



Coronavirus Briefing

India & the Coronavirus:

Modelling the Trajectory of Covid-19

Bhramar Mukherjee & the COV-IND-19 Study Group

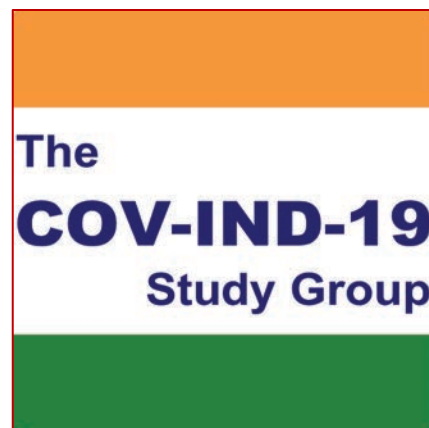
Webinar, Friday, April 10, 2020, 5:30 p.m. IST

Predictions, role of interventions and implications of a 21-day lockdown on the COVID-19 outbreak in India

COV-IND-19 Study Group

An interdisciplinary study group of data scientists

NCAER Webinar, April 10, 2020

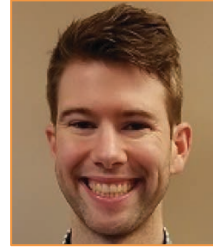




**Veera
Baladandayuthapani**



**Mousumi
Banerjee**



**Daniel
Barker**



**Rupam
Bhattacharyya**



**Debraj
Bose**



**Parikshit
Ghosh**



**Aritra
Halder**



**Michael
Kleinsasser**



**Shariq
Mohammed**



**Soumik
Purkayastha**



**Debashree
Ray**



**Alexander
Rix**



**Maxwell
Salvatore**



**Peter
Song**



**Lili
Wang**



The
COV-IND-19
Study Group

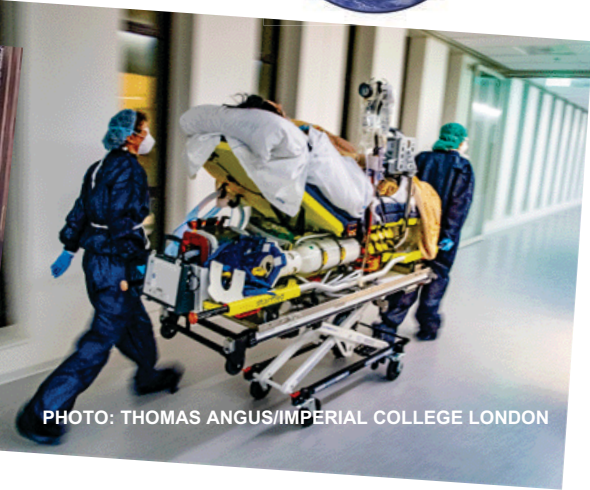


**Bhramar
Mukherjee**

COVID-19 Heroes



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



References to our work

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

Crisis Of Virus in INDia (COV-IND)

[Medium Article on March 20](#)



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

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

Outline

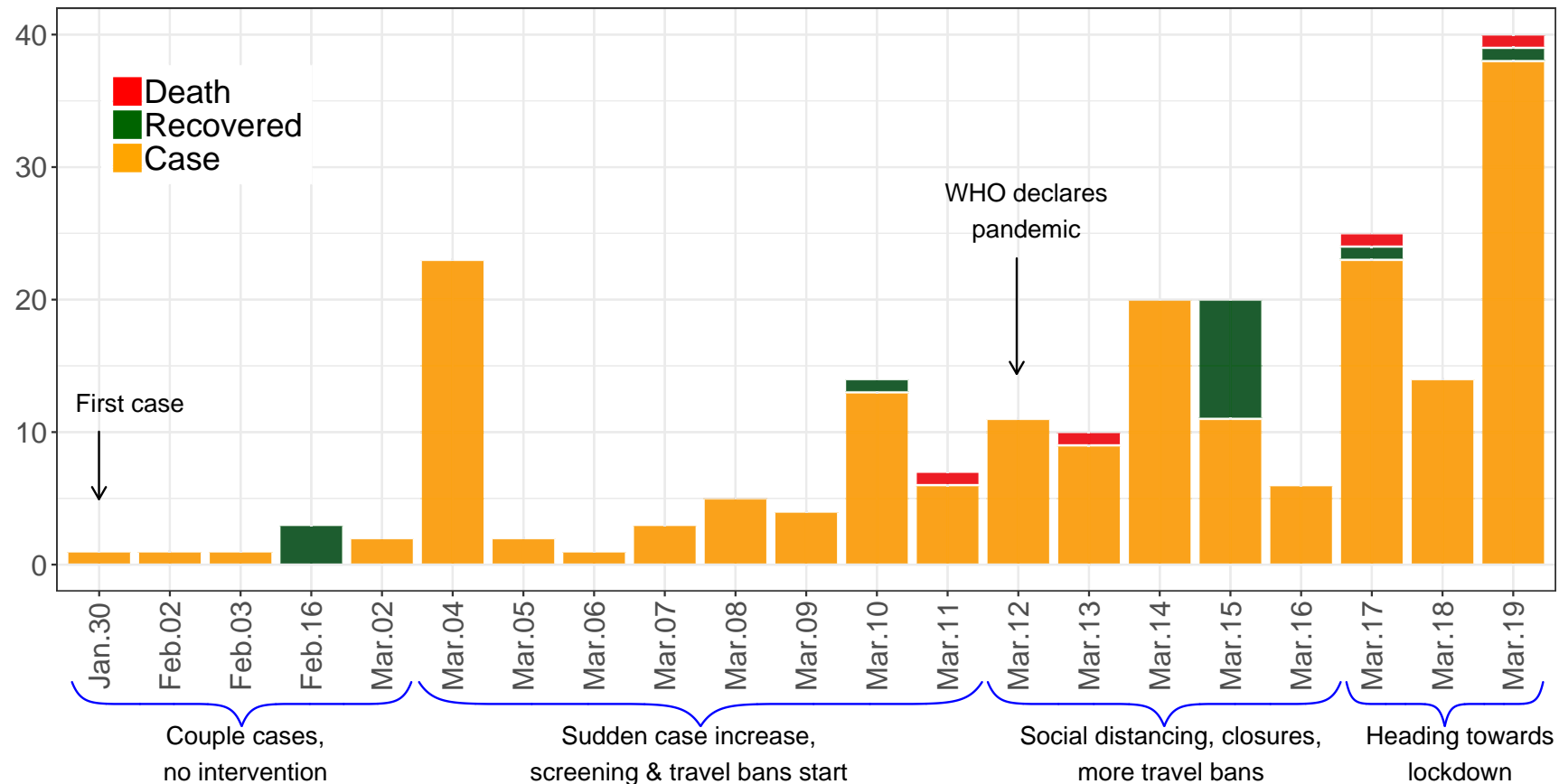
- Pre-lockdown forecasting
- Post-lockdown analysis
- Epidemiologic models: All are wrong, some are useful
- From numerical forecasting to strategic vision

When we started this work

COVID-19 Confirmed New Cases/Recovered/Deaths by Day in India

Data source: Johns Hopkins University CSSE

© COV-IND-19 Study Group



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](#)

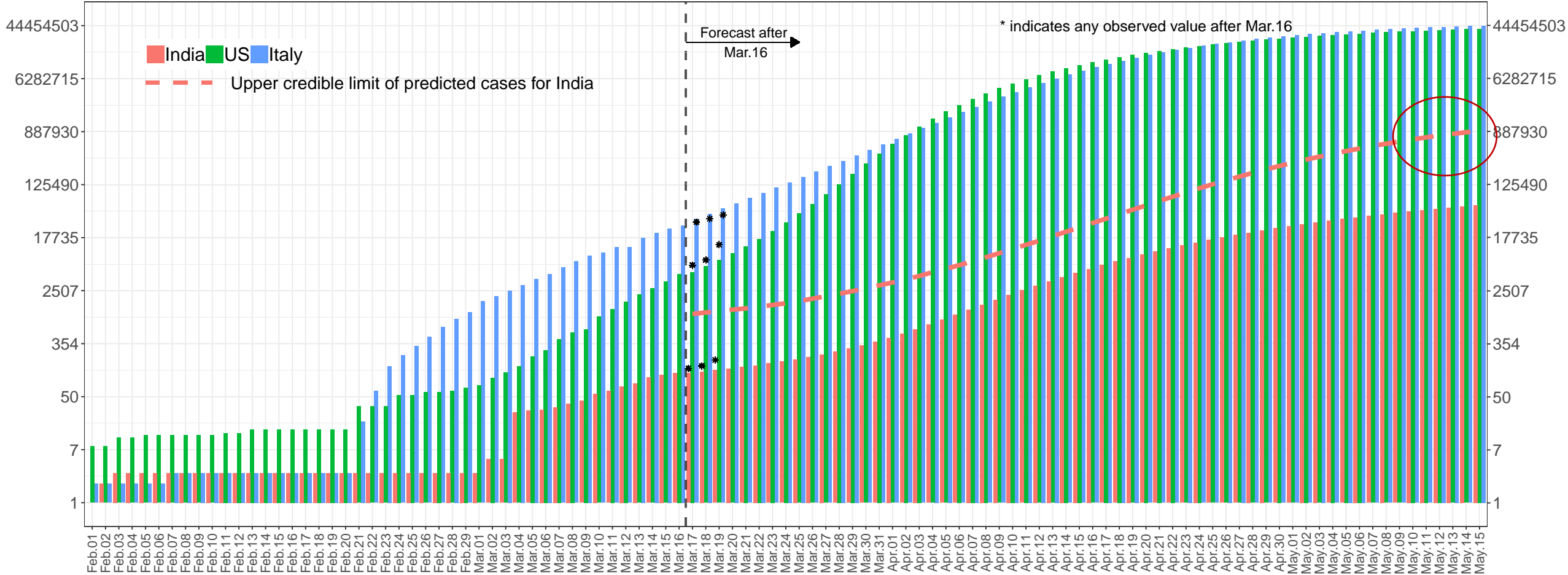
* age-standardized; ** risk; *** defined as within 5 kilometer distance of home or work

Abbrev.: COPD, chronic obstructive pulmonary disease; IDF, International Diabetes Federation;

NICPR, National Institute of Cancer Prevention and Research

Pre-lockdown forecast

COVID-19 Cumulative Confirmed Cases by Day



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



Prime Minister Narendra Modi announced an unprecedented national lockdown for 21 days on Tuesday. (Photo: via PTI)

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](#)).



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](#))

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
- Long-term strategy: instead of discrete short-term tactics



Had a picket fence



Need to build watch towers, dams, escape boats¹²

Questions that one can pose

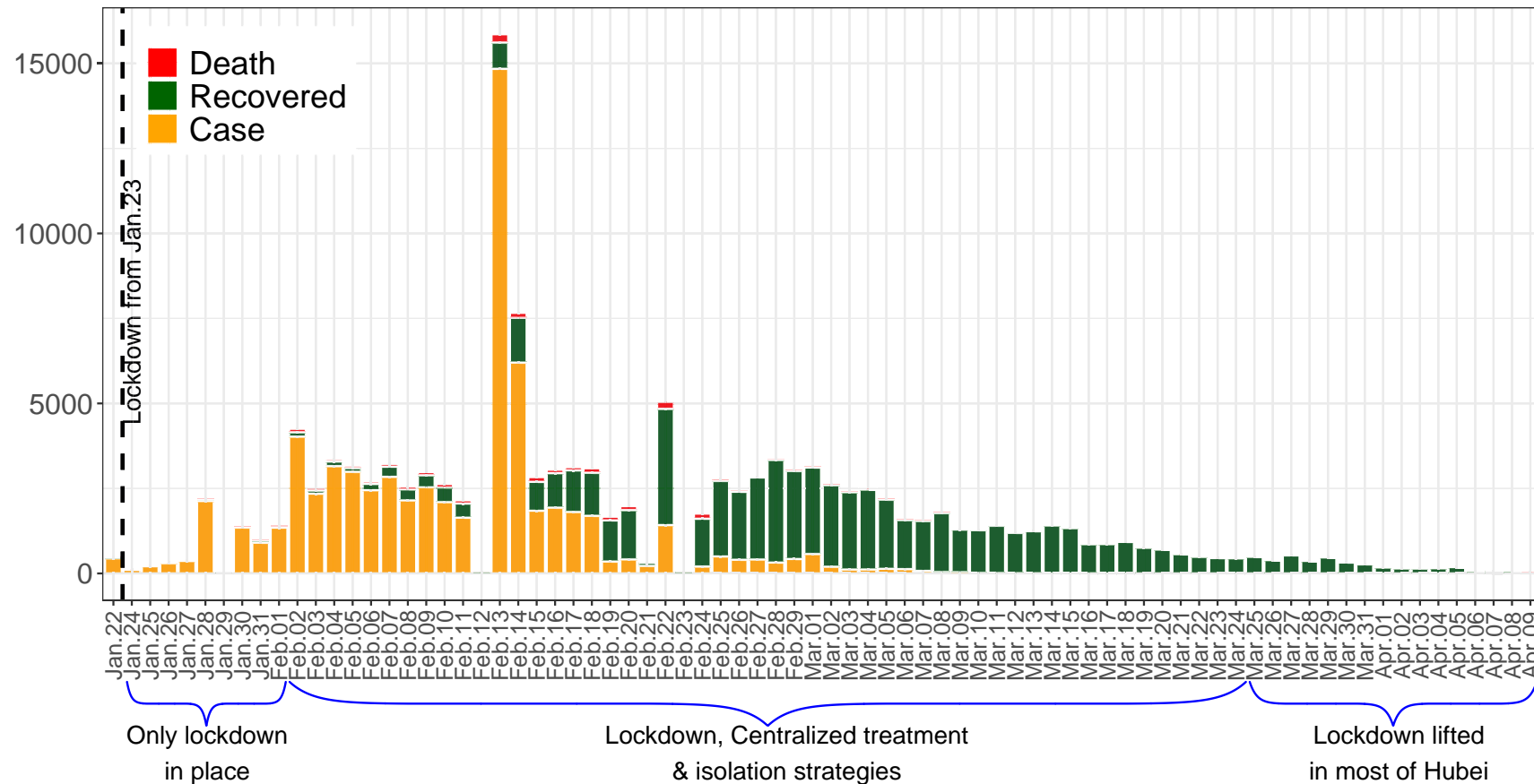
- How many cases do we expect to see post lockdown?
- When can we expect to see a decline in fatalities?
- What does a successful lockdown look like?
- How should we return to normalcy from lockdown?

