# What portion of the Americans relied on others' satisfaction when deciding to take the COVID-19 vaccination?

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# Introduction

# Vaccination coverage

- Vaccination is a key to achieve a desired public health status.
- Achieving **timely high enough vaccination coverage** is important.
- High vaccination coverage requires high vaccine acceptance.
- Vaccine acceptance is the collective outcome of the individuals' decision-making processes.

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**When it came to COVID-19 vaccination, how did people decide whether to get immunized?**

# Success-based learners & myopic rationalists

- In some contexts[1][2], people are assumed/reported to be mainly one of the followings:
- **Success-based learners (imitators):** who follow the decisions of the perceived most satisfied (successful) individuals in the population;
- **Myopic rationalists (influentials):** who take the action that maximizes their instant perceived payoff.

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[3] Bauch, C. T., & Bhattacharyya, S. (2012). Evolutionary game theory and social learning can determine how vaccine scares unfold. PLoS computational biology, 8(4), e1002452.

# Success-based learners & myopic rationalists

- The two types of decision makers also differ in the type of information they attend to[4].

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**When it came to COVID-19 vaccination, what population proportion of people behaved as Myopic rationalists ($\alpha$)?**

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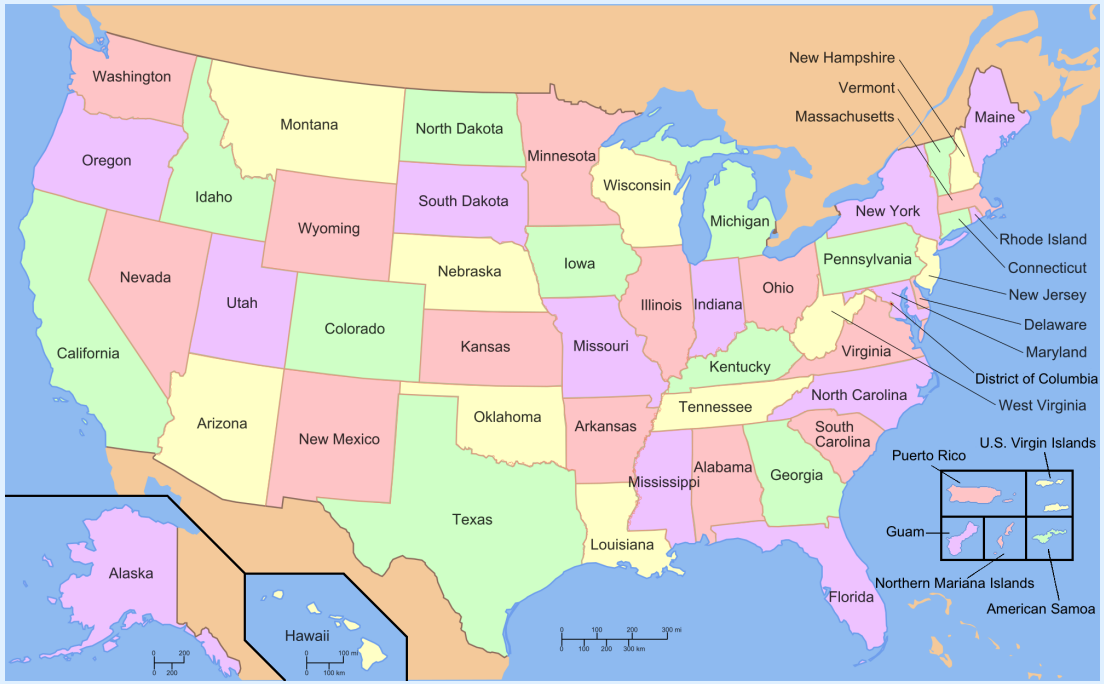
## Goal

To estimate the proportion of myopic rationalists in each US state, including D.C., when deciding whether to take the first dose of a COVID-19 vaccine




(Wikipedia)

# Model Formulation

## The excess payoff of vaccination

$$\Delta\pi(t) = \pi_v - \pi_{\bar{v}}$$

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## Population structure

- For each state, we have a large-enough, fixed-size, and well-mixed population,
- $N$: Number of people aged 12 and above,
- $N_n : (N - \text{VR})$: Number of *non vaccine-refusers*,
- $\alpha_1 N_n$: Number of Myopic rationalists,
- $(1 - \alpha_1)N_n$: Number of Success-based learners.
- $\alpha : \alpha_1 \frac{N_n}{N}$

