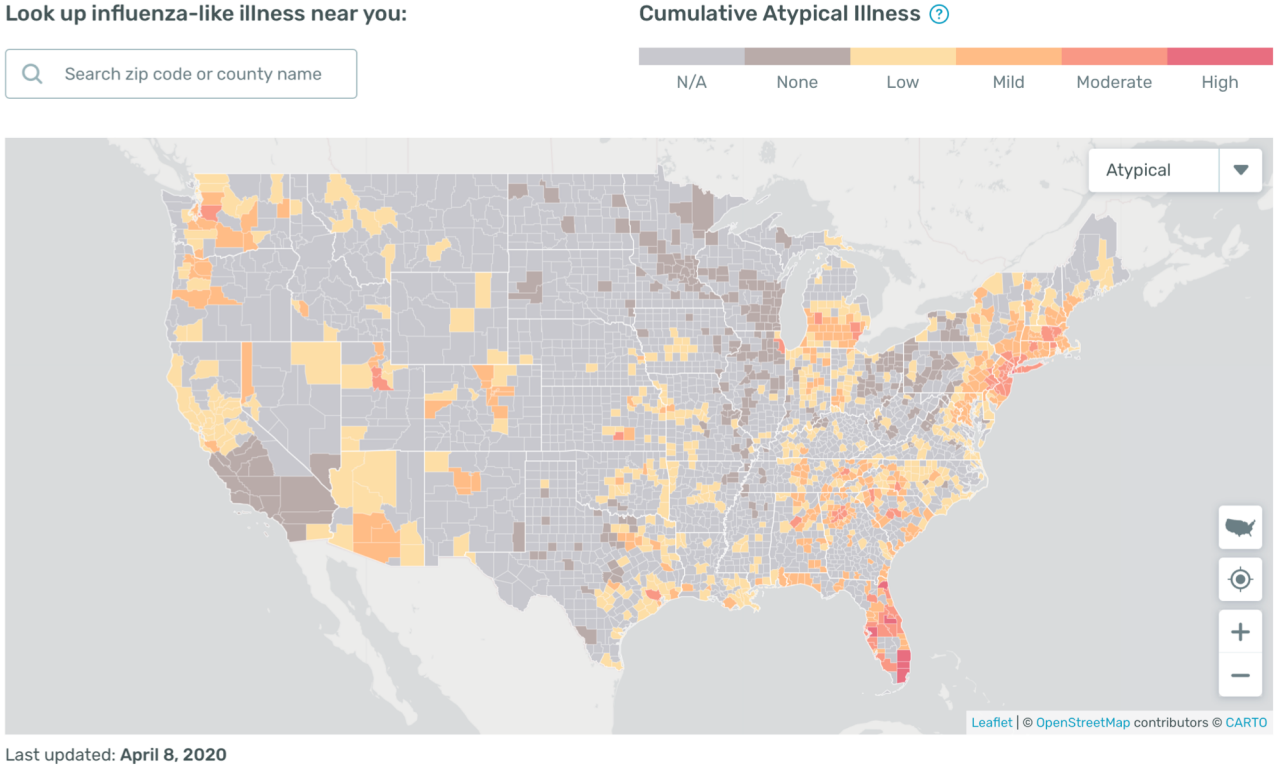
covind19.org

# Using proxy data to chase the disease tracks

## US Health Weather Map

Powered by kinsa INSIGHTS




Last updated: **April 8, 2020**

Source: https://healthweather.us/?mode=Atypical

Google COVID-19 Community Mobility Reports

See how your community is moving around differently due to COVID-19

Source: https://www.google.com/covid19/mobility/

# Moving Forward…

- Public has a serious role in public health. Community participation will be necessary and key. We need to manage risk in our daily lives.
- Use of data (mobile network, hospital admissions, temperature maps) to chase the epidemic and nip it in the bud
- Nimble policymaking (pause, push and drive) in a data adaptive way.
- Track daily death and admissions data compare to history.
- Use data to estimate need, deploy resources, how many beds, PPE, ICU beds, ventilators are needed and where?

