Supplementary Information:

State-level needs for social distancing and contact tracing to contain COVID-19 in the United States

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Extended Data Figures

Extended Data Figure 1. Correlations across states between $R_{eff}(t)$ and (A) ϑ_{min}, (B) η, (C) Δ, and (D) f_c. *For each state, 500 posterior samples are shown. Substantial state-to-state heterogeneity is evident in all parameters, with η, ϑ_{min}, r_{max}, and f_c contribute over 50% of the variance in $R_{eff}(t)$ under a linear model (estimated from ANOVA table [Table S1] using the sum-of-squares relative to the total sum-of-squares). For ϑ_{min}, interestingly, lower values were associated with greater current values of $R_{eff}(t)$. The other parameters correlate as expected: higher $R_{eff}(t)$ is correlated with lower contribution from hygiene practices (smaller η), more reopening (larger r_{max}), and lower rates of contact tracing (smaller f_c).*

Extended Data Figure 2. Contour maps for each state of the probability that $R_{eff}(t)$ at different levels contact tracing f_c and testing λ. *Contours are labeled as by median and 95% Credible interval, and current median estimates of f_c and λ are shown by the circle.*

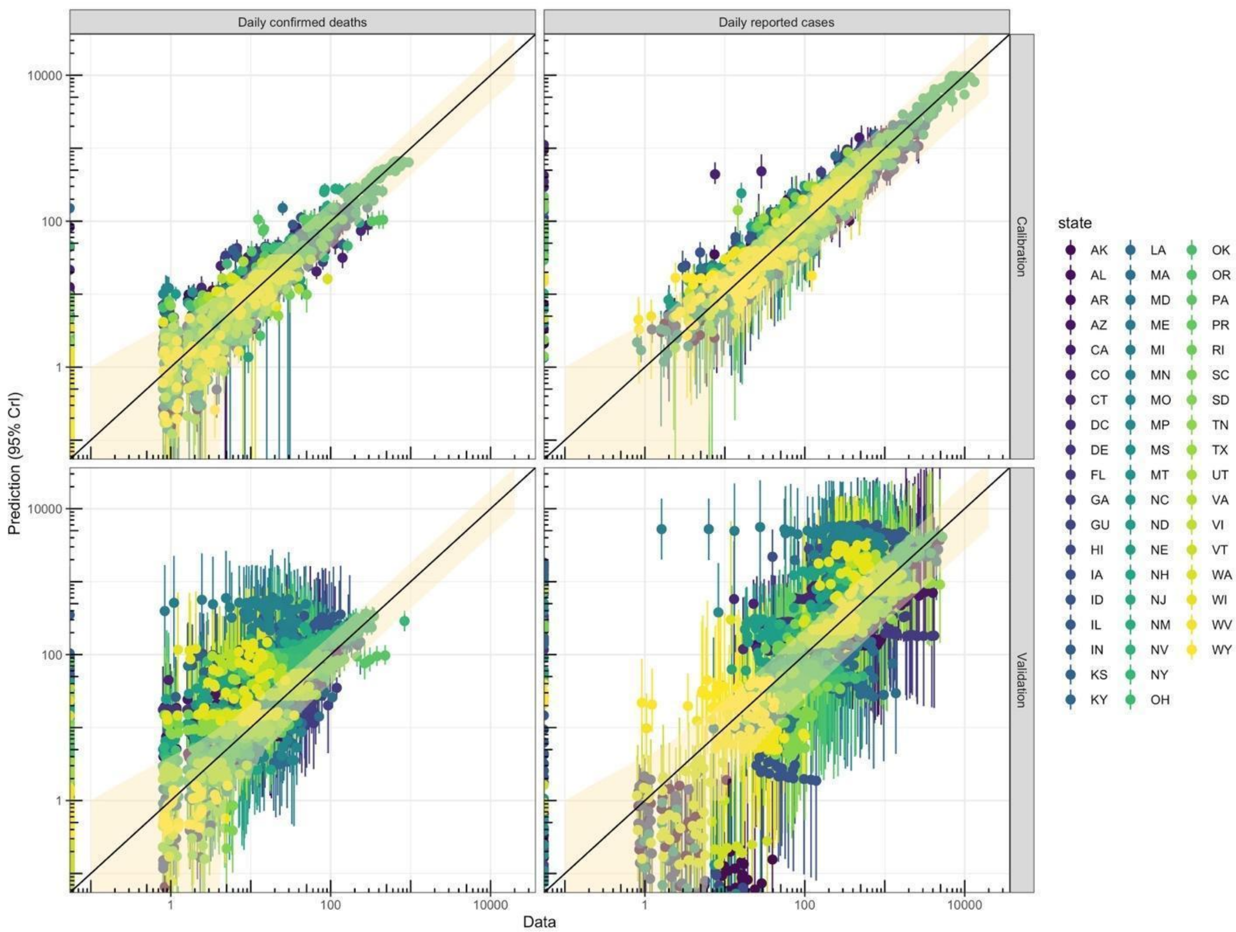
Extended Data Figure 3. Estimated testing and contact tracing rates needed for $R_{eff}(t) < 1$ as of July 22, 2020. *Boxplots (line = median, box = IQR, whiskers = 95% CrI) are filled based on the estimated $R_{eff}(t)$ on July 22, 2020, as shown in the legend. Top panel is changing testing rate alone, the middle panel is changing contact tracing rate alone, and the bottom panel is changing both to the same value. Also shown are the current median estimates of the testing and contact tracing rates.*

