Capping Mobility to Control COVID-19: A Collision-based Infectious Disease Transmission Model

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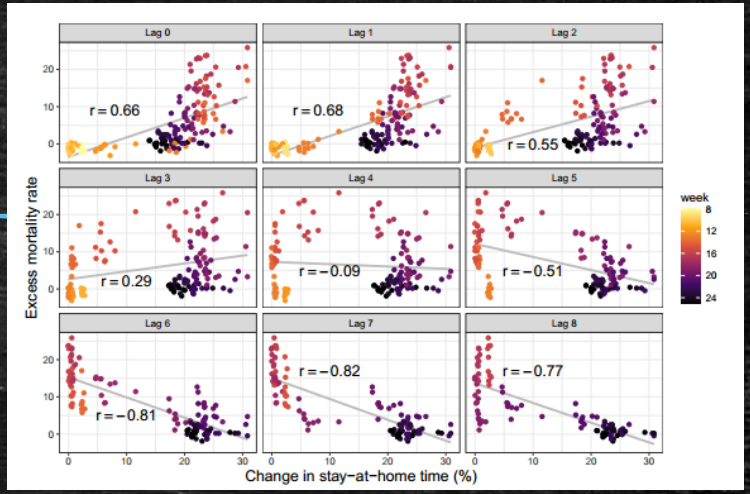
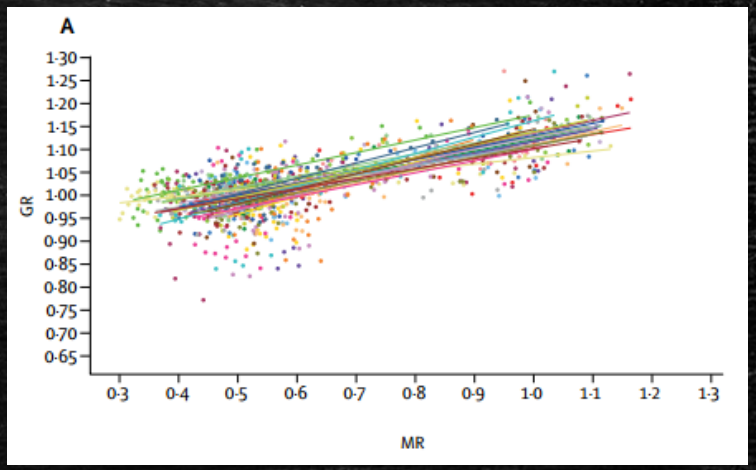
https://www.medrxiv.org/content/10.1101/2020.07.25.20162016v1

Do we have enough COVID-19 models already?

- Models are too complex and the danger of overfitting;
- Too many parameters, sensitive to policies/mandates, localities, demographics;
- No analytical solution, difficult to validate the model;
- Mobility information not explicitly considered in the classical SIR model;
- Lack of simple message to governments to impose lockdown or regulate reopening.



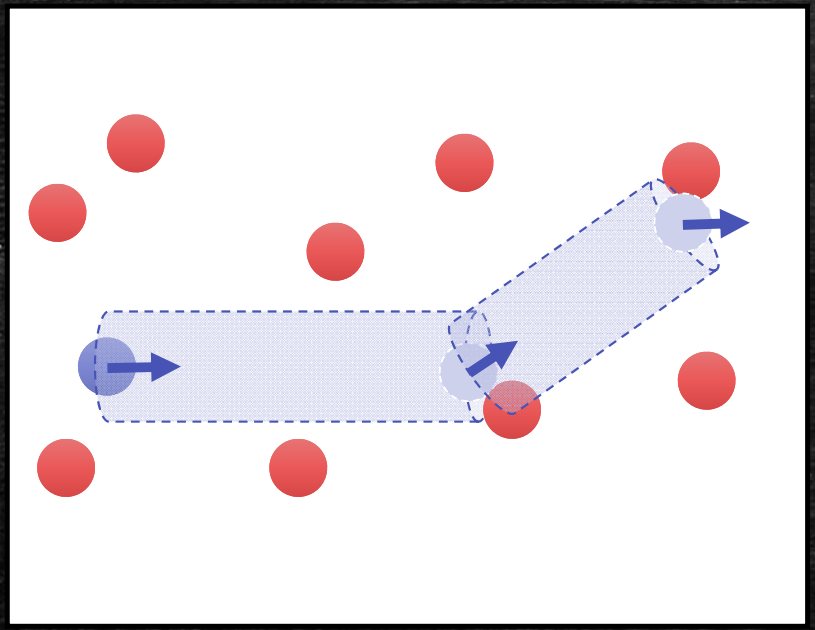
Basellini, Alburez-Gutierrez, et, al, 2020