# The tale of two disciplines: Economics versus(?) Public Health in the crisis of virus in India

COV-IND-19 Study Group

May 15 · 7 min read

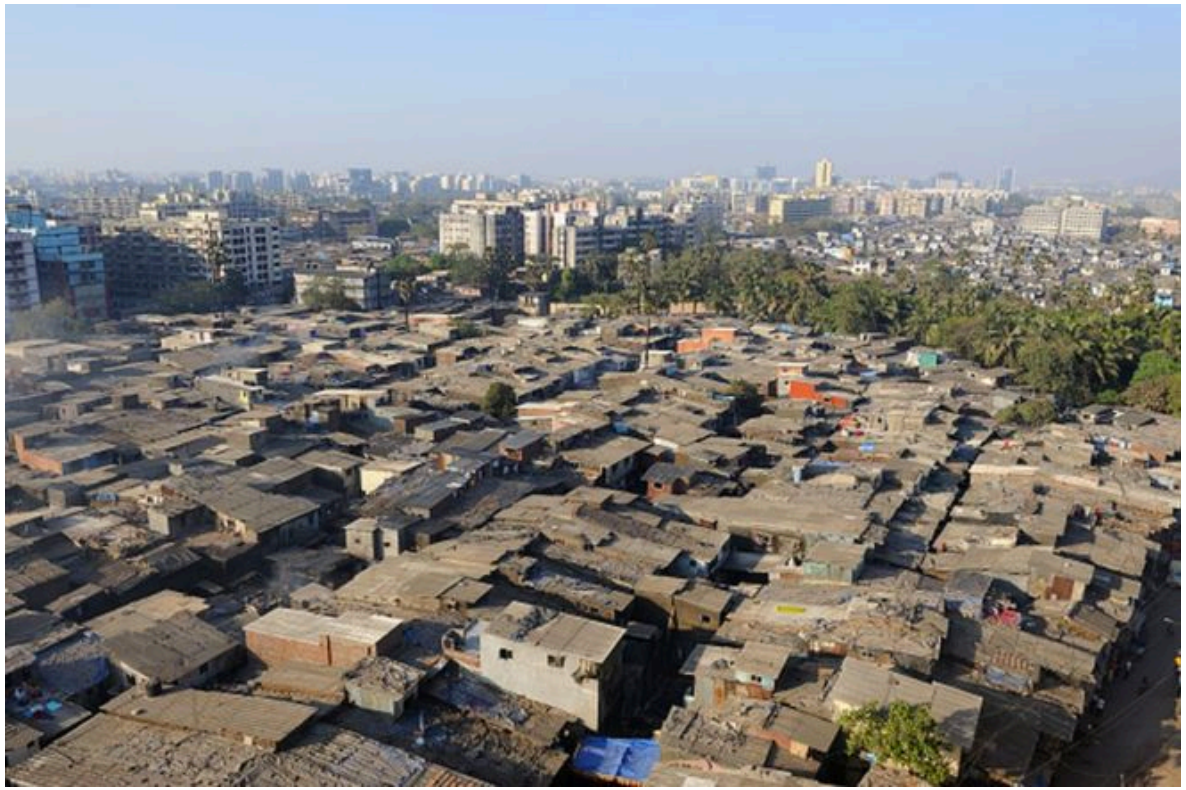
## A short commentary

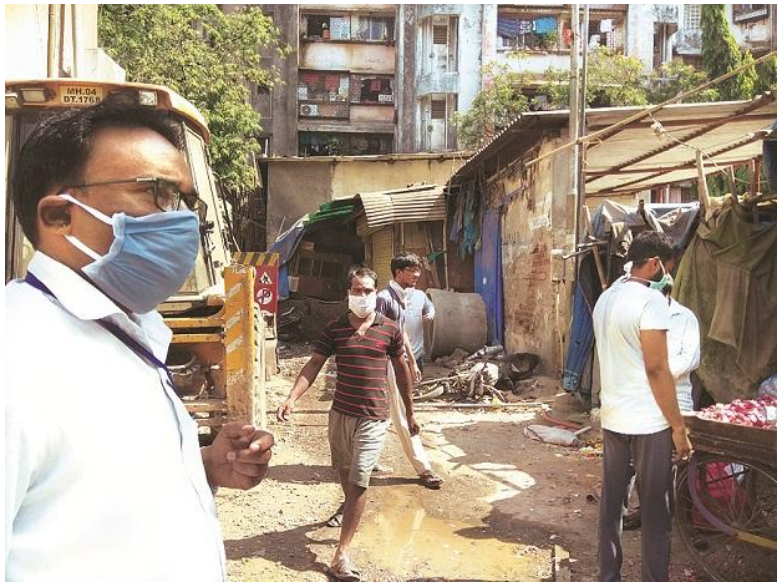
# On being human in the face of a pandemic