Extended Data Figure 4. Estimated testing and contact tracing rates needed for $R(t) < 1$ with complete re-opening (i.e., removal of all social distancing and hygiene mitigation). *Boxplots (line = median, box = IQR, whiskers = 95% CrI) are filled based on the estimated $R_{eff}(t)$ on July 22, 2020, as shown in the legend. Top panel is changing testing rate alone, the middle panel is changing contact tracing rate alone, and the bottom panel is changing both to the same value. Also shown are the current median estimates of the testing and contact tracing rates.*

Supplementary Figures

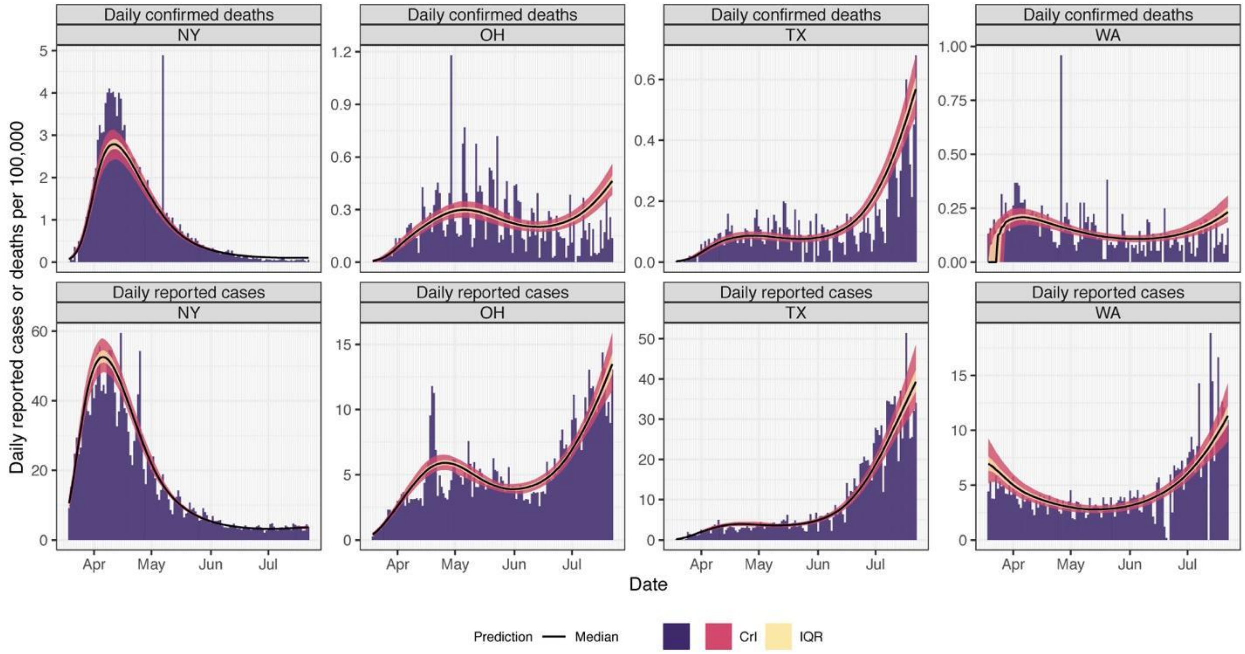
Supplementary Figure 1. *Model fitting of mobility data from Unacast, Google, and OpenTable, each state. Using March 1, 2020 as t=1, the initial decline is modeled as a Weibull function, with scale parameter τ_ϑ shape parameter n_ϑ, and minimum value ϑ_{min}. Then after a shelter-in-place period τ_s, a linear increase begins that lasts for a duration τ_r and plateaus at a value $\vartheta_{min} + r_{max}(1 - \vartheta_{min})$, where r_{max} is the maximum percentage increase relative to the minimum. The same model formulation is used for contact rate. The baseline for each mobility metric is ys. For each state, the first page shows the model fits, and the second page shows the distribution of best fit parameters for each mobility metric. [**Provided as separate file: "Chiu_Supplementary-Fig1.pdf"**]*