Qualitative comparison - Hubei, China

COVID-19 Confirmed New Cases/Recovered/Deaths by Day in Hubei, China

Data source: Johns Hopkins University CSSE

© COV-IND-19 Study Group

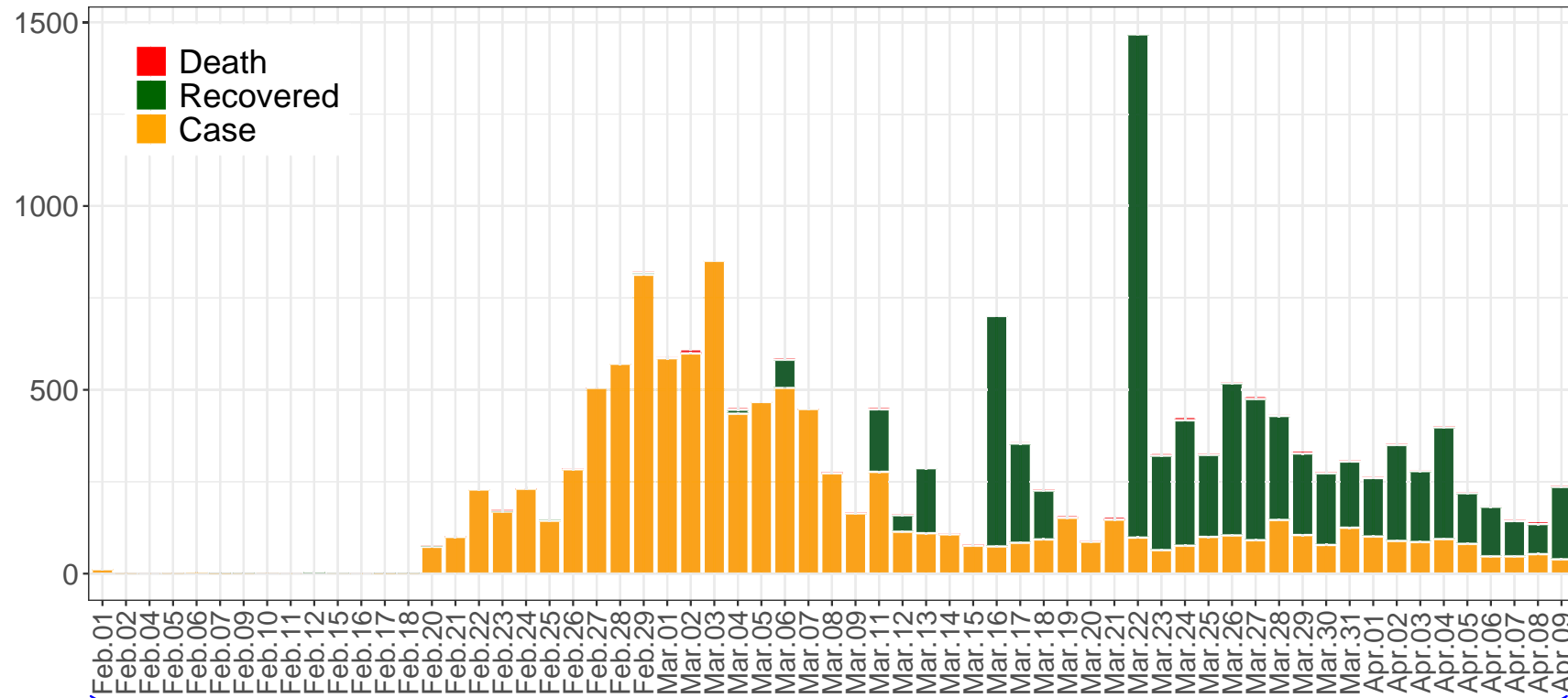


Qualitative comparison - South Korea

COVID-19 Confirmed New Cases/Recovered/Deaths by Day in South Korea

Data source: Johns Hopkins University CSSE

© COV-IND-19 Study Group



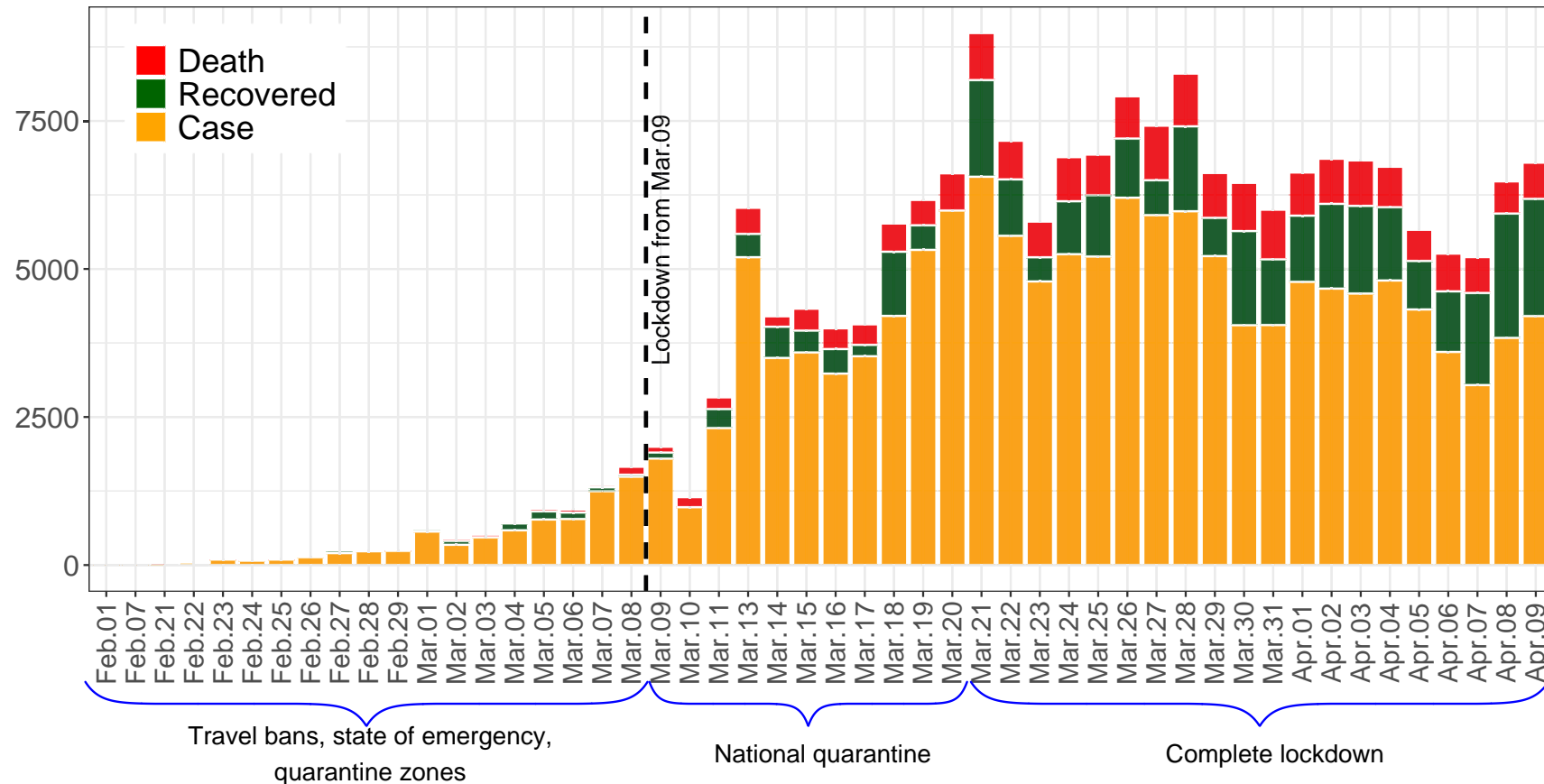
No lockdown; extensive testing, drive-through testing & contact tracing the whole time;
voluntary social distancing and self-quarantine recommended

Qualitative comparison - Italy

COVID-19 Confirmed New Cases/Recovered/Deaths by Day in Italy

Data source: Johns Hopkins University CSSE

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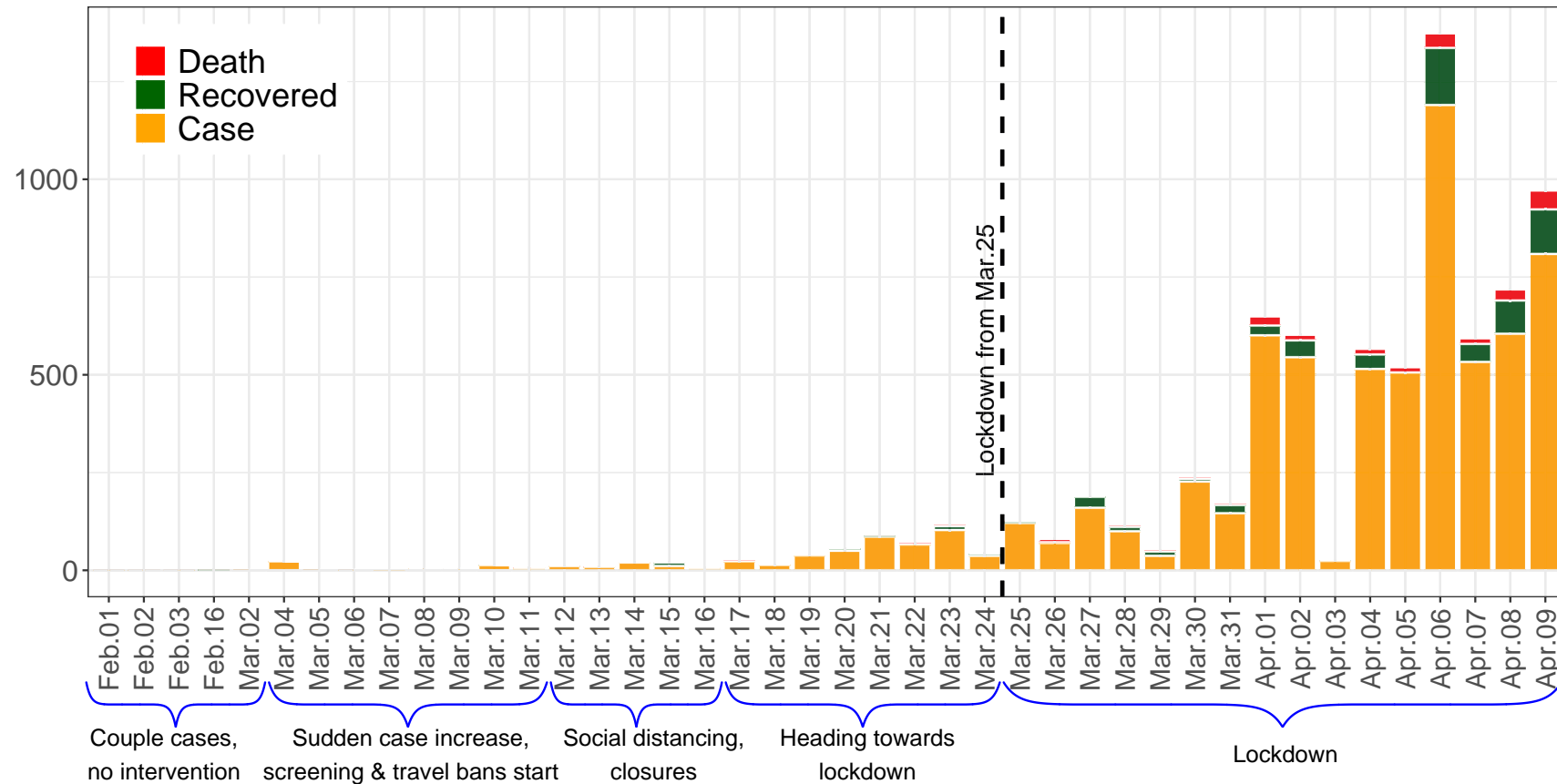


Qualitative comparison - India

COVID-19 Confirmed New Cases/Recovered/Deaths by Day in India

Data source: Johns Hopkins University CSSE

© COV-IND-19 Study Group

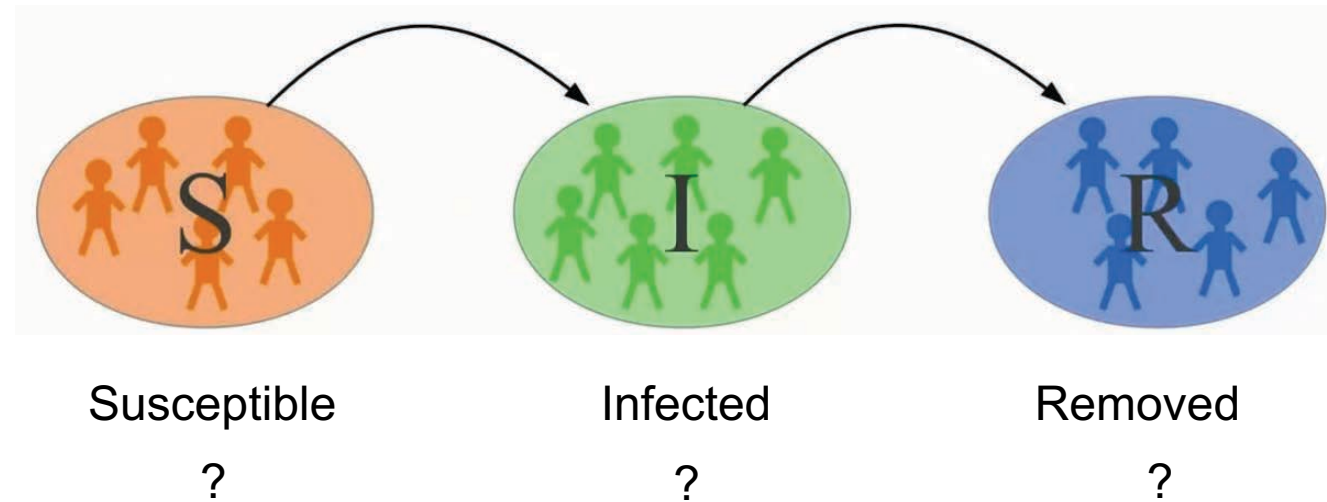


Forecasting Models (India specific)