*Nature Cancer* (2020) | Cite this article

30 Altmetric | Metrics

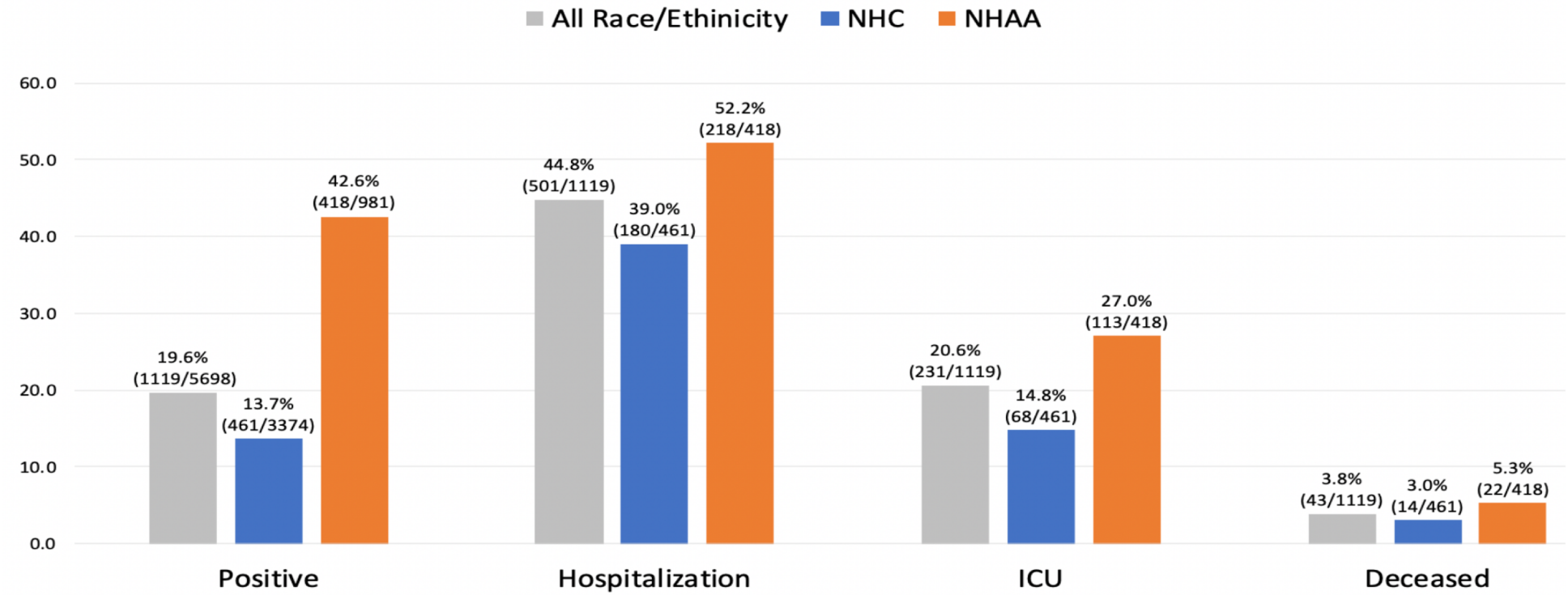
**As the COVID-19 pandemic sweeps through the world, we must reassess the principles that guide our individual and collective responses and the way we operate in society. In the face of crisis, we must lead with science and humanity.**