Supplementary Figure 2. *Model fitting and validation for each state. We fitted the model to daily reported cases and confirmed deaths until April 30th and validated its projections against data from May 1st to June 20th. On the model projections, the orange solid line is the median, the pink is the interquartile range (IQR), the orange band is the 95% credible interval (CrI), and the purple band includes the 95% CrI and dispersion for the negative binomial likelihood. [**Provided as separate file: "Chiu_Supplementary-Fig2.pdf"**]*

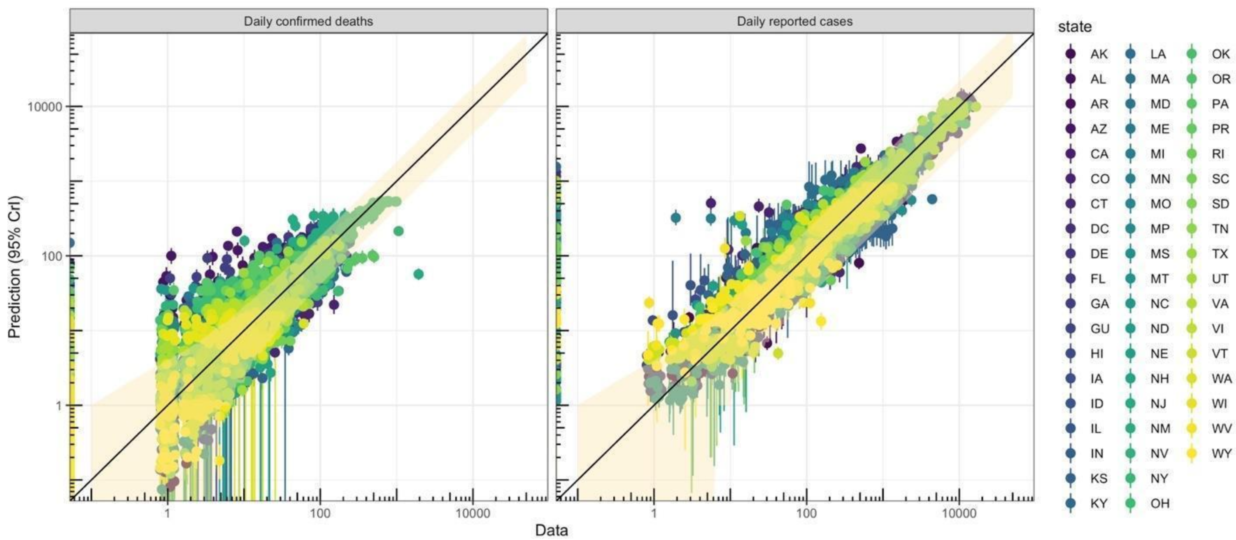


Supplementary Figure 3. *Validation runs: Comparison of data and predictions overall. Each panel shows data versus predictions for daily deaths (left column) or cases (right column), with calibration results shown in the top panels (March 19 through April 30) and validation results in the bottom panels (May 1 through June 20). Each point includes the 95% Credible Interval (CrI) for the prediction. The band centered on the y=x line shows the additional 95% CrI for the negative binomial likelihood, which is used to account for day-to-day variation in reporting.*

Supplementary Figure 4. *Model fitting for each state through July 22nd. On the model projections, the orange solid line is the median, the pink is the interquartile range (IQR), the orange band is the 95% credible interval (CrI), and the purple band includes the 95% CrI including dispersion with a negative binomial.* [***Provided as separate file: : "Chiu_Supplementary-Fig4.pdf"***]



Supplementary Figure 5. *Model calibration through July 22, 2020: time-courses for selected States.*



Supplementary Figure 6. *Model calibration through July 22, 2020: comparisons of data and predictions for all States.*

Supplementary Figure 7. *Comparison of prior and posterior parameter distributions for each state for model calibration through June 20, 2020.* ***[Provided as separate file: : "Chiu_Supplementary-Fig7.pdf"]***

Supplementary Table 1. *ANOVA table for $R_{eff}(t)$ with respect to key parameters*

	Df	Sum Sq	PctSumSq	Mean Sq	F value	Pr(>F)
R_0	1	72.4	6.3%	72.404	3737.133	< 2.2e-16
η	1	57.91	5.0%	57.913	2989.166	< 2.2e-16
θ_{min}	1	100.31	8.7%	100.308	5177.354	< 2.2e-16
r_{max}	1	155.99	13.5%	155.995	8051.61	< 2.2e-16
f_C	1	268.03	23.2%	268.026	13834.053	< 2.2e-16
f_A	1	0.41	0.0%	0.414	21.344	3.86E-06
λ	1	0.91	0.1%	0.907	46.813	7.99E-12
ρ	1	4	0.3%	3.998	206.33	< 2.2e-16
Residuals	25491	493.87	42.8%	0.019		
TOTAL		1153.83				

Supplementary Figure 8. *Predicted time-courses across states of daily reported cases (A, C) and deaths (B, D) under different testing rate (1X and 2X) and contact tracing (1X and 2X) scenarios, given current value of restriction relaxation (current Δ). [**Provided as separate file: : "Chiu_Supplementary-Fig8.pdf"**]*

Supplementary Table 2. *Critical rates (median and 95% CrI) of testing, contract tracing, or both, needed for $R_{eff}(t)<1$.*