- [ICMR](#)
- [Cambridge](#)
- [Armed Forces](#)
- [Sourish Das \(CMI\)](#)
- [Ohio State University](#)

SIR model: fundamentals

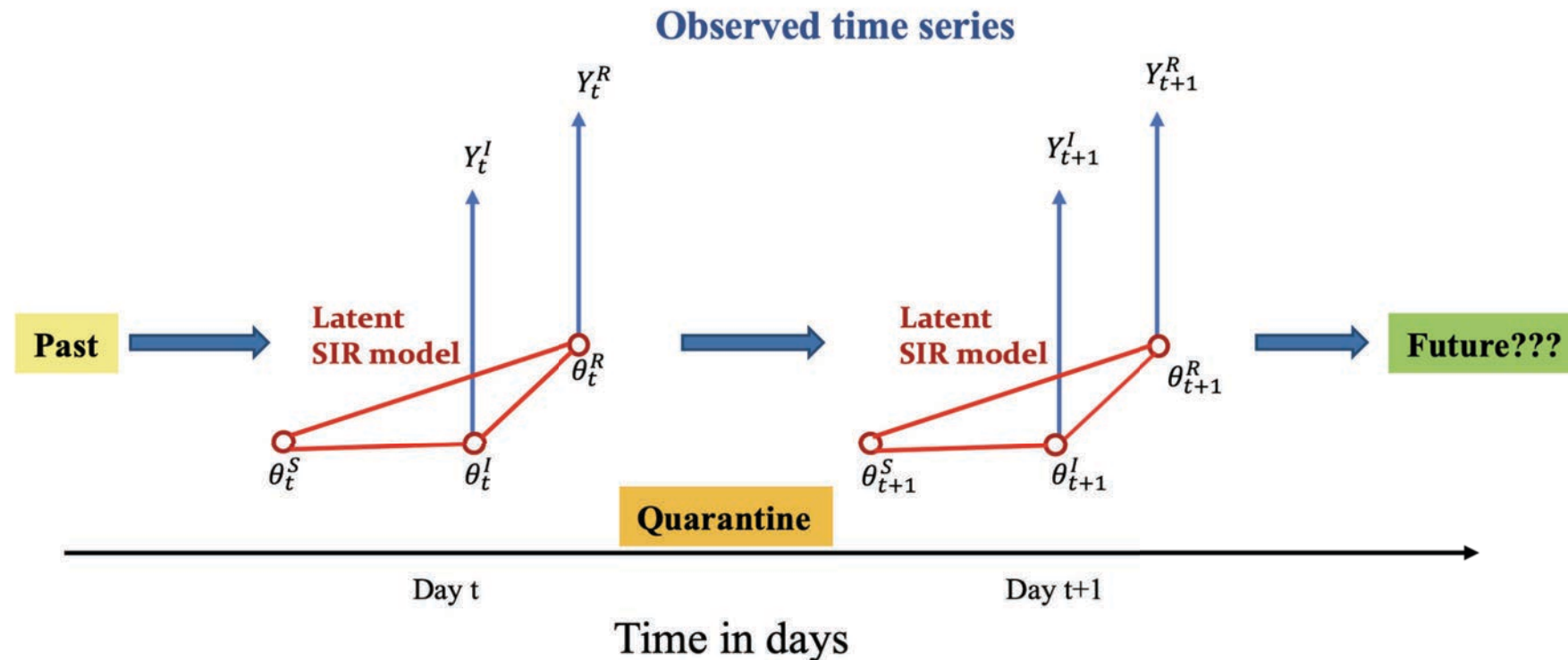
- **Structure:** Each person is in one of three 'states'.



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

Facing the challenge: extended SIR

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



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

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

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

Building autocorrelation

$$\boldsymbol{\theta}_t | \boldsymbol{\theta}_{t-1}, \boldsymbol{\tau} \sim \text{Dirichlet}(\kappa f(\boldsymbol{\theta}_{t-1}, \beta, \gamma)).$$

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

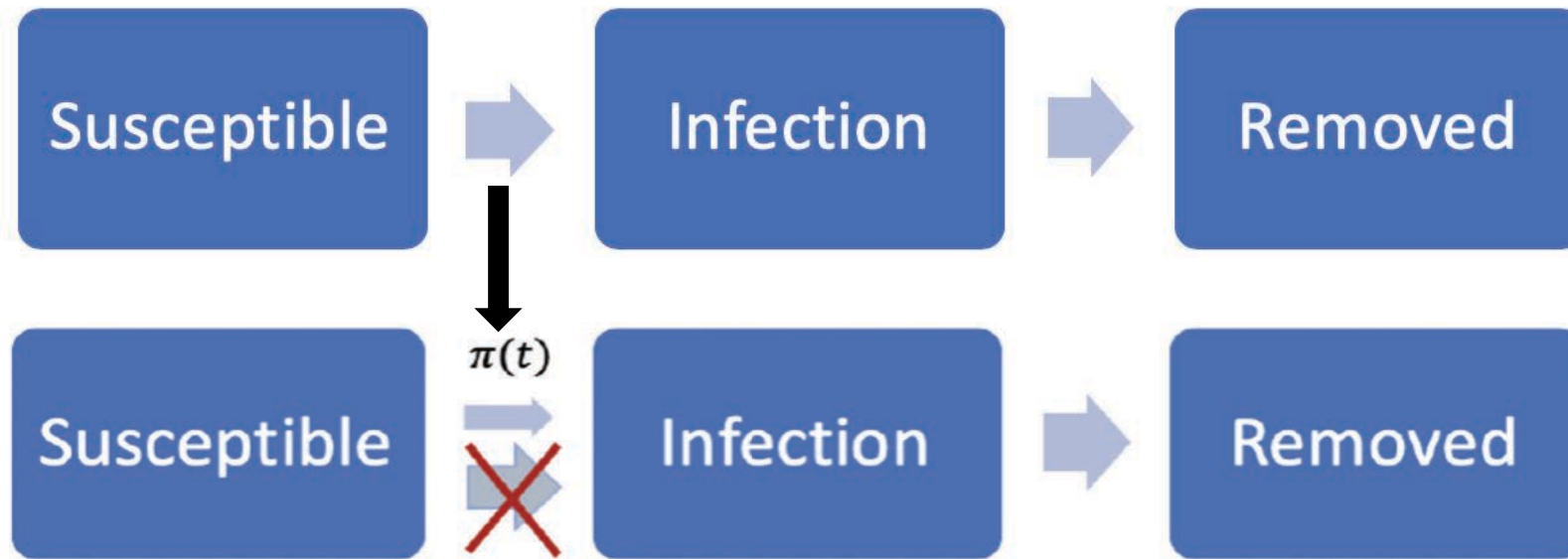
Bayesian specification and Markov chain Monte Carlo (MCMC) sampling

- **Priors:** $\theta_0 \sim \text{Dirichlet}(1 - Y_1^I - Y_1^R, Y_1^I, Y_1^R)$, $\theta_0^S = 1 - \theta_0^I - \theta_0^R$.
- Can set priors/initial choices for R_0, γ in data dependent way.
- Begin with large variances that can be tuned with more data coming in.

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

- Learn the SIR dynamics from the observed data first, and then use MCMC to iterate between latent and observed proportions.

Modeling interventions



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

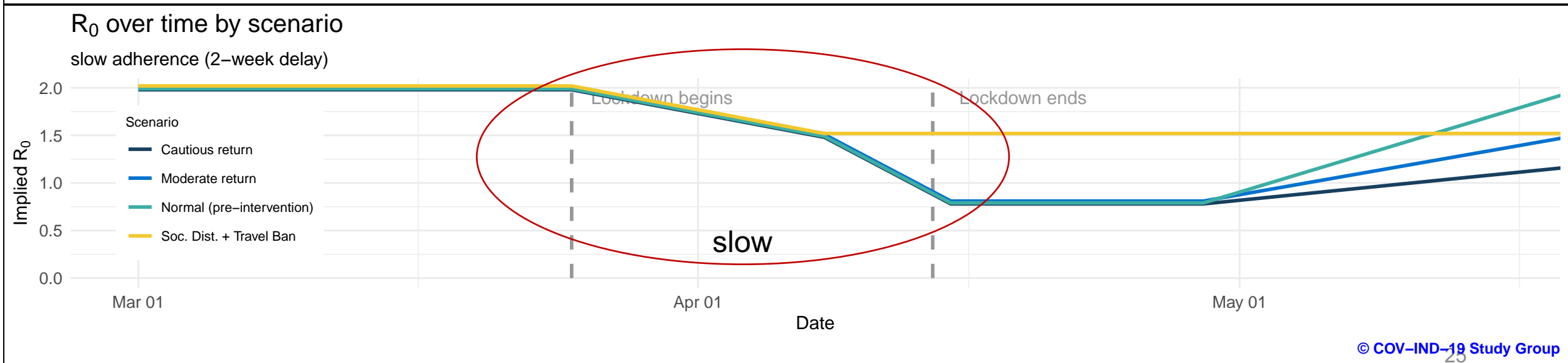
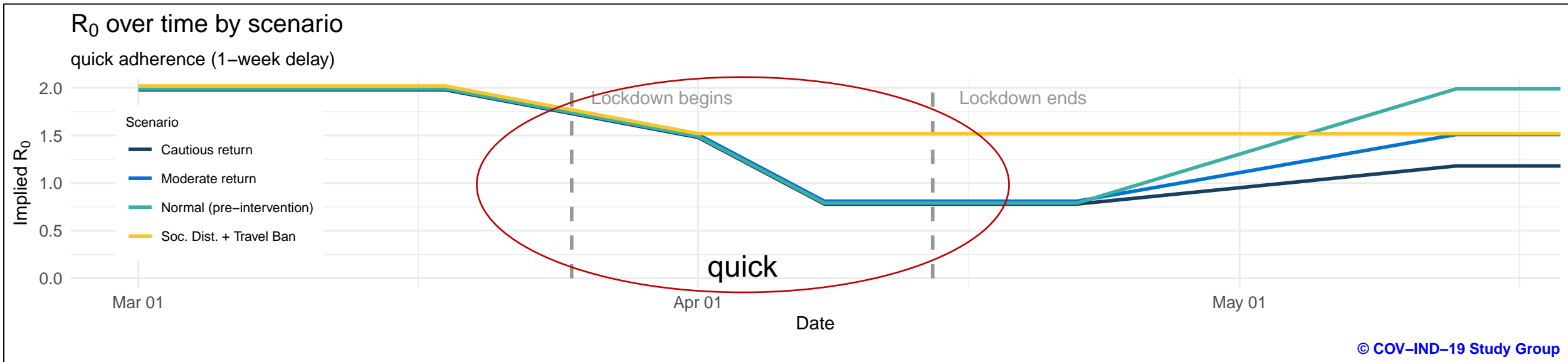
Forecasting scenarios and assumptions

- 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)

R_0 under two hypothetical scenarios

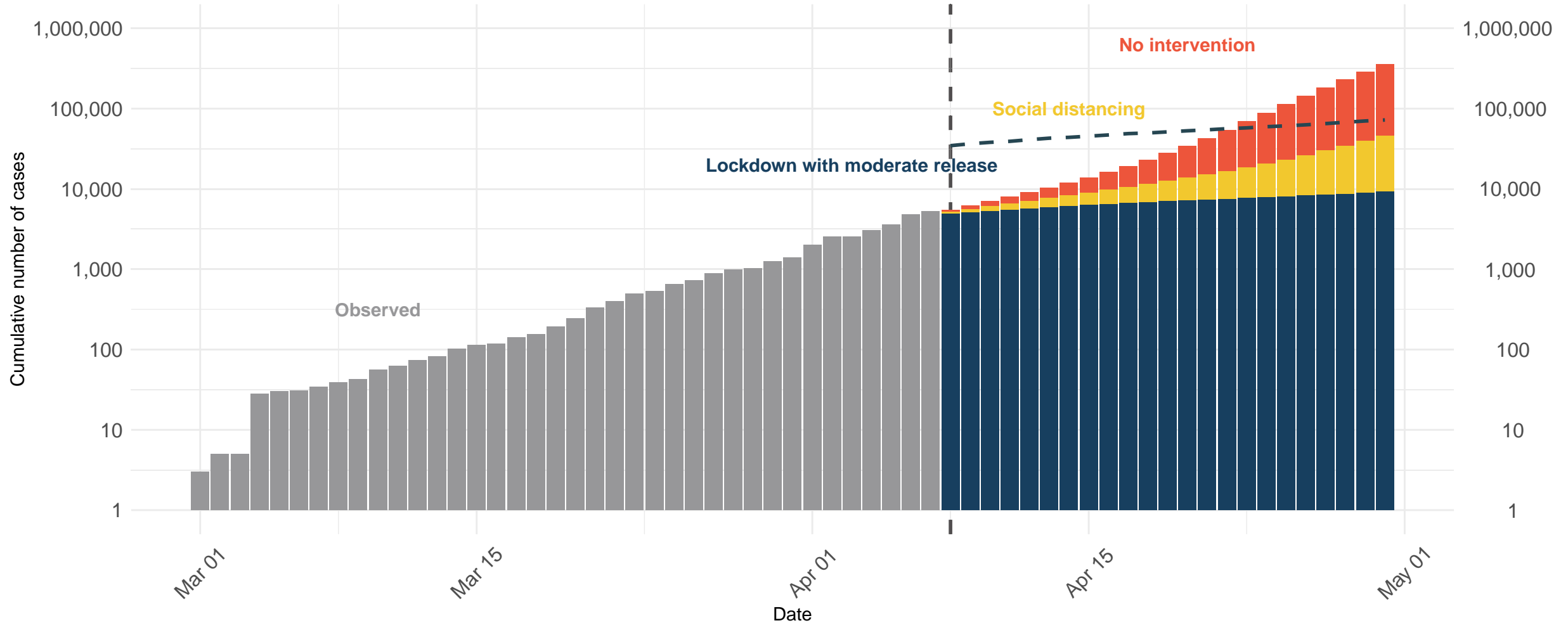


Short term – quick adherence

COVID-19 Cumulative Cases by Day for India

as of 07 April 2020

	April 30 estimate	Upper limit
No intervention	357,849	2,299,442
Social distancing	46,023	266,551
Lockdown (moderate)	9,181	72,245