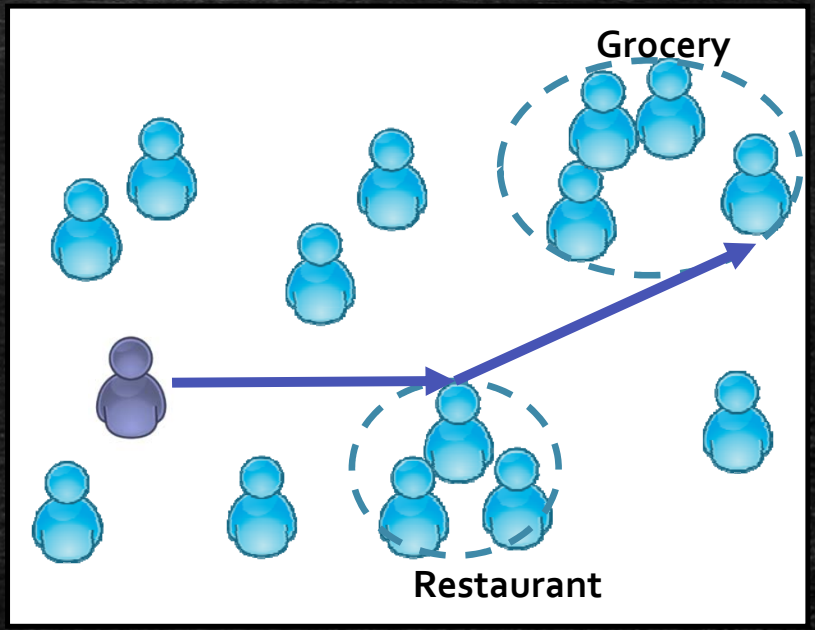


Badr, Du, et, al, Lancet, 2020

Theory of Collision

Anderson McKendrick: "The occurrence of a new infection depends on a collision between an infected and an infected animal."





- The number of ***reactions*** increases with the average mobility.
- The number of ***infections*** increases with the average mobility.

Simplified SIR Model

$$\frac{dI}{dt} = \beta \cdot (N \cdot m) \cdot \frac{I}{N} - \gamma \cdot I$$

$$\frac{dI}{dt} = I \cdot \beta \cdot (m - \frac{\gamma}{\beta})$$

$$I(t) = I(t_0) e^{\beta \cdot M(t) - \gamma \cdot t}$$

$$M(t) = \int_{t_0}^{t} m(t) \cdot dt$$

I: infectious population
β: Infection rate
N: population
m: current mobility
γ: recovery rate

- Omitting the immunization of recovered, no birth/death.
- The cumulative mobility plays the role of time.