State	Testing only	Tracing only	Both testing and tracing
AK	0.29 (0-Inf)	0.48 (0.37-0.64)	0.26 (0.14-0.46)
AL	0.1 (0.04-0.37)	0.34 (0.2-0.53)	0.14 (0.07-0.31)
AR	0.1 (0.03-0.37)	0.33 (0.19-0.52)	0.15 (0.07-0.3)
AZ	0 (0-0.07)	0.07 (0-0.31)	0.03 (-0.03-0.13)
CA	0.07 (0.04-0.17)	0.35 (0.24-0.49)	0.12 (0.07-0.23)
CO	0.11 (0.04-0.47)	0.37 (0.2-0.55)	0.15 (0.07-0.31)
CT	0 (0-0.05)	0.36 (0-0.59)	0.16 (0.01-0.37)
DC	0.09 (0.02-0.27)	0.32 (0.17-0.48)	0.13 (0.06-0.24)
DE	0.09 (0.01-0.24)	0.5 (0.3-0.64)	0.24 (0.12-0.43)
FL	0.08 (0.03-0.25)	0.33 (0.16-0.46)	0.11 (0.05-0.23)
GA	0.11 (0.05-0.32)	0.36 (0.23-0.53)	0.14 (0.07-0.27)
HI	0.33 (0-Inf)	0.43 (0.35-0.54)	0.22 (0.13-0.35)
IA	0.08 (0.03-0.21)	0.45 (0.26-0.63)	0.2 (0.1-0.4)
ID	0.19 (0-Inf)	0.49 (0.36-0.66)	0.23 (0.11-0.43)
IL	0.16 (0.07-0.47)	0.47 (0.32-0.61)	0.2 (0.12-0.35)
IN	0.09 (0.04-0.27)	0.36 (0.23-0.56)	0.13 (0.07-0.28)
KS	0.09 (0.02-0.31)	0.33 (0.16-0.54)	0.15 (0.07-0.33)
KY	0.09 (0.03-0.35)	0.35 (0.19-0.57)	0.15 (0.07-0.34)
LA	0.11 (0.04-0.37)	0.35 (0.23-0.51)	0.14 (0.07-0.27)
MA	0.1 (0.01-0.3)	0.3 (0.12-0.46)	0.13 (0.05-0.24)
MD	0.16 (0.08-0.6)	0.47 (0.35-0.57)	0.18 (0.11-0.32)
ME	0 (0-0.03)	0.44 (0.13-0.7)	0.16 (0.03-0.49)
MI	0.11 (0.06-0.42)	0.46 (0.33-0.58)	0.15 (0.09-0.27)
MN	0.1 (0.01-0.36)	0.53 (0.37-0.67)	0.26 (0.14-0.45)
MO	0.14 (0.06-0.65)	0.41 (0.29-0.58)	0.17 (0.09-0.34)