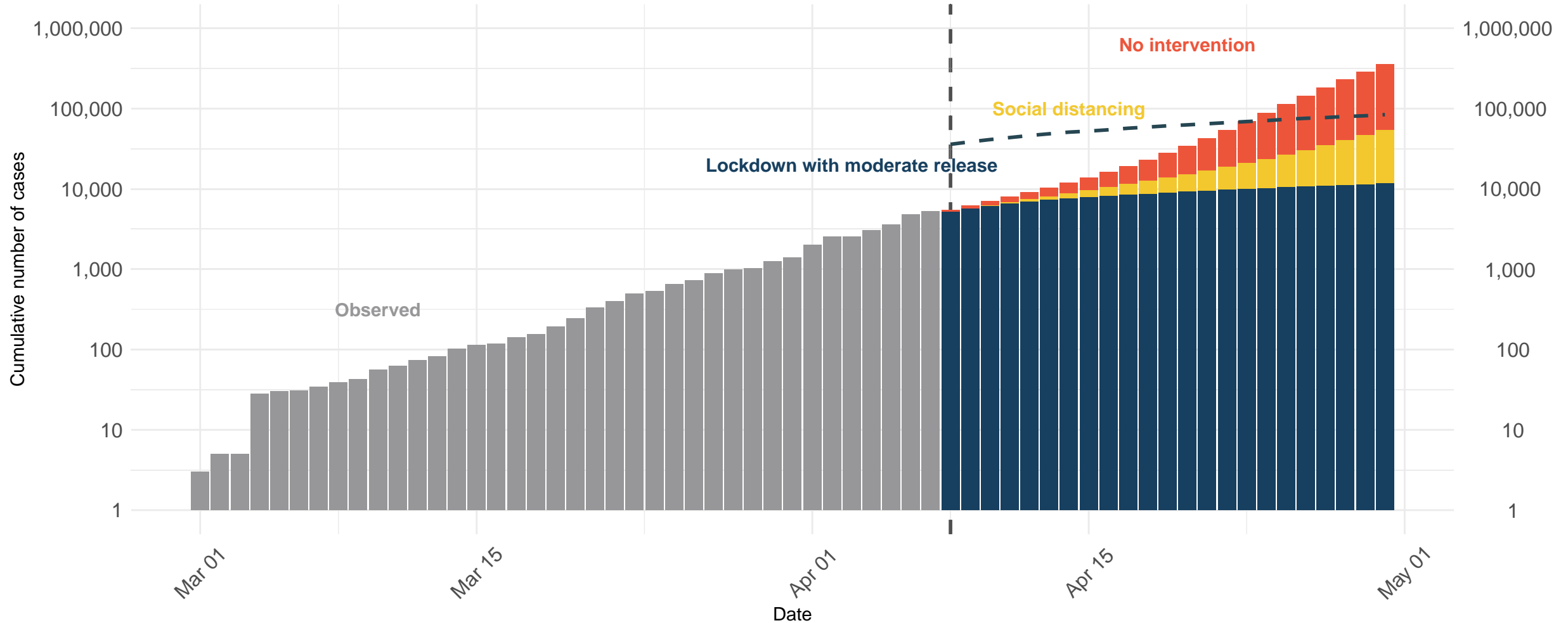


Short term – slow adherence

COVID-19 Cumulative Cases by Day for India

as of 07 April 2020

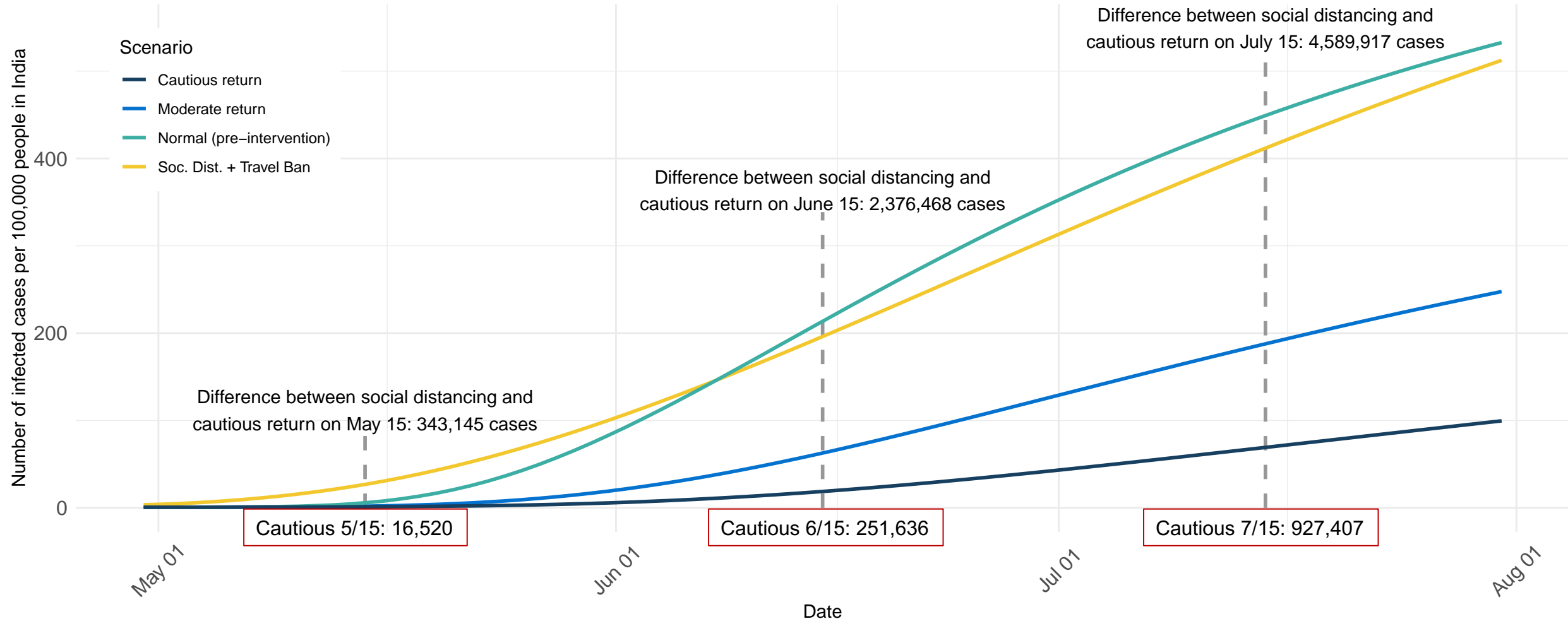
	April 30 estimate	Upper limit
No intervention	357,849	2,299,442
Social distancing	54,728	332,032
Lockdown (moderate)	11,626	84,285