- $M(t)$ (resp. $L(t)$): Number of vaccinated myopic rationalists (resp. success-based learners)

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- $M_s(t)$ (resp. $L_s(t)$): Number of unvaccinated myopic rationalists (resp. success-based learners) who are vaccine-seeker

$$M_s(t) = (\alpha_1 N_n - M(t))1(\Delta\pi(t)),$$

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$$\underbrace{\dot{i}(t)}_{\substack{\text{rate of change of} \\ \text{vaccinated of class i}}} = \underbrace{\kappa\, i_s(t) \min\{1, \frac{v(t)-L(t)-M(t)}{L_s(t)+M_s(t)}\}}_{\substack{\#\text{of vaccine-seekers} \\ \text{of class i who} \\ \text{can get a vaccine}}}, \quad i = L, M.$$

$$\Delta\pi(t) = C_{\bar{v}} - C_v(t) + C_d\frac{D(t)}{\mathtt{N}} + C_i\frac{I(t)}{\mathtt{N}},$$

- $C_{\bar{v}}$ (resp. $C_v$): the perceived risk of remaining unvaccinated (getting a dose of COVID-19 vaccine) in a disease-free situation,
- $C_i$ (resp. $C_d$): the perceived cost reduction in morbidity (mortality) due to contracting COVID-19 obtained from a dose of a COVID-19 vaccine,
- $D(t)$ (resp. $I(t)$): number of newly confirmed deaths due to COVID-19 (resp. cases of COVID-19 infection),
- $\mathtt{N}$: total population.

$$\Delta\pi(t) = C_{\bar{v}} - c_{v0}(t - t_0 + 1)^{\lambda} + 1\frac{D(t)}{\mathtt{N}} + C_i\frac{I(t)}{\mathtt{N}}$$

$$M_s(t) = (\alpha_1 N_n - M(t))\mathtt{1}(\Delta\pi(t)),$$

$$L_s(t) = ((1-\alpha_1)N_n - L(t))\frac{L(t)+M(t)}{N}\sigma\max\{0, \Delta\pi(t)\},$$

$$\dot{i}(t) = \kappa i_s(t)\min\{1, \frac{v(t) - L(t) - M(t)}{L_s(t) + M_s(t)}\}, \quad i = L, M.$$

- $\lambda < 0$ was estimated using the experimental Household Pulse Survey.
- $t_0$: date of roll-out of COVID-19 vaccine.

## Fitting phase

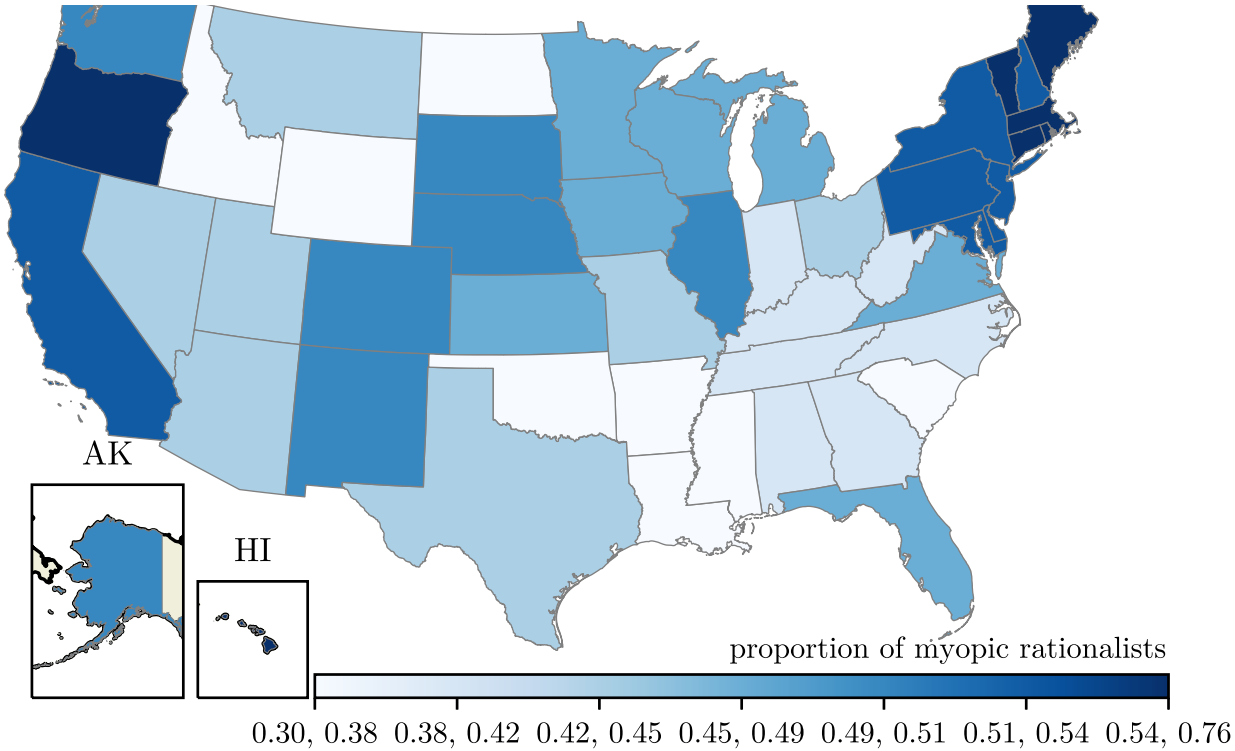
$$\text{optimization: } \min_{\underline{\theta}} \sum_i (e(t_i))^2$$