MS	0.1 (0.03-0.34)	0.33 (0.2-0.53)	0.13 (0.06-0.26)
MT	0.35 (0-Inf)	0.52 (0.4-0.65)	0.29 (0.16-0.5)
NC	0.06 (0.01-0.17)	0.35 (0.16-0.53)	0.14 (0.05-0.3)
ND	0.21 (0.07-Inf)	0.46 (0.32-0.61)	0.2 (0.11-0.41)
NE	0.05 (0-0.12)	0.31 (0.12-0.53)	0.14 (0.07-0.32)
NH	0 (0-0.04)	0.16 (0-0.51)	0.06 (0-0.27)
NJ	0.04 (0-0.11)	0.22 (0-0.48)	0.1 (0.04-0.2)
NM	0.1 (0.04-0.39)	0.39 (0.24-0.55)	0.16 (0.07-0.34)
NV	0.08 (0.04-0.21)	0.38 (0.23-0.51)	0.12 (0.06-0.24)
NY	0.02 (0-0.06)	0.42 (0.23-0.58)	0.13 (0.07-0.26)
OH	0.11 (0.06-0.32)	0.41 (0.29-0.59)	0.16 (0.08-0.34)
OK	0.1 (0.05-0.26)	0.43 (0.28-0.57)	0.16 (0.08-0.33)
OR	0.13 (0.06-0.46)	0.41 (0.28-0.54)	0.16 (0.09-0.32)
PA	0.13 (0.04-0.5)	0.42 (0.26-0.58)	0.18 (0.09-0.35)
RI	0.02 (0-0.12)	0.31 (0.02-0.57)	0.12 (0.03-0.34)
SC	0.11 (0.04-0.44)	0.35 (0.22-0.51)	0.14 (0.07-0.29)
SD	0.05 (0.01-0.17)	0.26 (0.06-0.54)	0.12 (0.04-0.33)
TN	0.12 (0.05-0.47)	0.36 (0.23-0.56)	0.15 (0.07-0.32)
TX	0.08 (0.04-0.19)	0.36 (0.21-0.53)	0.13 (0.07-0.25)
UT	0.09 (0.03-0.35)	0.32 (0.19-0.48)	0.14 (0.07-0.31)
VA	0.11 (0.03-0.36)	0.38 (0.21-0.54)	0.17 (0.09-0.33)
VT	0.08 (0.02-0.22)	0.27 (0.14-0.46)	0.12 (0.06-0.26)
WA	0 (0-Inf)	0.42 (0.31-0.55)	0.34 (0.13-0.47)
WI	0.09 (0.03-0.61)	0.39 (0.21-0.71)	0.15 (0.07-0.36)
WV	0.18 (0.07-0.98)	0.46 (0.33-0.65)	0.21 (0.11-0.42)
WY	0.15 (0-Inf)	0.44 (0.27-0.62)	0.2 (0.08-0.42)