Long term – quick adherence

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

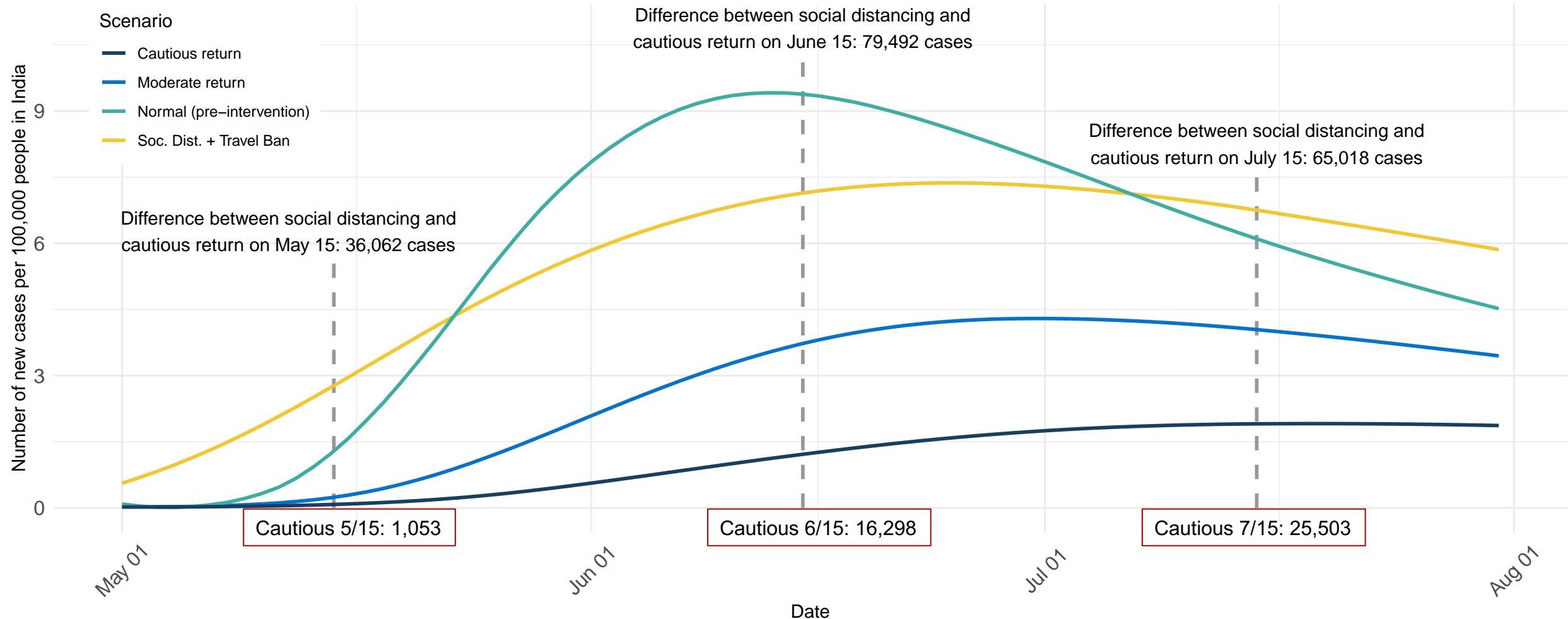
as of 07 April 2020



Long term – quick adherence

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

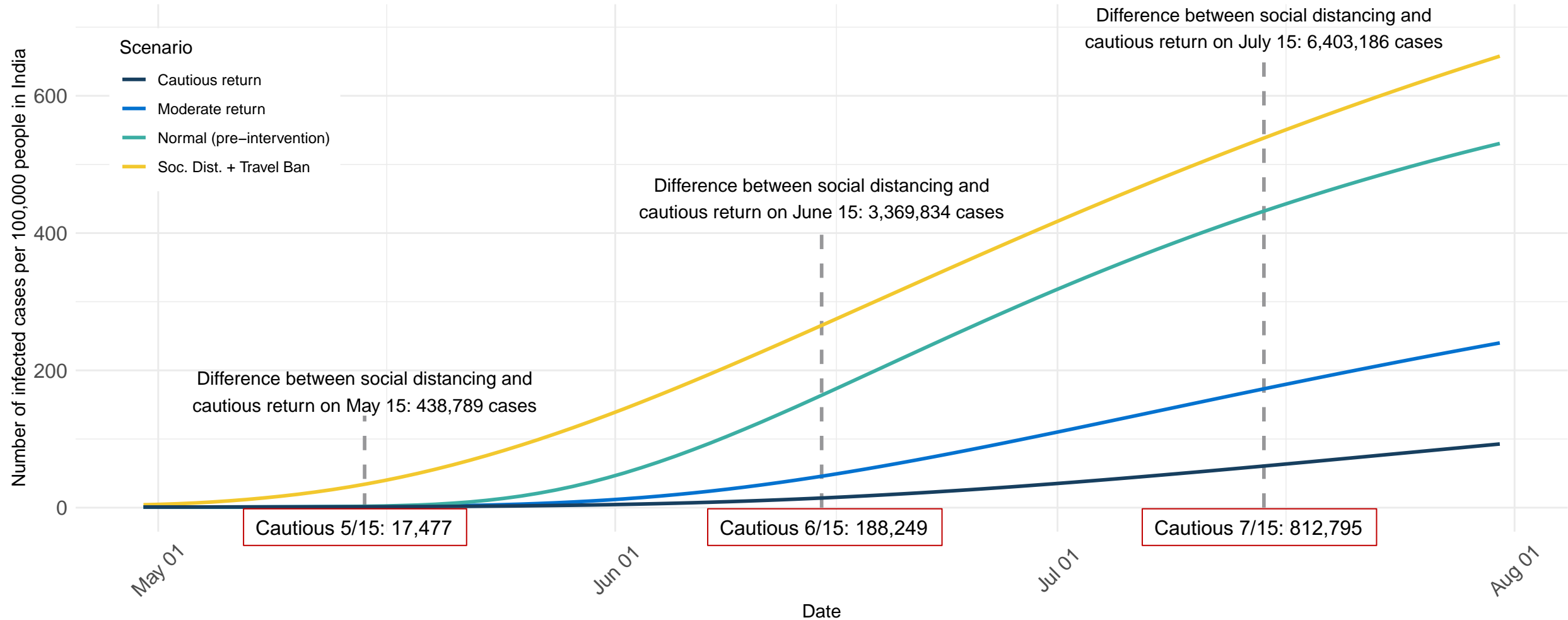
as of 07 April, 2020



Long term – slow adherence

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

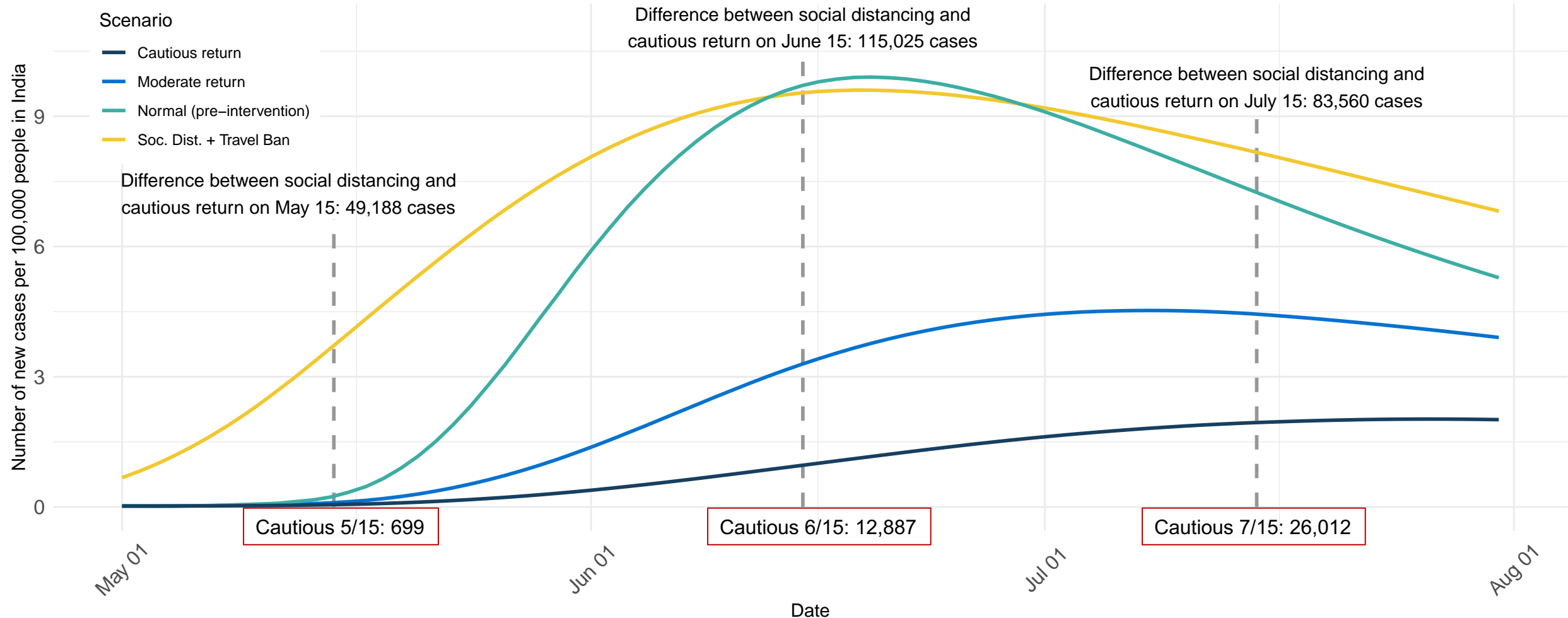
as of 07 April 2020



Long term – slow adherence

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


as of 07 April, 2020



COVIND19.org (Please check it out!)

COVID-19 Outbreak in India

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.

Read the accompanying April 3 article: [link forthcoming](#)

Read the original March 21 article: [Medium article](#)

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

Country-level data source: [JHU CSSE COVID-19 GitHub](#)

State-level data source: [COVID-19 in India Kaggle](#)

R modeling package: [eSIR R package](#)

Source code: [COV-IND-19 GitHub](#)

Please direct inquiries to [Maxwell Salvatore](#), [Alexander Rix](#), [Michael Kleinsasser](#), and [Bhramar Mukherjee](#)

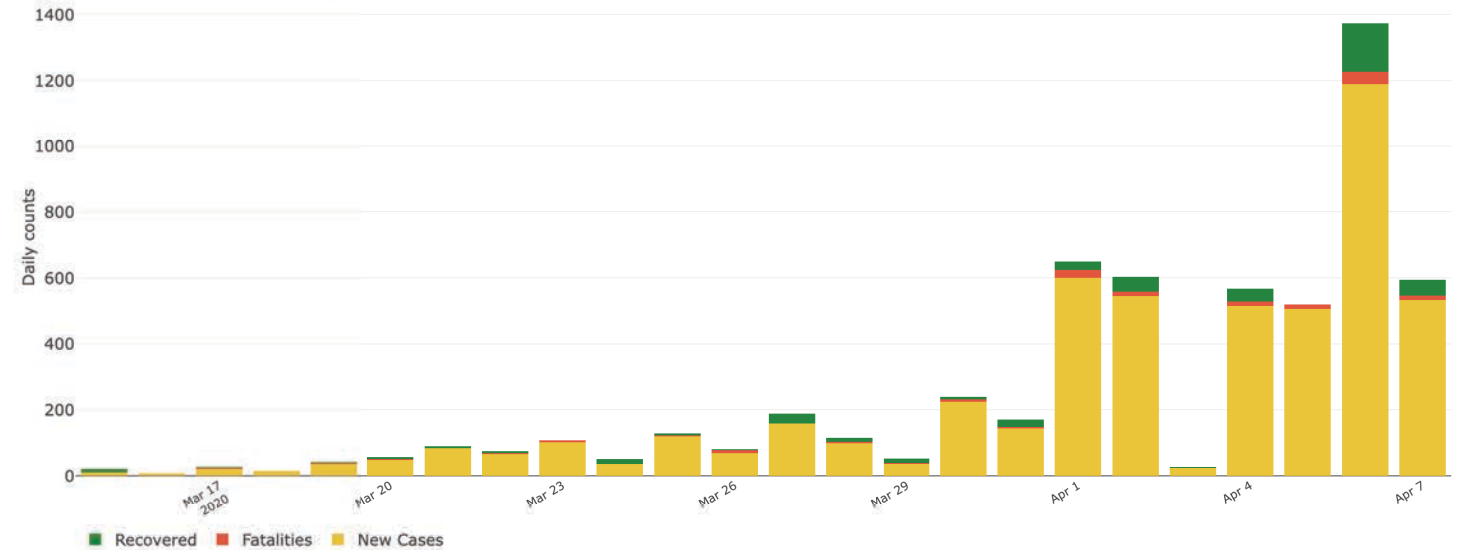
The COV-IND-19 study group is comprised of: Maxwell Salvatore, Alexander Rix, Michael Kleinsasser, Daniel Barker, Lili Wang, Rupam Bhattacharyya, Soumik Purkayastha, Debashree Ray, Shariq Mohammed, Aritra Halder, Debraj Bose, Peter Song, Mousumi Banerjee, Veera Baladandayuthapani, and Parikshit Ghosh.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

(Please wait a few seconds for the figures to load)
Data last updated April 08

Daily number of COVID-19 new cases, fatalities and recovered cases in India since March 1

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.

© COV-IND-19 Study Group. Last updated: Apr 8

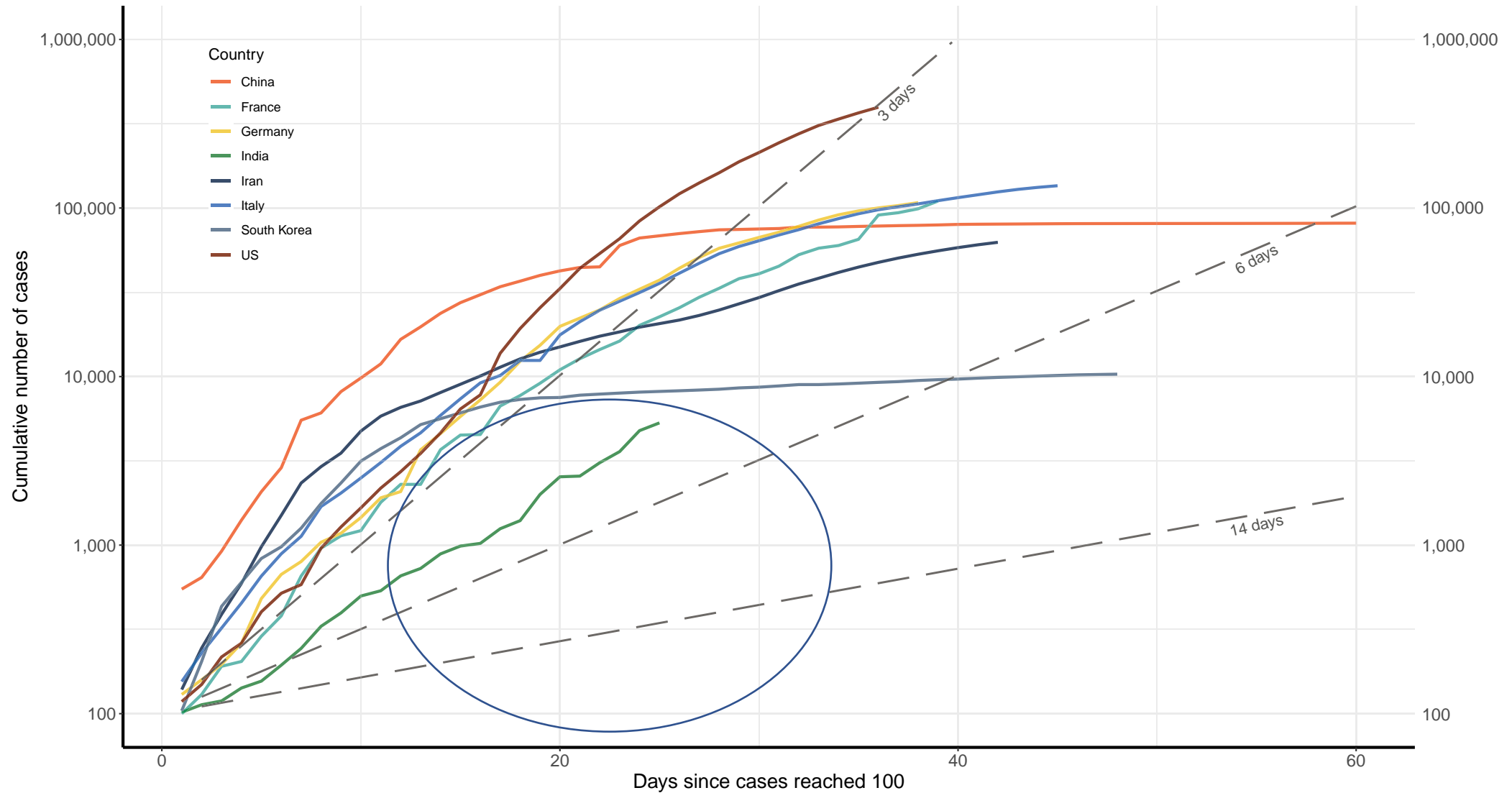


Our contribution and service as data scientists

Takeaway messages

- High uncertainty in predicted numbers (note large upper credible limit)
- Variation in predictions increases as we go further in time
- Outputs change everyday and data trumps models
- Relative comparison of interventions are still meaningful
- Need some form of suppression in place post-lockdown (cautious return)
- A rigorous lens to quantify the pulse and movements of an epidemic but an incomplete description of the costs of interventions and what society is undergoing as a whole

Is India truly different?



Hypotheses

- Limited Testing, Testing Strategy and Criteria
- Reporting of deaths
- Temperature
- [BCG vaccinations](#), use of antimalarials, genetics, immunity
- Younger population

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



30 March 2020

Imperial College COVID-19 Response Team

Estimating the number of infections and the impact of non-pharmaceutical interventions on COVID-19 in 11 European countries

Seth Flaxman*, Swapnil Mishra*, Axel Gandy*, H Juliette T Unwin, Helen Coupland, Thomas A Mellan, Harrison Zhu, Tresnia Berah, Jeffrey W Eaton, Pablo N P Guzman, Nora Schmit, Lucia Cilloni, Kylie E C Ainslie, Marc Baguelin, Isobel Blake, Adhiratha Boonyasiri, Olivia Boyd, Lorenzo Cattarino, Constanze Ciavarella, Laura Cooper, Zulma Cucunubá, Gina Cuomo-Dannenburg, Amy Dighe, Bimandra Djaafara, Ilaria Dorigatti, Sabine van Elsland, Rich FitzJohn, Han Fu, Katy Gaythorpe, Lily Geidelberg, Nicholas Grassly, Will Green, Timothy Hallett, Arran Hamlet, Wes Hinsley, Ben Jeffrey, David Jorgensen, Edward Knock, Daniel Laydon, Gemma Nedjati-Gilani, Pierre Nouvellet, Kris Parag, Igor Siveroni, Hayley Thompson, Robert Verity, Erik Volz, Caroline Walters, Haowei Wang, Yuanrong Wang, Oliver Watson, Peter Winskill, Xiaoyue Xi, Charles Whittaker, Patrick GT Walker, Azra Ghani, Christl A. Donnelly, Steven Riley, Lucy C Okell, Michaela A C Vollmer, Neil M. Ferguson¹ and Samir Bhatt^{*1}