$$e(t_i) = \underbrace{\tilde{n}_v(t_i)}_{n_v(t_i)-n_v(t_{i-1})} - \underbrace{\tilde{n}_v(t_i, \underline{\theta})}_{\Delta M(t_i)+\Delta L(t_i)} , \tag{1}$$

where $\underline{\theta} = (\kappa, \alpha_1, C_{\bar{v}}, c_{v0}, C_i, \sigma)$.

- Optimization algorithm: Simulated Annealing approach

# Proportion of myopic rationalists, $\alpha = \alpha_1 N_n / N$



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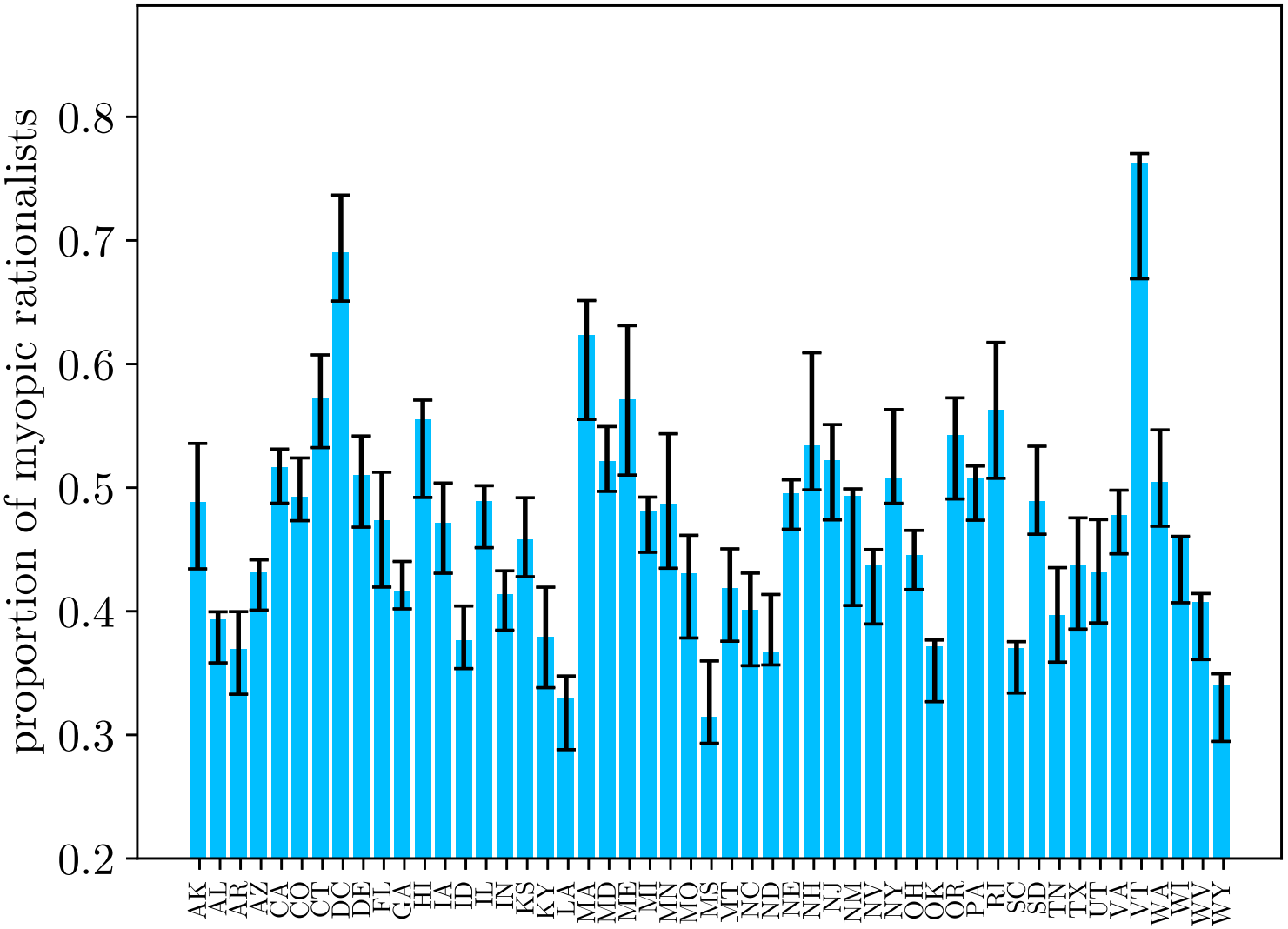