Note: If the required testing rate is > 1 per day, then a value of "Inf" is used, showing that level of testing is unachievable.

Supplementary Table 3. *Critical rates (median and 95% CrI) of testing, contract tracing, or both, needed for R(t)<1 with complete re-opening (i.e., removal of all social distancing and hygiene mitigation).*

state	Testing only	Tracing only	Both testing and tracing
AK	0.33 (0-Inf)	0.52 (0.41-0.66)	0.29 (0.16-0.48)
AL	0.2 (0-Inf)	0.47 (0.34-0.63)	0.21 (0.12-0.41)
AR	0.19 (0-Inf)	0.44 (0.3-0.6)	0.21 (0.11-0.43)
AZ	0.33 (0-Inf)	0.54 (0.44-0.63)	0.29 (0.16-0.44)
CA	0.16 (0.08-0.69)	0.47 (0.37-0.59)	0.18 (0.11-0.34)
CO	0.16 (0.06-Inf)	0.43 (0.26-0.59)	0.18 (0.09-0.36)
CT	0.01 (0-0.18)	0.45 (0.12-0.63)	0.21 (0.07-0.43)
DC	0.2 (0.08-Inf)	0.45 (0.3-0.57)	0.2 (0.11-0.35)
DE	0.18 (0.06-Inf)	0.6 (0.43-0.71)	0.32 (0.17-0.53)
FL	0.28 (0-Inf)	0.55 (0.46-0.64)	0.25 (0.15-0.43)
GA	0.24 (0-Inf)	0.52 (0.39-0.65)	0.23 (0.13-0.43)
HI	0.34 (0-Inf)	0.44 (0.35-0.55)	0.23 (0.13-0.36)
IA	0.15 (0.06-0.88)	0.53 (0.35-0.67)	0.27 (0.14-0.48)
ID	0.33 (0-Inf)	0.63 (0.49-0.75)	0.34 (0.19-0.56)
IL	0.23 (0.1-Inf)	0.55 (0.4-0.66)	0.25 (0.16-0.43)
IN	0.16 (0.07-0.99)	0.46 (0.32-0.61)	0.19 (0.1-0.35)
KS	0.13 (0.04-0.61)	0.39 (0.2-0.59)	0.18 (0.09-0.38)
KY	0.12 (0.04-0.6)	0.41 (0.24-0.61)	0.18 (0.09-0.38)
LA	0.24 (0-Inf)	0.51 (0.37-0.65)	0.23 (0.13-0.42)
MA	0.17 (0.04-0.85)	0.4 (0.22-0.55)	0.18 (0.1-0.33)
MD	0.29 (0-Inf)	0.58 (0.49-0.66)	0.27 (0.17-0.45)
ME	0 (0-0.04)	0.46 (0.19-0.71)	0.18 (0.04-0.5)
MI	0.22 (0.09-Inf)	0.56 (0.44-0.66)	0.22 (0.14-0.4)
MN	0.15 (0.05-0.97)	0.57 (0.42-0.7)	0.3 (0.16-0.5)
MO	0.2 (0.06-Inf)	0.47 (0.34-0.62)	0.21 (0.11-0.41)
MS	0.21 (0-Inf)	0.48 (0.31-0.64)	0.21 (0.11-0.41)
MT	0.38 (0-Inf)	0.56 (0.46-0.68)	0.34 (0.19-0.52)
NC	0.14 (0.06-0.54)	0.46 (0.3-0.61)	0.21 (0.1-0.4)
ND	0.25 (0-Inf)	0.52 (0.36-0.66)	0.24 (0.13-0.48)
NE	0.09 (0.03-0.24)	0.4 (0.17-0.6)	0.19 (0.09-0.42)