Cumulative total tests versus cases per million

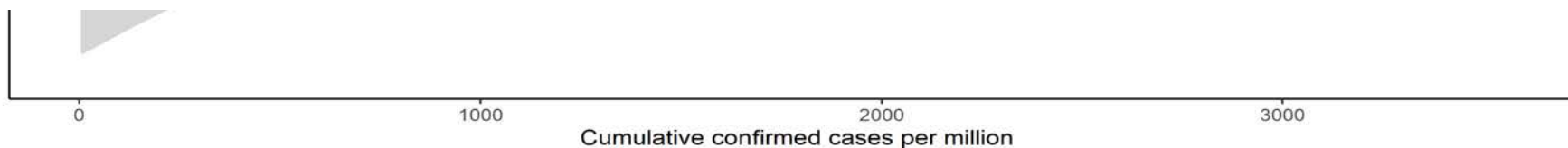


HEALTH • CORONAVIRUS

Why Iceland's approach to coronavirus testing may be better than America's

BY VIVIENNE WALT

March 27, 2020 9:30 AM EDT



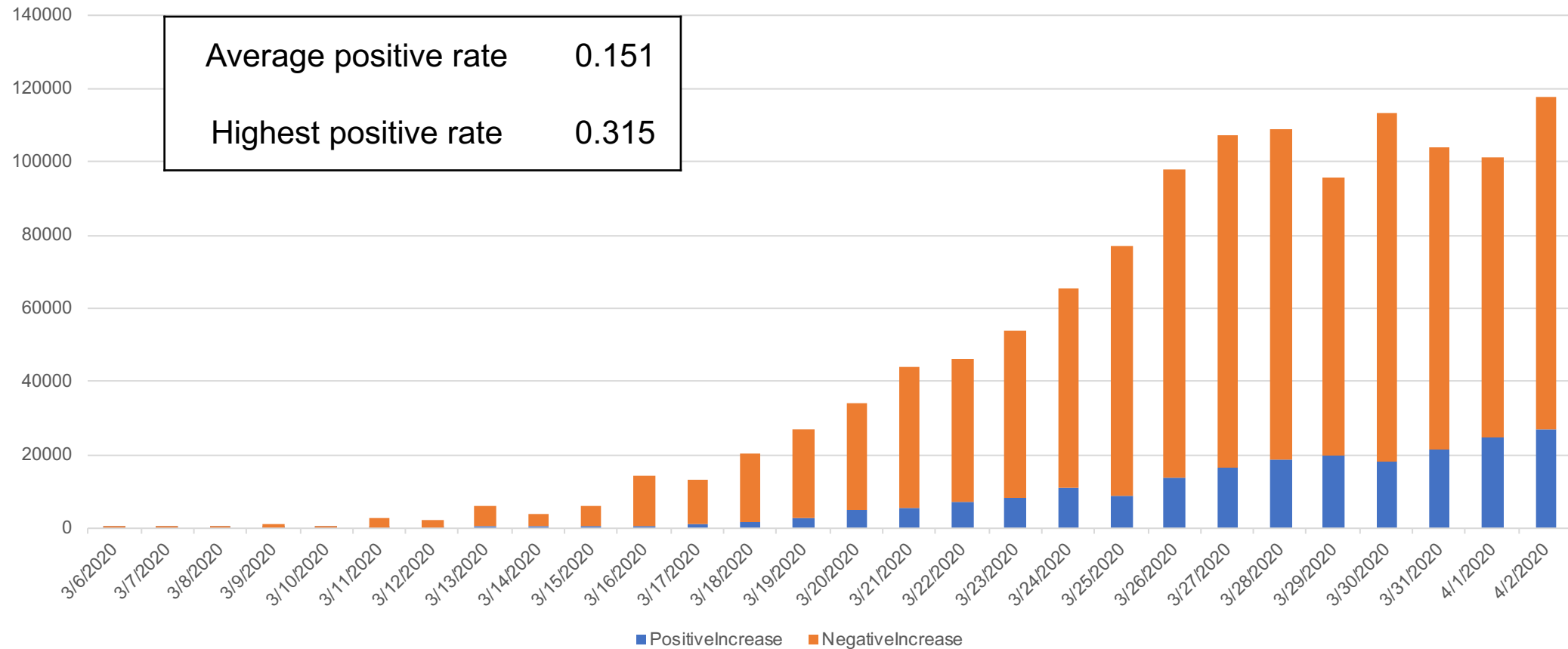
Note:

- Units of tests may not be the same for all countries.
- **Model:** Cumulative total tests per million \sim Cumulative confirmed cases per million
- Adjusted R-squared=0.687