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**$\rightarrow$Identifiabiliy**

# Identifiability

Consider the following reference state space model $\Sigma_\theta$

$$\Sigma_\theta \begin{cases} \dot{x}(t) = f_\theta(x(t), u(t)), \\ y(t) = h_\theta(x(t), u(t)), \end{cases}$$

where

- $x(t) \in \mathcal{X} \subseteq \mathbf{R}^n$ is the state vector,
- $u(t) \in \mathcal{U} \subseteq \mathbf{R}^m$ is the input vector,
- $y(t) \in \mathcal{Y} \subseteq \mathbf{R}^p$ is the output vector,
- $\theta \in \Theta \subseteq \mathbf{R}^l$ is the parameter vector.

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Now consider the emulated state space model $\Sigma'_{\hat{\theta}}$

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**Definition**

The parameter $\theta^i$ is *structurally globally identifiable* if for almost all $\theta \in \Theta$

$$y(u(t), \theta) = y'(u(t), \hat{\theta}) \Rightarrow \hat{\theta}^i = \theta^i.$$

# Inputs and the outputs

$$
\begin{aligned}
M_s(t) &= (\alpha_1 N_n - x_2(t))1(\frac{1}{\sigma}\sum_{i=0}^{i=3} c_i u_i(t)),\\
L_s(t) &= ((1-\alpha_1)N_n - x_1(t))\frac{x_1(t)+x_2(t)}{N}\max\{0, \sum_{i=0}^{i=3} c_i u_i(t)\},\\
\dot{x}_1(t) &= \kappa L_s(t)\min\{1, \frac{u_4(t)-x_1(t)-x_2(t)}{L_s(t)+M_s(t)}\},\\
\dot{x}_2(t) &= \kappa M_s(t)\min\{1, \frac{u_4(t)-x_1(t)-x_2(t)}{L_s(t)+M_s(t)}\},\\
y(t) &= x_1(t)+x_2(t)
\end{aligned}
\tag{2}
$$