Validation #1

$$\frac{1}{t}\ln\frac{I(t)}{I(t_0)} = \beta \cdot \frac{M(t)}{t} - \gamma$$

Use fatality to infer infected

$$\frac{I(t)}{I(t_0)} = \frac{f(t+t_d)}{f(t_0+t_d)}$$

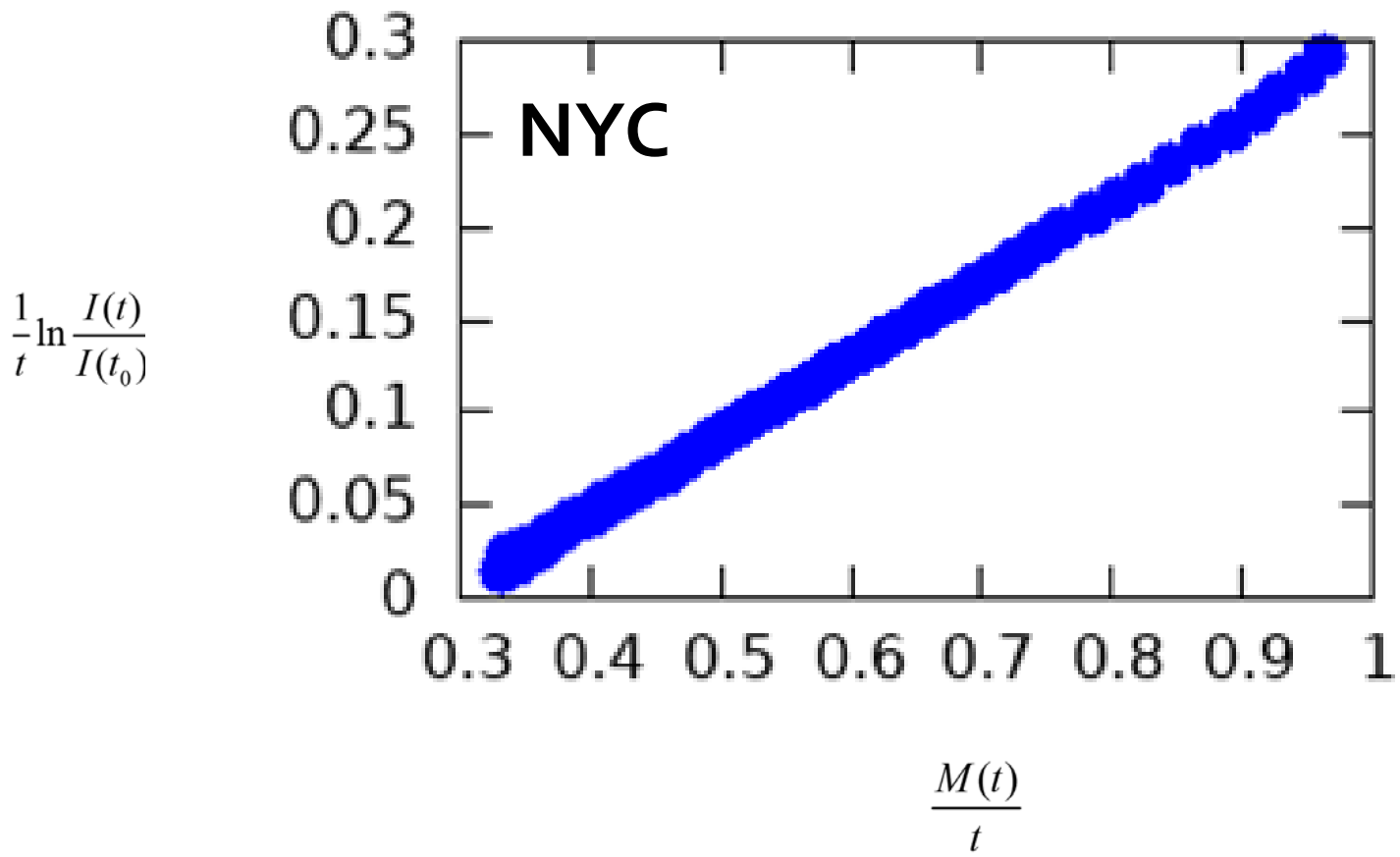
t_d: Time delay
(35 days, or 20 days for NYC)

Use google mobility

- **Retail_and_recreation**
- Grocery_and_pharmacy
- Parks
- Transit station
- Workplace
- Residential