Source: <https://ourworldindata.org/covid-testing>; covid19india.org

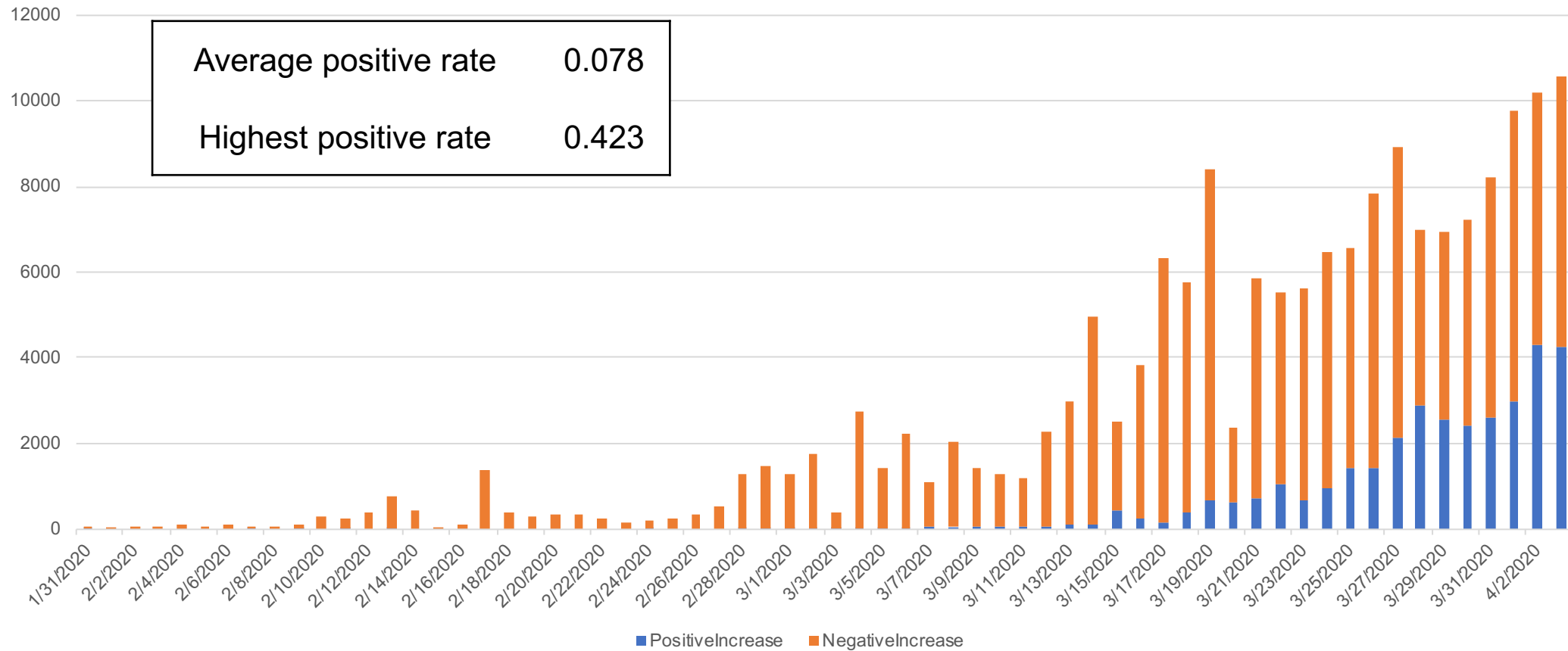
US daily tests versus daily incidence

US

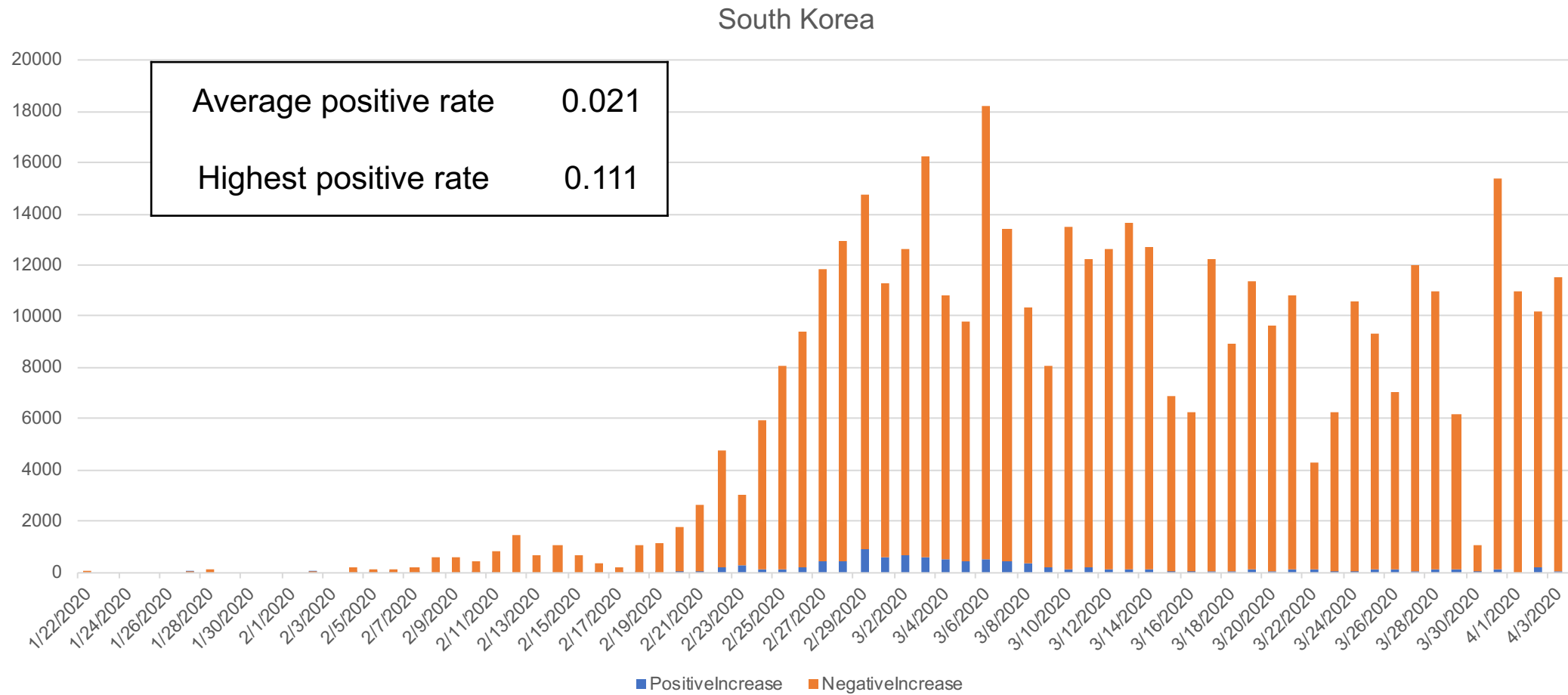


UK daily tests versus daily incidence

UK

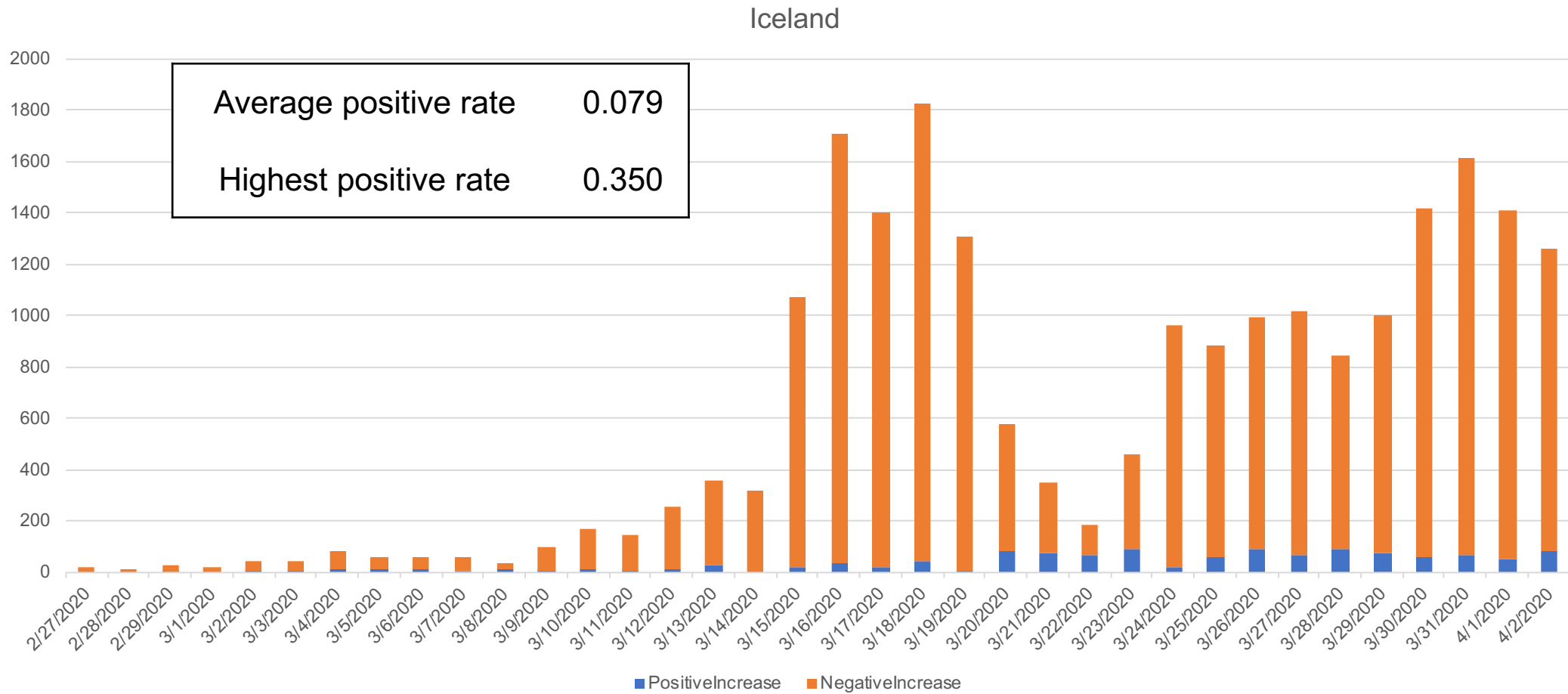


South Korea daily tests versus daily incidence

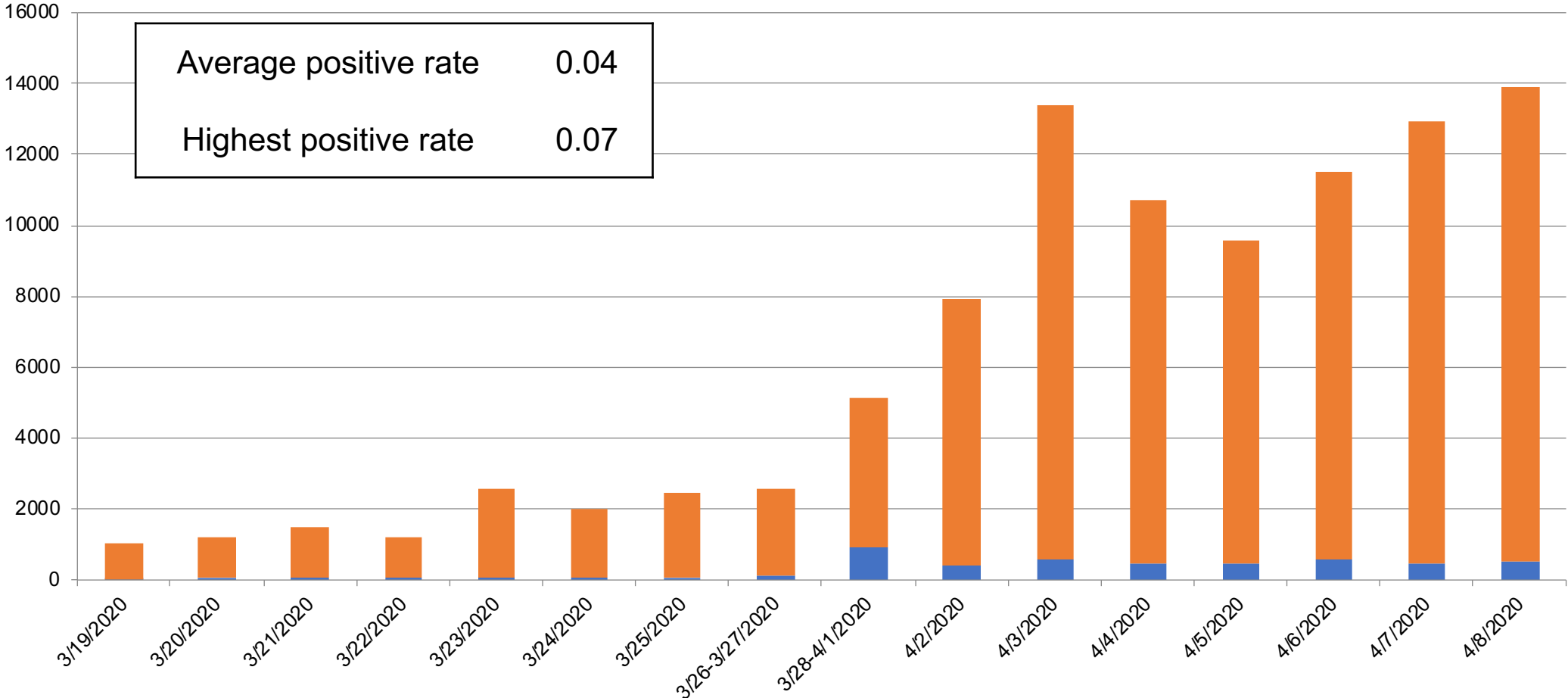


Iceland

daily tests versus daily incidence



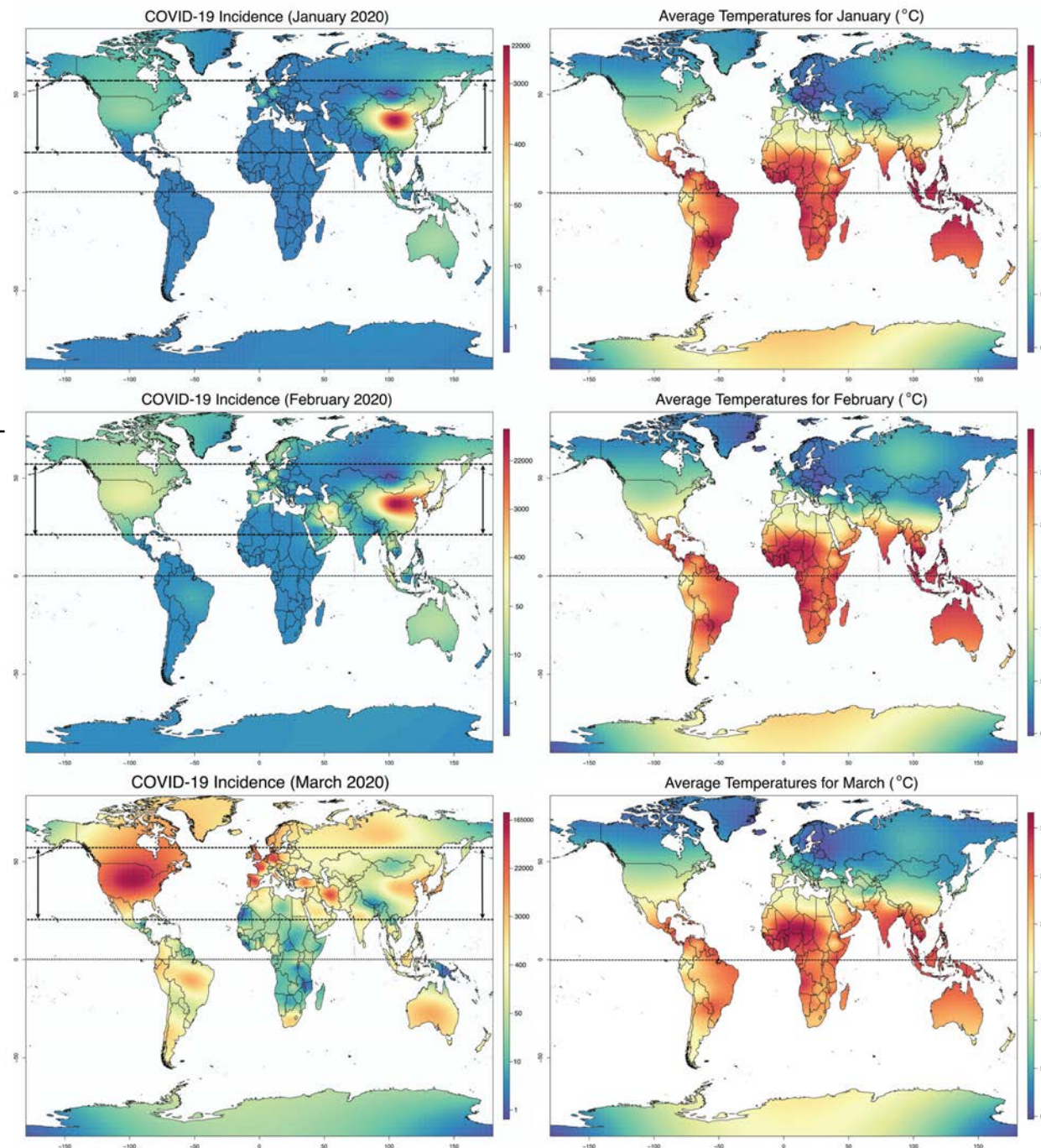
India daily tests versus daily incidence



Source: <https://ourworldindata.org/covid-testing>; covid19india.org

Summer Boon?

Month	Correlation	95% Confidence Interval	Countries with non-zero incidence
January	-0.185	[-0.55, 0.24]	24
February	-0.110	[-0.362, 0.157]	56
March	-0.173	[-0.314, -0.026]	175



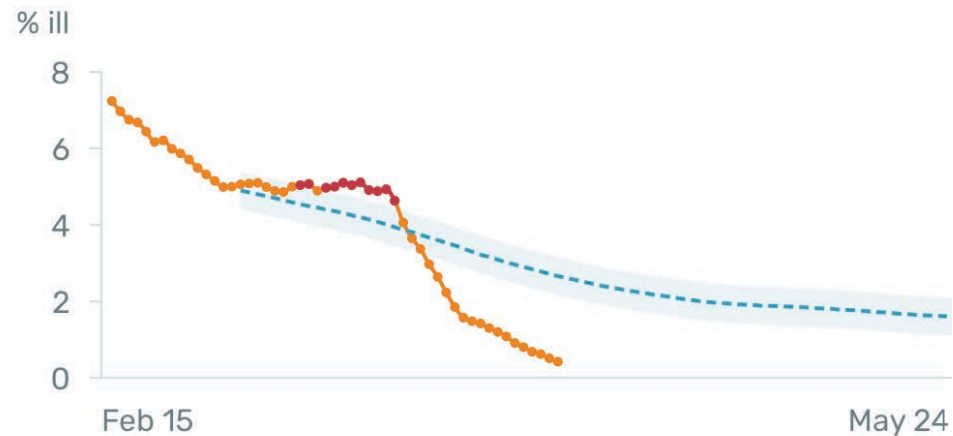
Using data to chase the disease tracks

US Health Weather Map

Powered by 

United States

● Observed ● Atypical ● Expected ● Typical Range

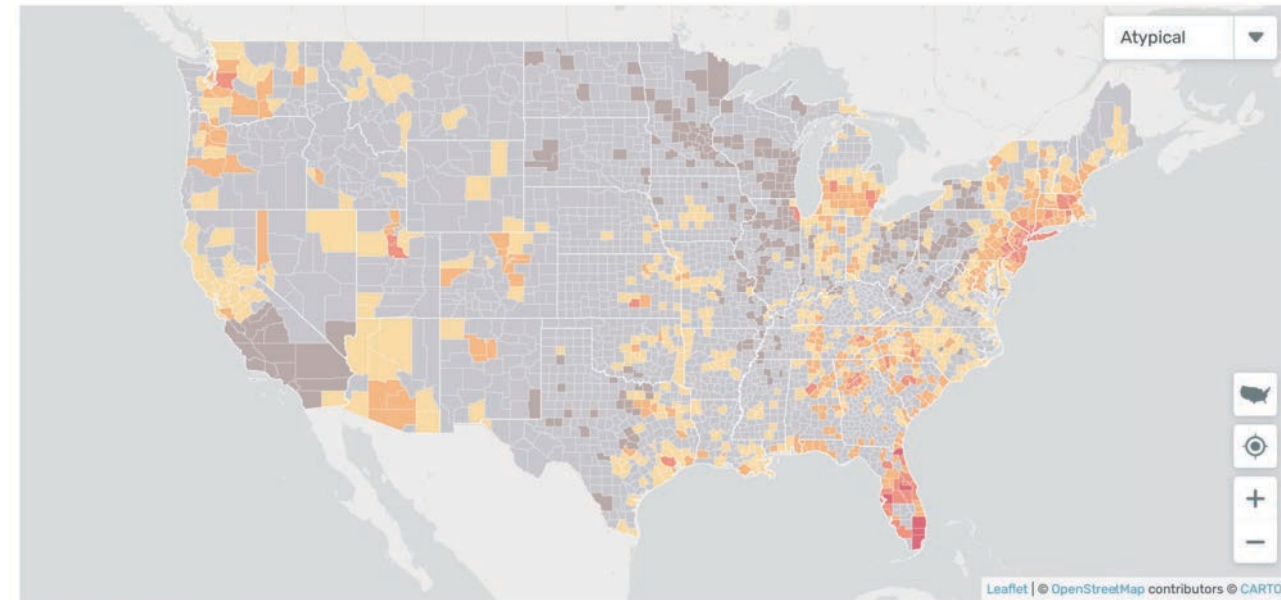


Look up influenza-like illness near you:

Search zip code or county name

Cumulative Atypical Illness ?

N/A None Low Mild Moderate High



Last updated: April 8, 2020

 COVID-19 Community Mobility Reports

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

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

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

Summary (as data scientists)

- Public health and economics are at a competing interest
- 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
- Use data to estimate need, deploy resources, how many beds, PPE, ICU beds, ventilators are needed and where?

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.

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, Stay Home!