NH	0 (0-0.05)	0.21 (0-0.53)	0.07 (0.01-0.29)
NJ	0.07 (0.01-0.17)	0.3 (0.1-0.53)	0.12 (0.06-0.25)
NM	0.17 (0.07-Inf)	0.47 (0.32-0.61)	0.21 (0.1-0.42)
NV	0.24 (0-Inf)	0.57 (0.46-0.66)	0.24 (0.13-0.43)
NY	0.14 (0.08-0.51)	0.6 (0.5-0.68)	0.25 (0.18-0.42)
OH	0.17 (0.08-Inf)	0.49 (0.36-0.64)	0.21 (0.12-0.43)
OK	0.22 (0.09-Inf)	0.54 (0.42-0.65)	0.24 (0.13-0.44)
OR	0.18 (0.08-Inf)	0.46 (0.33-0.6)	0.19 (0.11-0.37)
PA	0.16 (0.06-Inf)	0.47 (0.3-0.62)	0.21 (0.11-0.4)
RI	0.07 (0-0.42)	0.43 (0.15-0.63)	0.19 (0.08-0.42)
SC	0.23 (0-Inf)	0.5 (0.38-0.64)	0.23 (0.12-0.44)
SD	0.08 (0.03-0.31)	0.34 (0.12-0.6)	0.15 (0.06-0.39)
TN	0.22 (0-Inf)	0.48 (0.34-0.64)	0.22 (0.12-0.43)
TX	0.23 (0-Inf)	0.53 (0.42-0.63)	0.23 (0.14-0.4)
UT	0.26 (0-Inf)	0.47 (0.33-0.6)	0.25 (0.12-0.42)
VA	0.16 (0.06-0.92)	0.44 (0.27-0.59)	0.21 (0.11-0.39)
VT	0.09 (0.03-0.25)	0.3 (0.16-0.49)	0.13 (0.07-0.28)
WA	0 (0-Inf)	0.45 (0.34-0.59)	0.37 (0.16-0.51)
WI	0.14 (0-Inf)	0.47 (0.28-0.74)	0.2 (0.09-0.45)
WV	0.22 (0-Inf)	0.49 (0.35-0.67)	0.23 (0.12-0.46)
WY	0.18 (0-Inf)	0.49 (0.3-0.66)	0.23 (0.09-0.49)

Note: If the required testing rate is > 1 per day, then a value of “Inf” is used, showing that level of testing is unachievable.

Supplementary Figure 9. *Scatter plots shown the parameter fits to Unacast, Google, and OpenTable mobility data as compared to the posterior distributions from the SEIR model calibration. For each of the parameters ϑ_{min} [ThetaMin], τ_{ϑ} [TauTheta], n_{ϑ} [PwrTheta], τ_s [TauS], τ_r [TauR], and r_{max} [rMax], each panel represents the correlation between the mobility data-base parameter fits and the posterior distributions, with each point representing a different state, with the error bars representing the posterior 95% CrI. Also shown are the linear regression line (including equation and r^2), and the y=x line.* ***[Provided as separate file: : "Chiu_Supplementary-Fig9.pdf"]***