Validation #1

$$\frac{1}{t}\ln\frac{I(t)}{I(t_0)} = \beta \cdot \frac{M(t)}{t} - \gamma$$

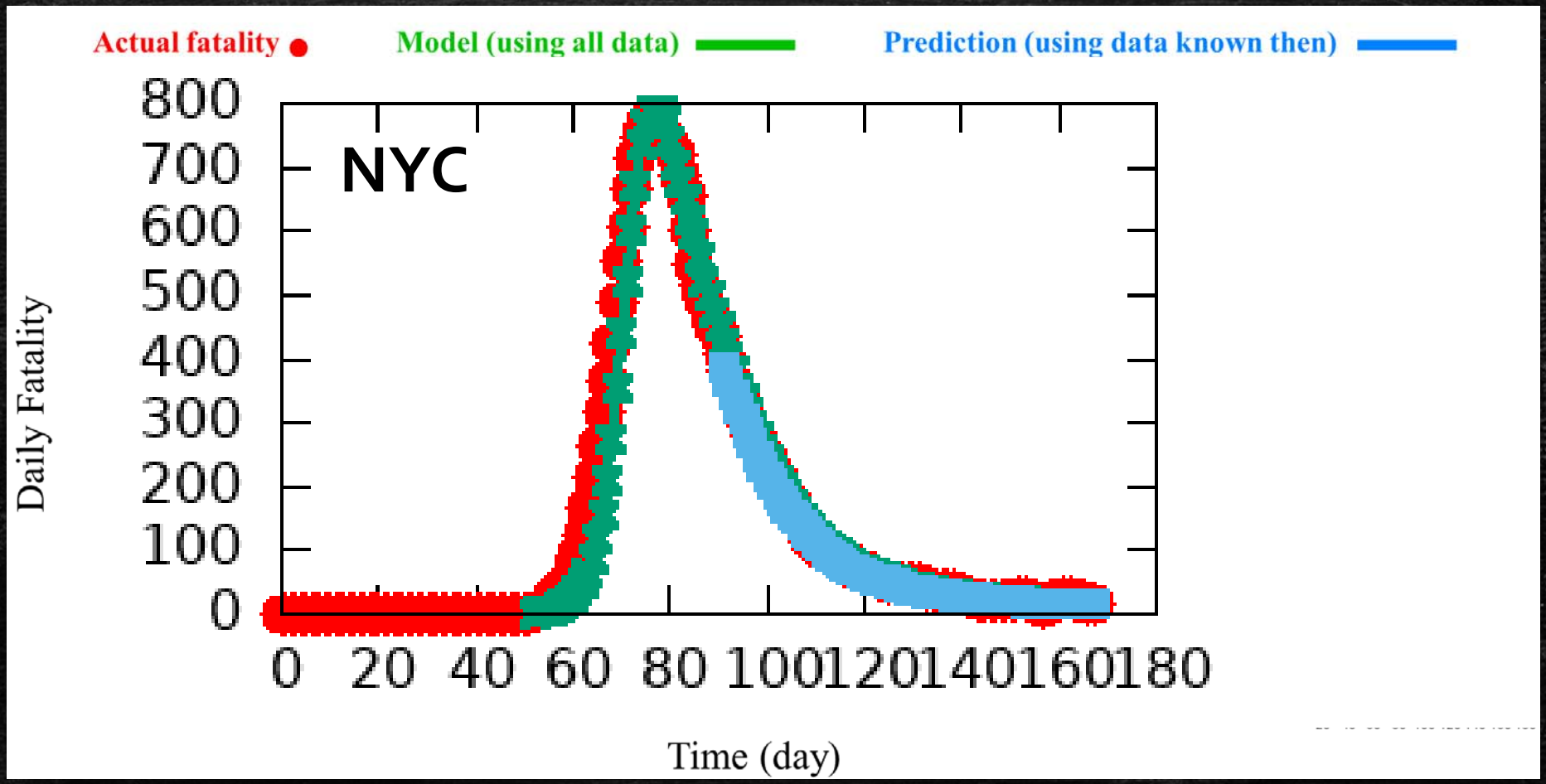


Infection rate and recovery rate

State	County	Population Density ($1/km^2$)	Reference Date t_0	t_d (day)	β (1/day)	γ (1/day)	R^2	m_c
California	Los Angeles	2910	3/22/2020	35	0.26	0.14	0.98	55%
Connecticut	Fairfield	744	3/23/2020	35	0.37	0.26	0.94	69%
Connecticut	Hartford	2713	3/30/2020	35	0.40	0.27	0.95	67%
Florida	Miami-Dade	400	3/31/2020	35	0.13	0.07	0.87	55%
Illinois	Cook	2195	3/21/2020	35	0.31	0.18	0.96	60%
Massachusetts	Essex	582.6	3/29/2020	35	0.27	0.17	0.90	65%
Massachusetts	Middlesex	709.6	3/29/2020	35	0.29	0.17	0.94	58%
Michigan	Oakland	535	3/23/2020	35	0.24	0.15	0.96	63%
Michigan	Wayne	1148	3/22/2020	35	0.33	0.23	0.96	69%
New Jersey	Bergen	1499.8	3/27/2020	35	0.21	0.12	0.90	54%
New Jersey	Essex	2398	3/27/2020	35	0.28	0.16	0.93	58%
New Jersey	Hudson	5566	3/30/2020	35	0.16	0.10	0.61	62%
New Jersey	Middlesex	1496	3/27/2020	35	0.19	0.10	0.90	54%
New Jersey	Passaic	8563.6	3/27/2020	35	0.22	0.13	0.93	58%
New Jersey	Union	2014	3/30/2020	35	0.20	0.14	0.84	67%
New York	Nassau	1840	3/23/2020	35	0.31	0.20	0.95	65%
New York	New York	10715	3/13/2020	20	0.42	0.12	1.00	29%
New York	Suffolk	632	3/21/2020	35	0.34	0.23	0.93	68%
New York	Westchester	760	3/26/2020	35	0.28	0.17	0.98	62%
Pennsylvania	Philadelphia	4337	3/27/2020	35	0.26	0.16	0.90	60%