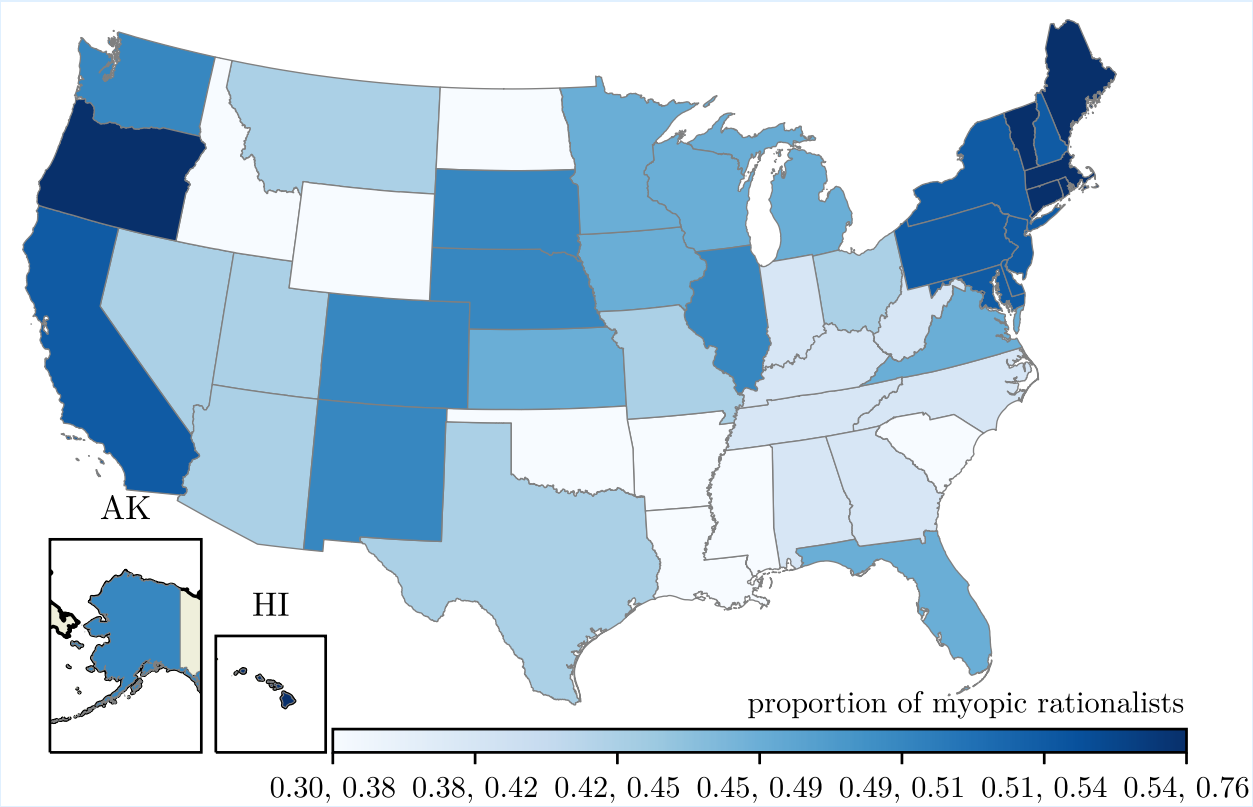
- $\Delta\pi(t) = \sum_{i=0}^{i=3} c_i u_i(t)$, where
  - $c_0 = \sigma C_{\bar{v}}$, $c_1 = \sigma c_{v0}$, $c_2 = \sigma\frac{C_i}{\mathtt{N}}$, $c_3 = \frac{\sigma}{\mathtt{N}}$.
  - $u_0 = 1$, $u_1(t) = (t - t_0 + 1)^{\lambda}$, $u_3(t) = D(t)$, $u_2(t) = I(t)$.
- $u_4(t) = v(t)$; $L(t)$ (resp. $M(t)$) is denoted by $x_1(t)$ (resp. $x_2(t)$).

**Proposition**

*The parameters* $\kappa, \alpha_1, C_i, C_{\bar{v}}, c_{v_0}, \sigma$ *of the dynamical system* (2) *with single output* $y(t)$*, and five inputs,* $u_i, i = 0, \ldots, 4$ *are uniquely identifiable provided that some assumptions hold.*

# Results

## Proportion of myopic rationalists, $\alpha = \alpha_1 N_n / N$




- The nationwide estimated proportion of myopic rationalists was 47%.
- There was a high degree of variation across the 51 jurisdictions, i.e., 31% for Mississippi to 76% for Vermont.