Dharavi, Mumbai

Asia’s Largest Slum




| | Positive | Hospitalization | ICU | Deceased |
|---|---|---|---|---|
| NHC vs. NHAA: | P < .001 | P < .001 | P < .001 | P = 0.23 |
| OR (95% CI) | | | | |
| Unadjusted | 4.69 (4.00, 5.50) | 1.70 (1.30, 2.22) | 2.14 (1.53, 2.99) | 1.77 (0.89, 3.51) |
| Unadjusted (Firth[a]) | 4.69 (4.00, 5.50) | 1.70 (1.30, 2.22) | 2.13 (1.53, 2.98) | 1.75 (0.89, 3.44) |
| Adjustment 1[b] (Firth) | 3.59 (2.96, 4.36) | 1.77 (1.20, 2.61) | 1.95 (1.20, 3.14) | 1.58 (0.58, 4.31) |
| Adjustment 2[c] (Firth) | 3.50 (2.85, 4.31) | 1.61 (1.06, 2.46) | 1.53 (0.90, 2.57) | 1.24 (0.42, 3.63) |
| Adjustment 3[d] (Firth) | 3.45 (2.79, 4.28) | 1.68 (1.09, 2.60) | 1.51 (0.88, 2.58) | 0.98 (0.32, 2.96) |

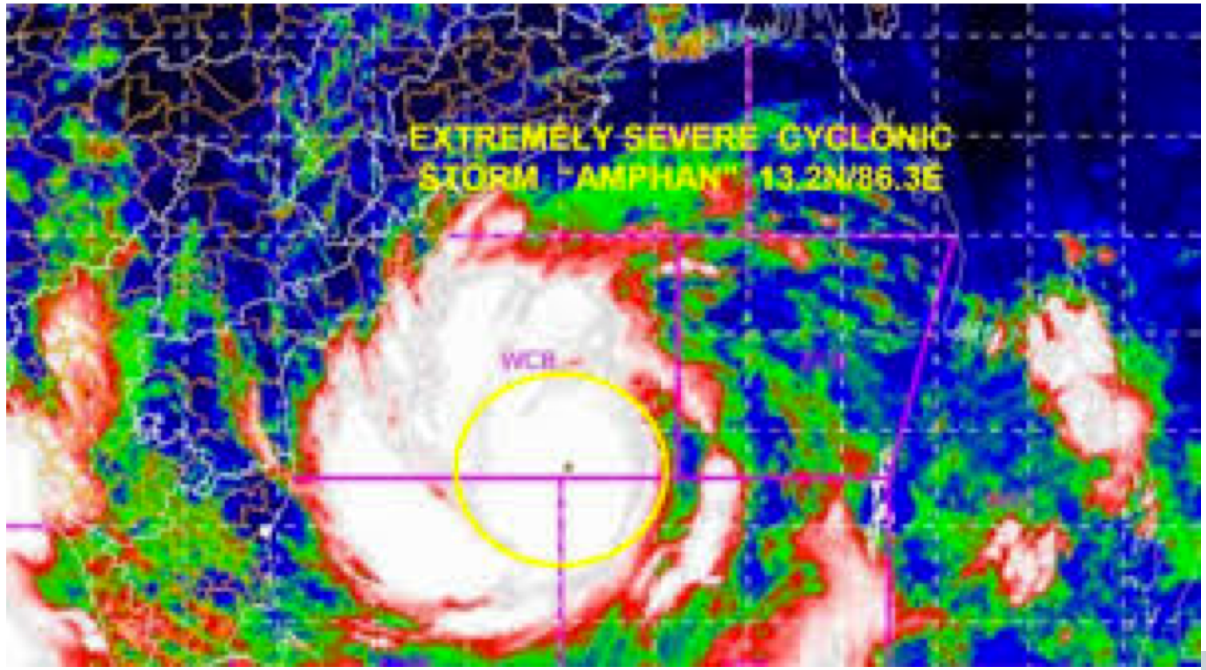
Abbreviations: NHC, non-Hispanic Caucasian; NHAA, non-Hispanic African American; ICU, intensive care unit; OR, odds ratio.

[a] Firth correction applied.

[b] Adjust for age, gender, race/ethnicity, persons perSquareMile$^2$.