Validation #2

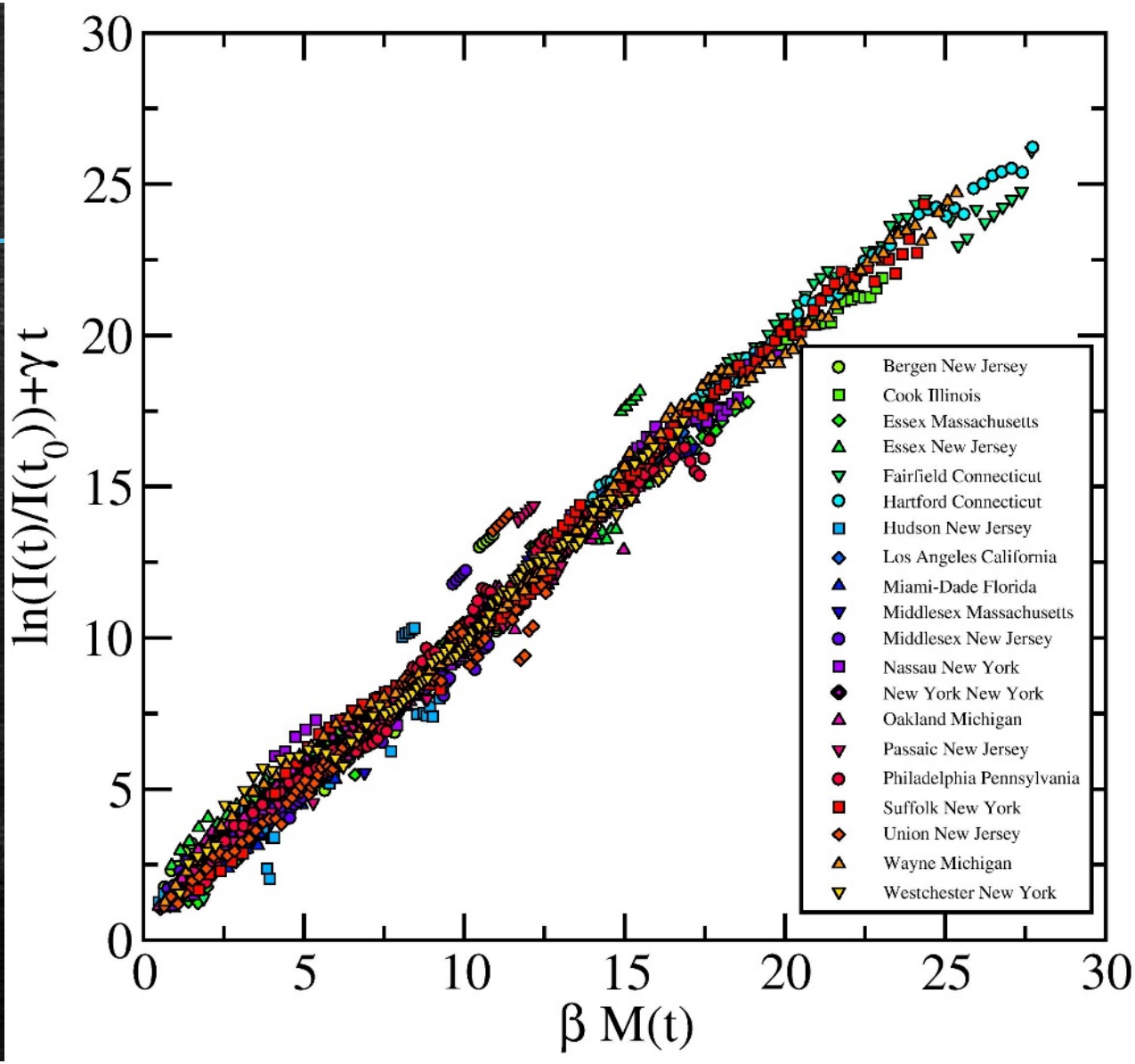
$$\frac{I(t)}{I(t_0)} = \frac{f(t+t_d)}{f(t_0+t_d)} = e^{\beta \cdot M(t) - \gamma \cdot t}$$