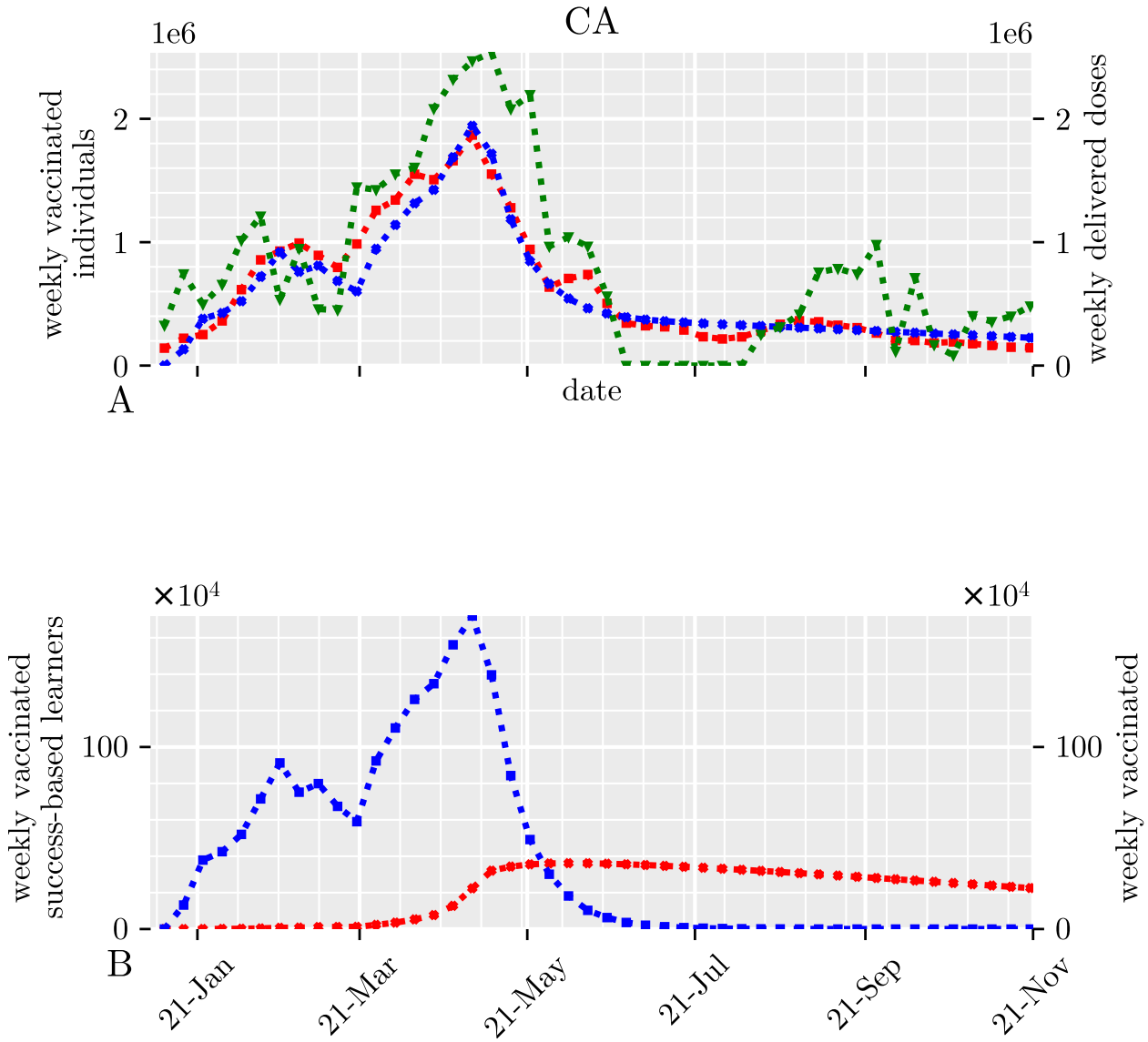

CA
1e6
1e6
weekly vaccinated individuals
weekly delivered doses
2
1
0
date
A
×10^4
×10^4
weekly vaccinated success-based learners
weekly vaccinated
100
0
B
21-Jan
21-Mar
21-May
21-Jul
21-Sep
21-Nov

Table: Linear correlation between explanatory variables and the estimated proportion of myopic rationalists.

| **Predictor variable** | **Pearson-r** | **r-squared** |
|---|---|---|
| Vaccination coverage | 0.87 | 0.76 |
| Proportion of votes in favor of Democrats | 0.82 | 0.68 |
| Education score | 0.74 | 0.54 |

# Conclusion

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- We proved that the proportion of myopic rationalists is identifiable, and the obtained narrow confidence intervals supported the validity of the estimated values.
- Hopefully, the approach may be useful for health management and guide tailored communication towards promoting vaccination uptake.

# Acknowledgments


Pouria Ramazi
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Mark Lewis
Department of Mathematical and Statistical Sciences
Department of Biological Sciences
University of Victoria

# Thank you!