[c] Adjust for adjustment 1 plus less than high school education, unemployed, annual income below federal poverty level (FPL). [c] Adjust for adjustment 2 plus Charlson comorbidity score.

# The Distribution of Loss is Uneven: Racial Differences in COVID-19 Outcome in Michigan Medicine



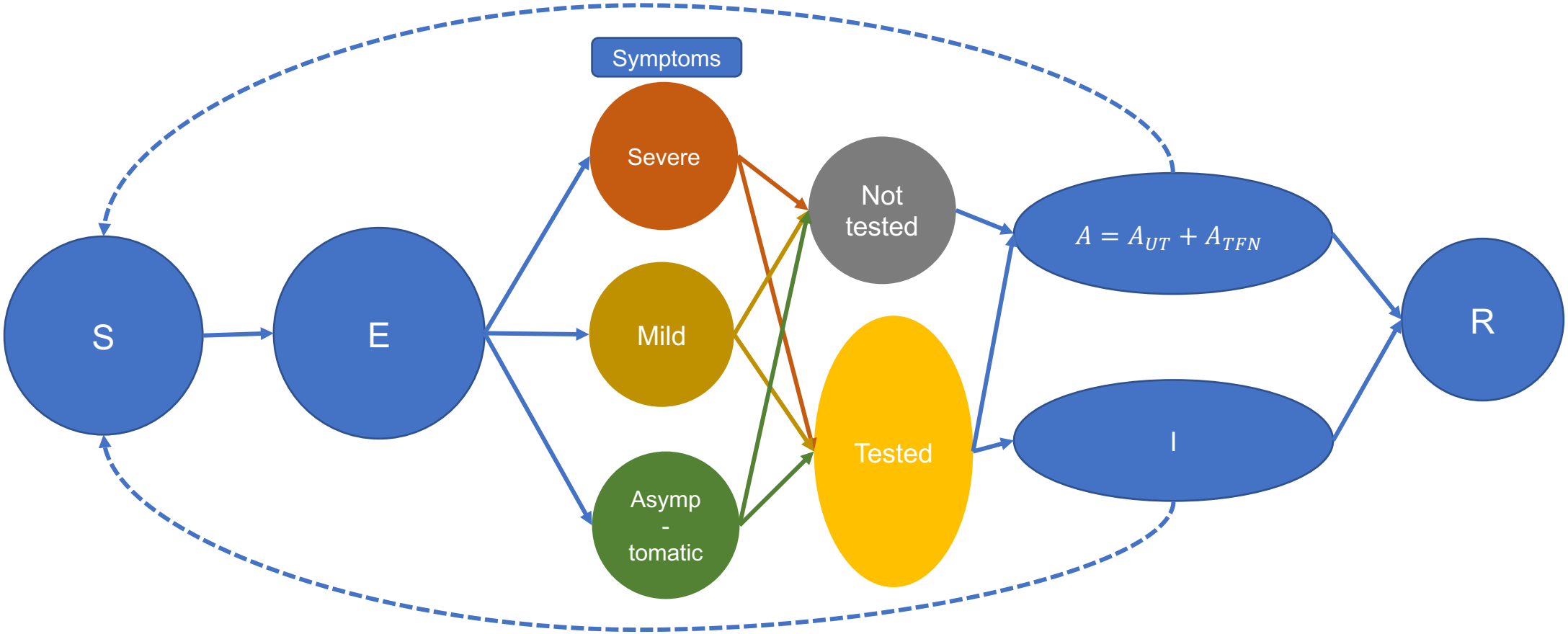
In addition to COVID-19

Cyclone Amphan Hits West Bengal, Odisha

Darwinian theory being truly tested.