Validation #3

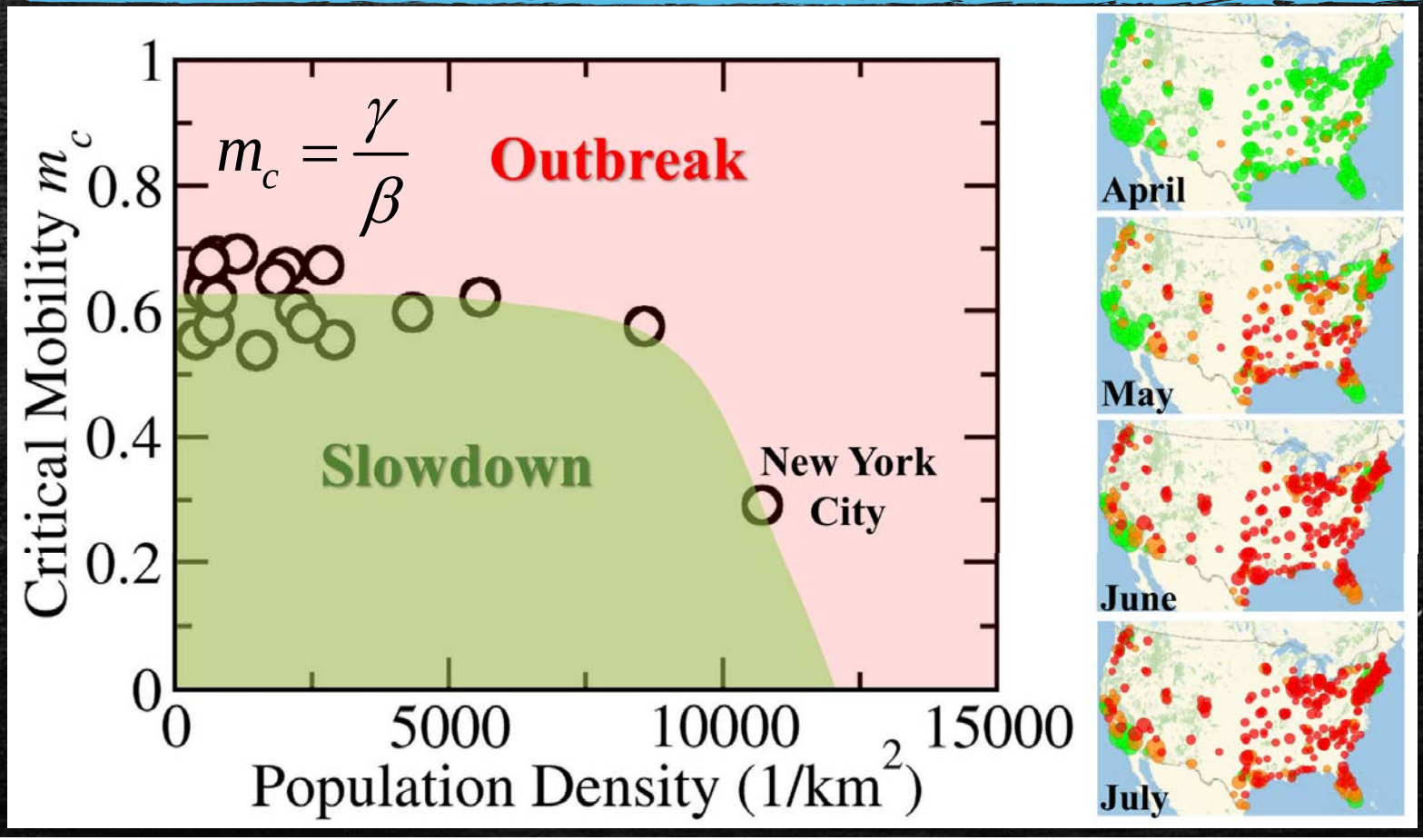
$$\ln\left(\frac{I(t)}{I(t_0)}\right)+\gamma\cdot t=\beta\cdot M(t)$$

- Only two fitting parameters
- All counties behave the same showing universal behaviors captured by this simple model
- No policy input.