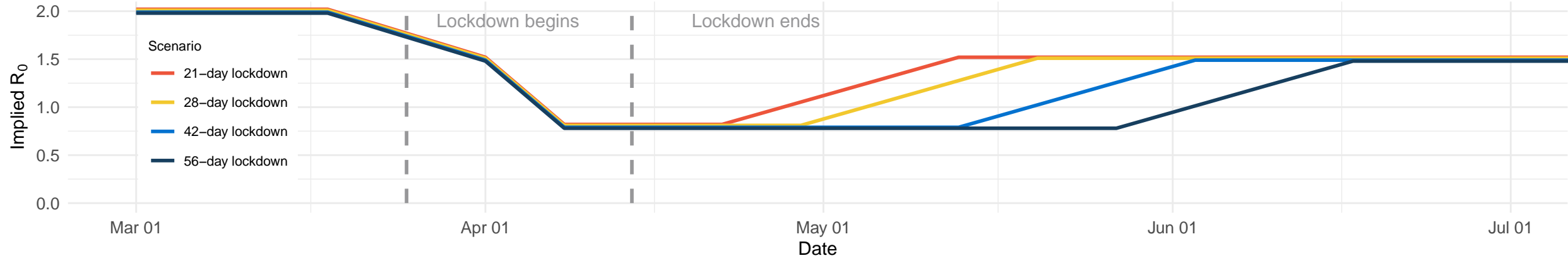


Back up slides: Length of lockdown

R_0 under lockdown length scenarios

R_0 over time by scenario

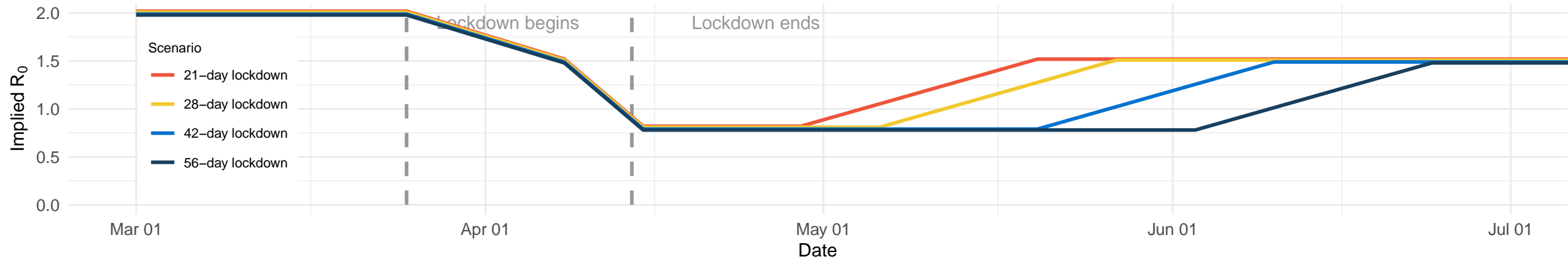
as of 07 April, 2020



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R_0 over time by scenario

as of 07 April, 2020

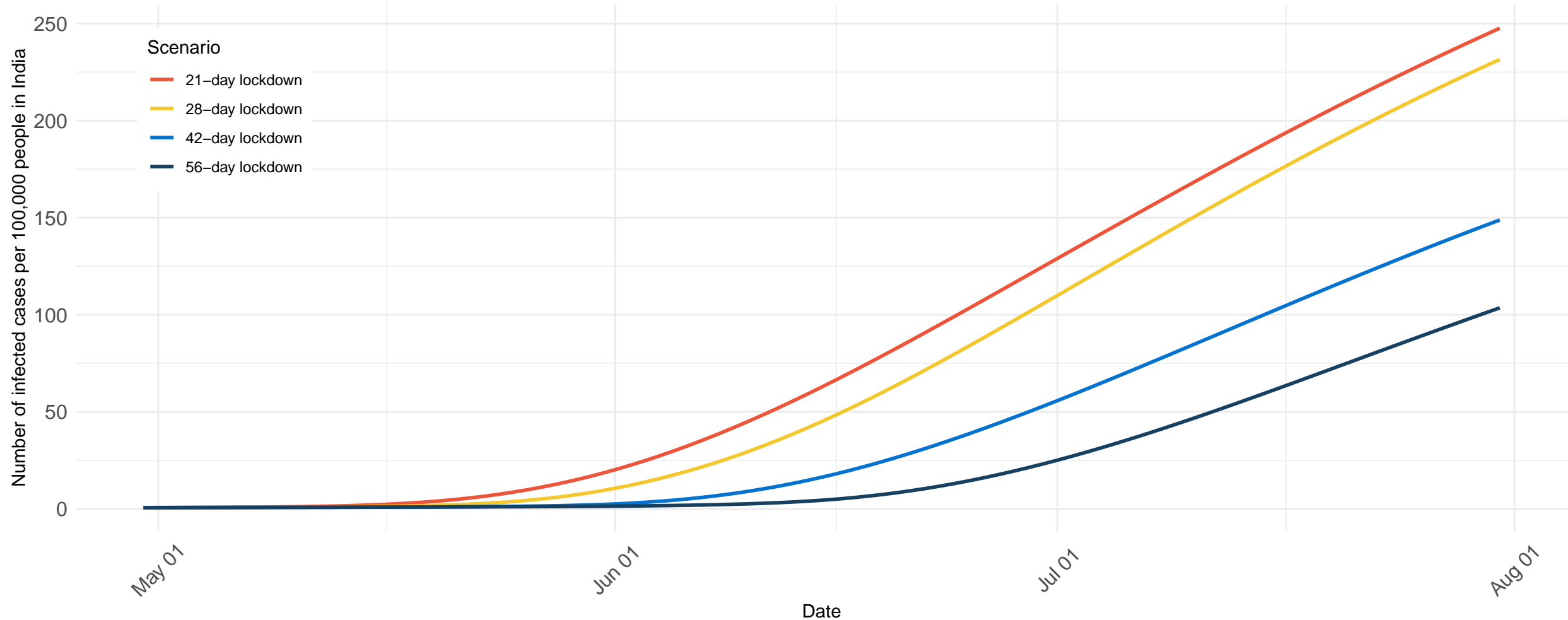


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Lockdown lengths – quick adherence

Predicted number of COVID-19 infections under varying lockdown lengths

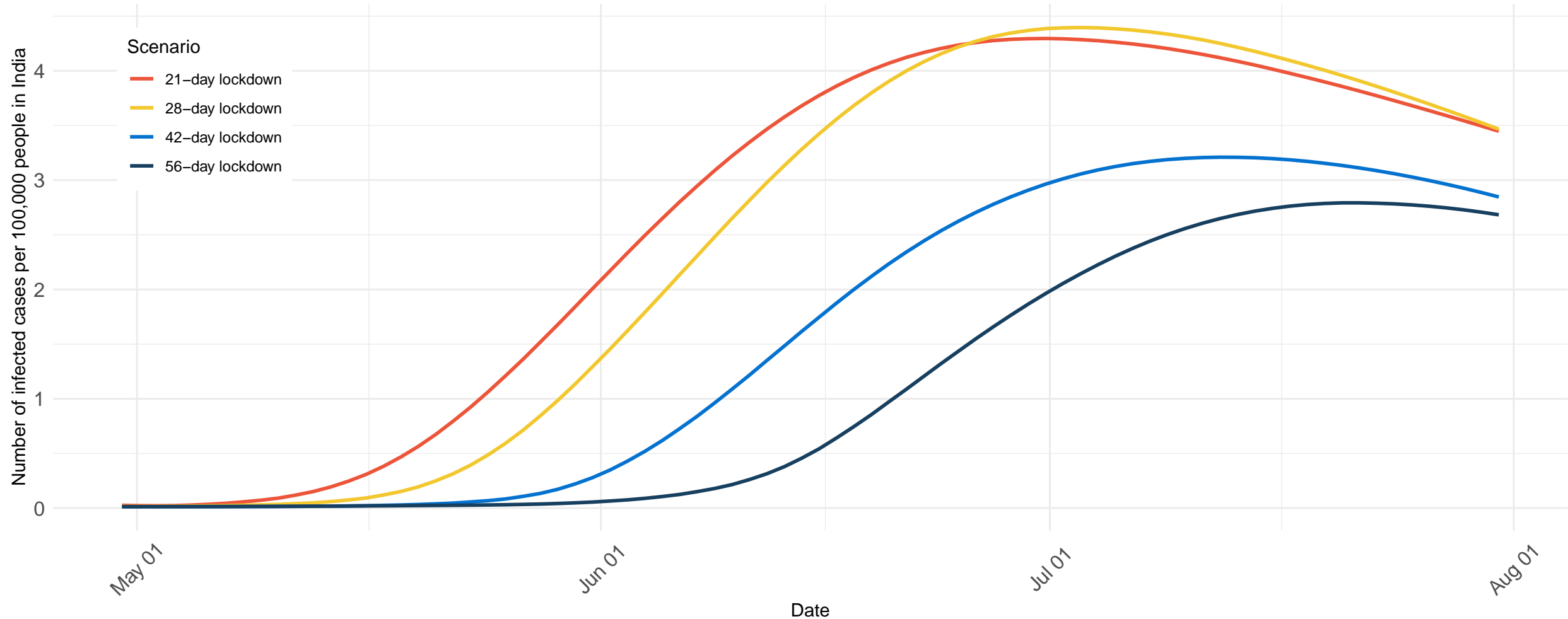
as of 07 April, 2020



Lockdown lengths – quick adherence

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

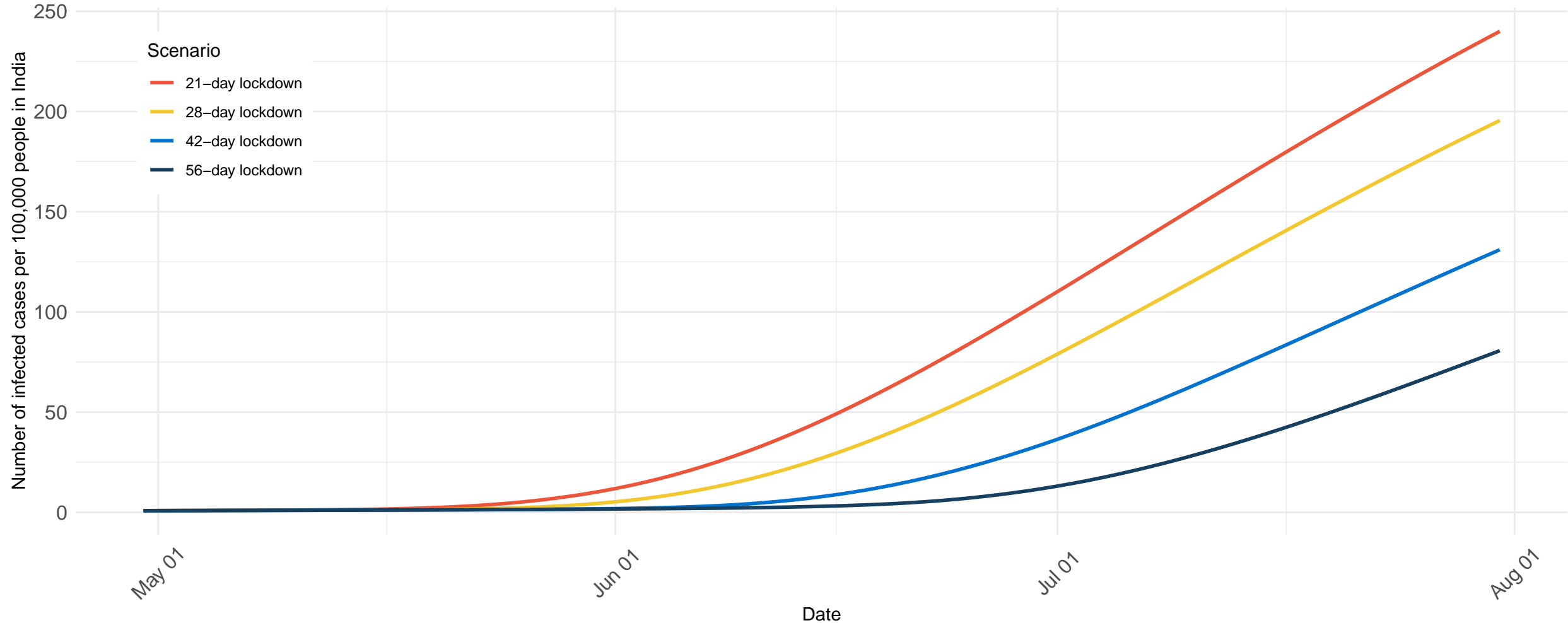
as of 07 April, 2020



Lockdown lengths – slow adherence

Predicted number of COVID-19 infections under varying lockdown lengths

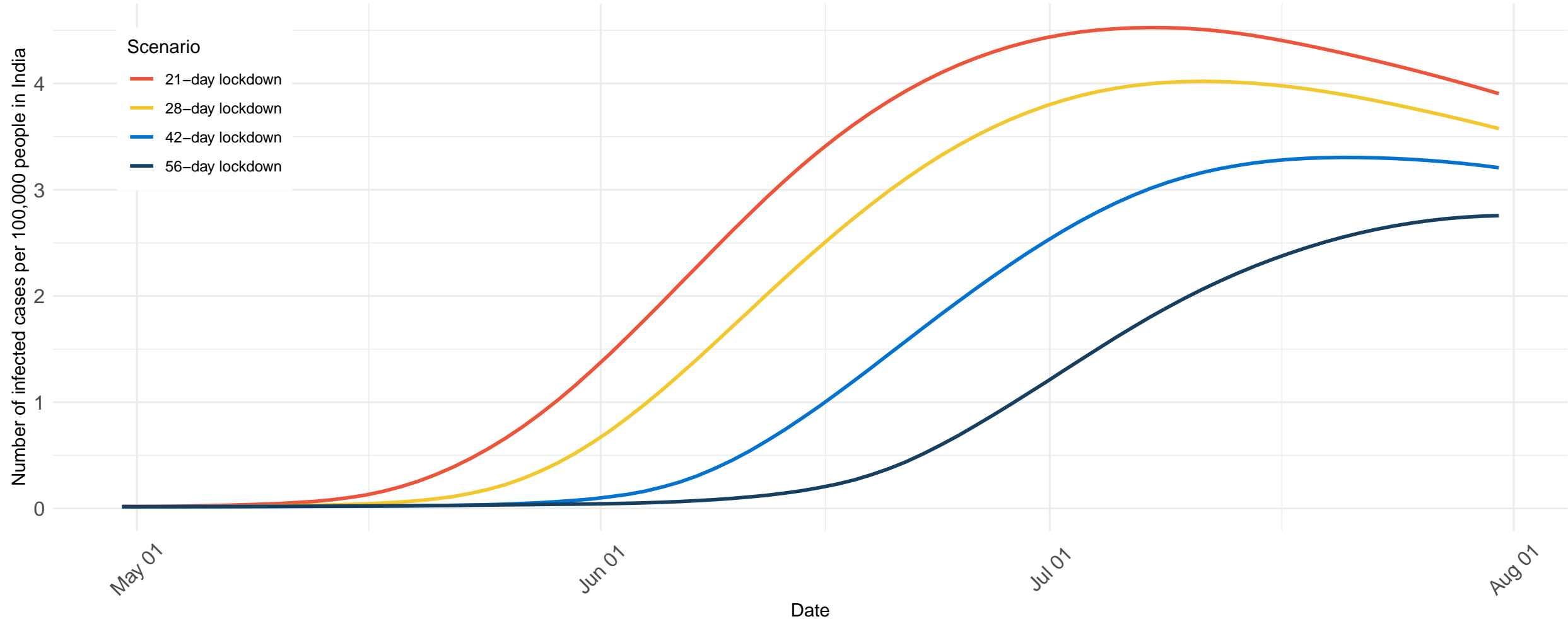
as of 07 April, 2020



Lockdown lengths – slow adherence

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

as of 07 April, 2020



A Conceptual Model