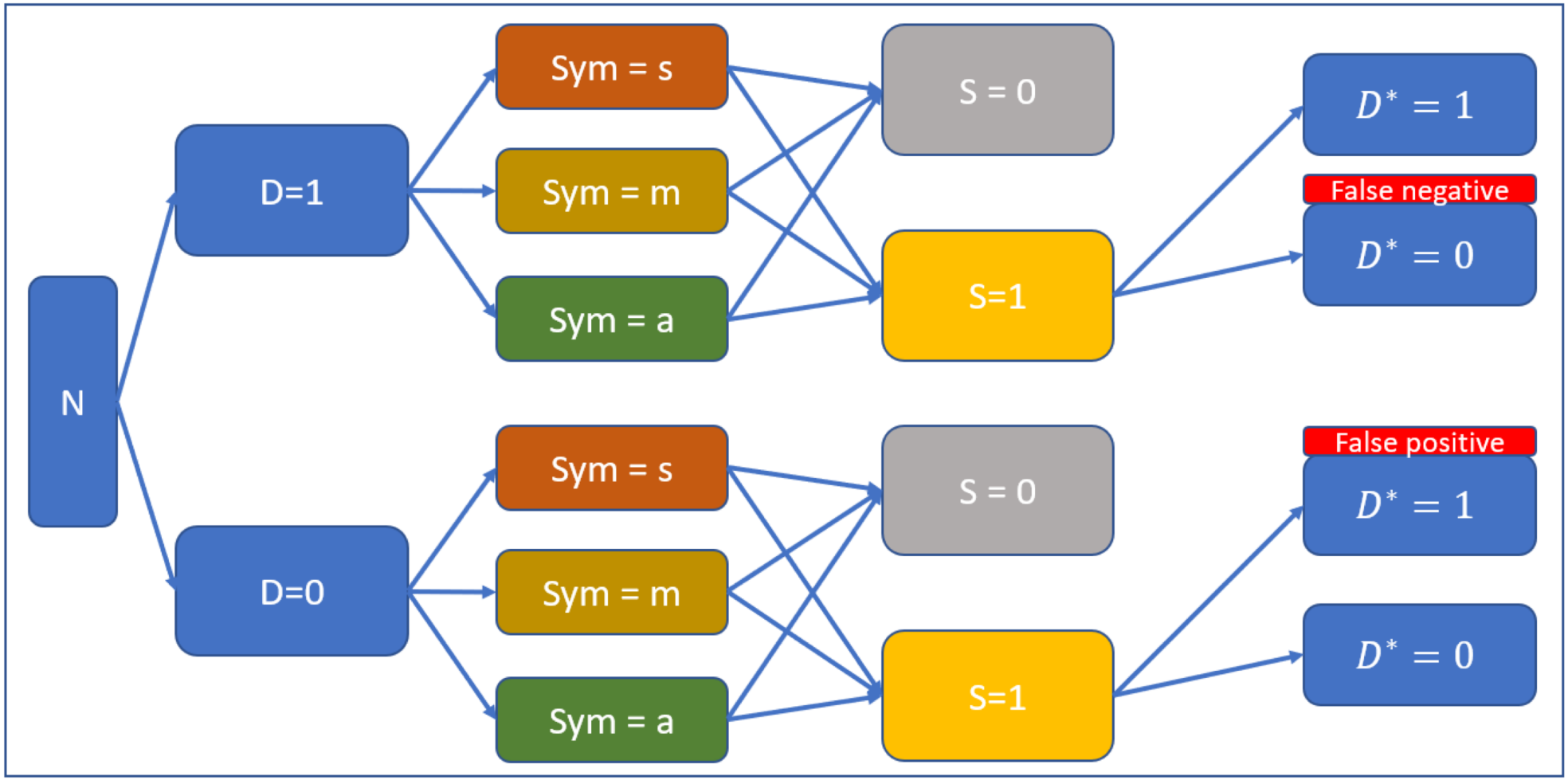
Austrian Poet Rainer Maria Rilke said, “Let everything happen to you. The beauty and the terror. Just keep going. No feeling is final.”

# Thank You and Please Stay Safe!




S: susceptible population.
E: latent cases.
I : reported infected cases.
A: unreported cases.
$A_{UT}$: unreported cases that are not tested.
$A_{TFN}$: unreported false negative cases.
R: removed cases due to recover or death.

SEIR Model With Selection And Misclassification




- *D:* true disease status.
- *Sym:* people's symptom.
- *s, m, a:* severe, mild, and asymptomatic.
- *S:* indicator of selection.
- $D^*$: observed disease status.