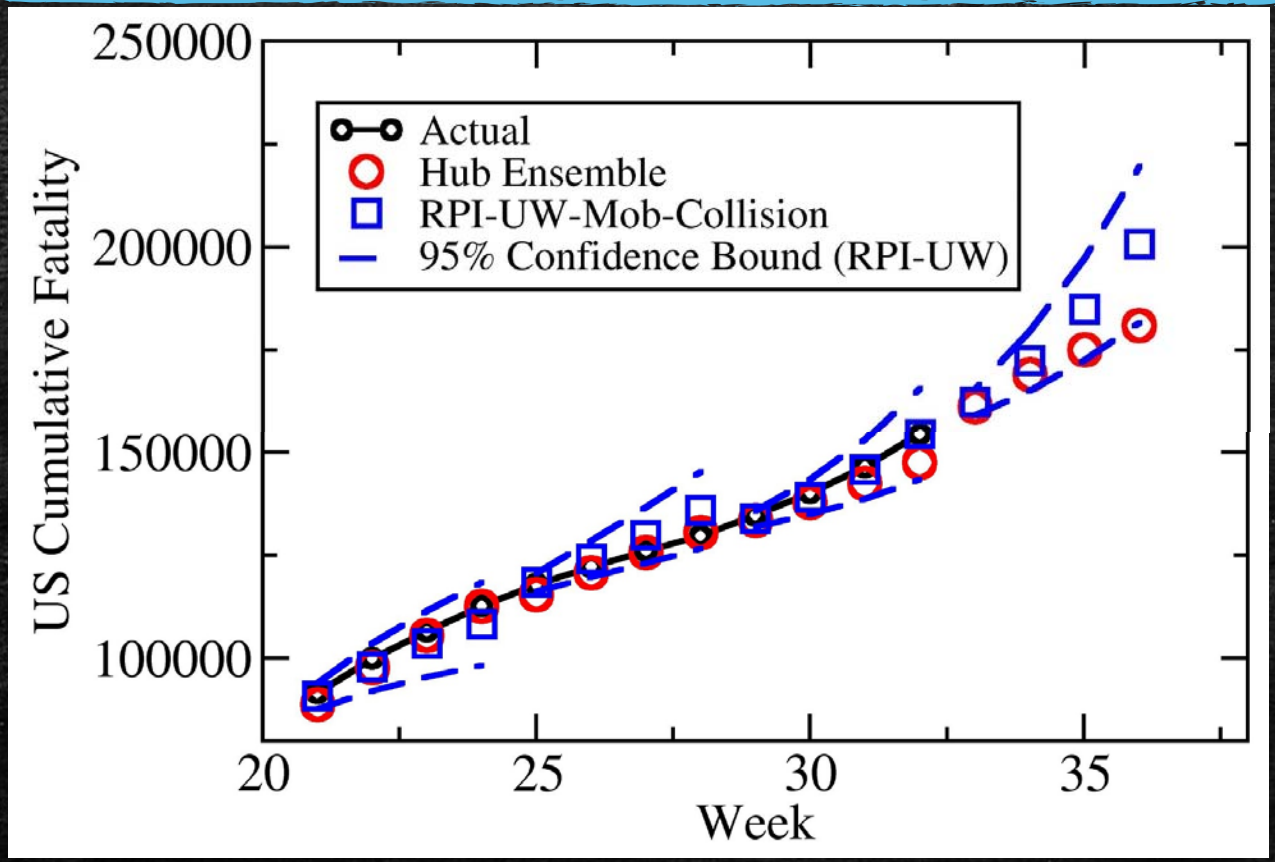


Critical Relative Mobility

$$\frac{dI}{dt} = I \cdot \beta \cdot (m - \frac{\gamma}{\beta})$$



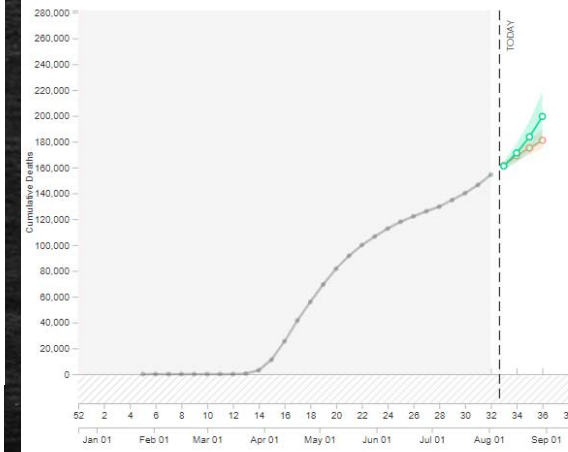
Forecasting



COVID-19 ForecastHub

COVID-19 Forecasts

Week Ahead



Conclusions

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- We built a simple mobility-informed collision model for COVID-19 transmission, with two fitting parameters without any inputs.
- The model works well with twenty hardest-hit counties in the US.
- Cumulative mobility plays the role of time in disease transmission.
- Critical mobility plays the role of basic reproduction number (very different meanings).
- The critical mobility is 60% for all counties except NYC. NYC has a 30% critical mobility.
- Governments can monitor the local mobility to regulate reopening. The average cumulative mobility can be used to design second lockdown.
- PPE usage can reduce infection rate thus increase the critical mobility.