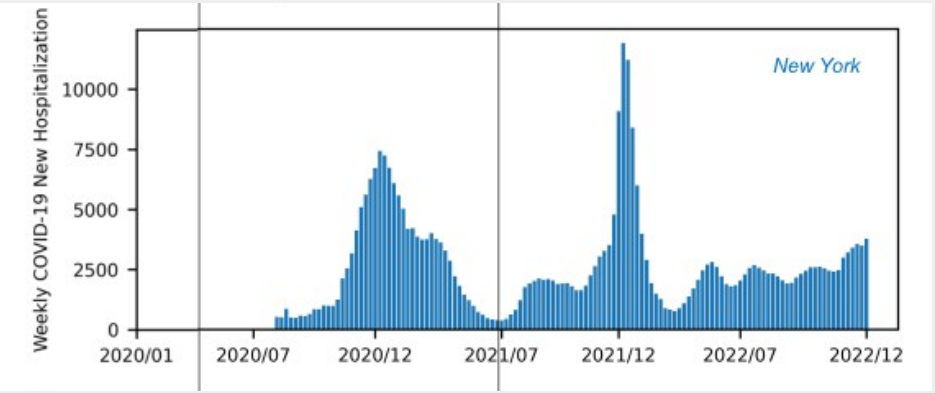
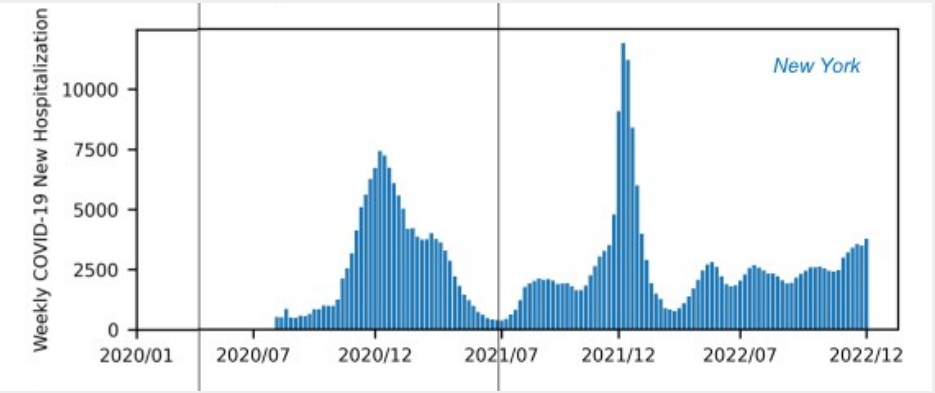
Adaptability Reveals the Healthcare Resilience to Pandemics

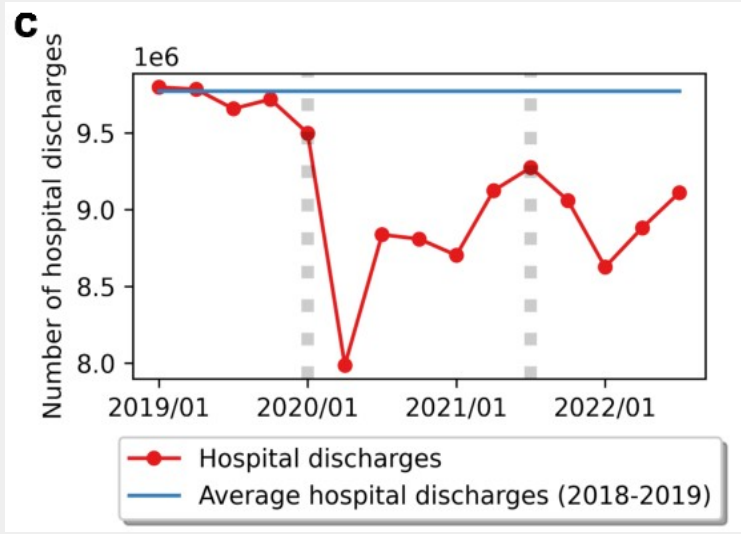
By: **Dimitri Lopez**, Lu Zhong, Sen Pei, and Jianxi Gao

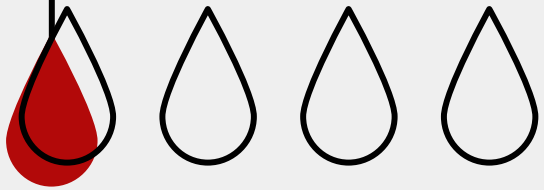
Unprecedented Burdens on the US Healthcare System



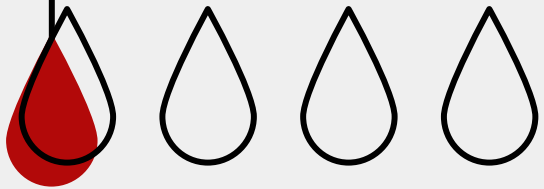
Unprecedented Burdens on the US Healthcare System







Why is this a problem?



Why is this a problem?

Some services can not be delayed or missed.

Measles Outbreak in Europe

96%

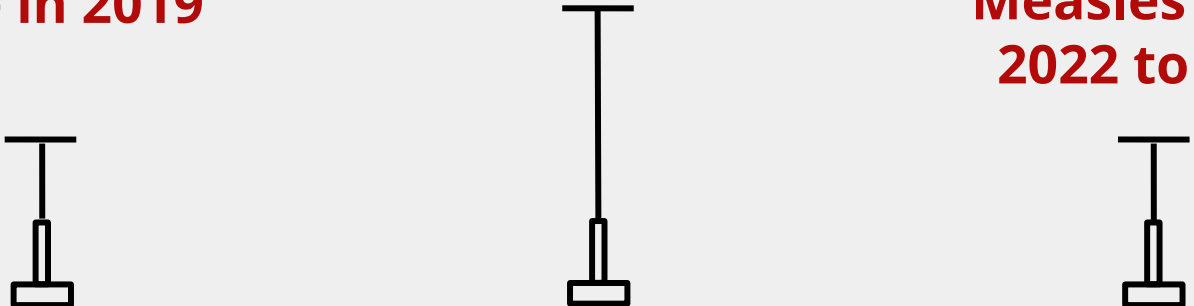
Vaccination Rate in 2019

93%

Vaccination Rate in 2022

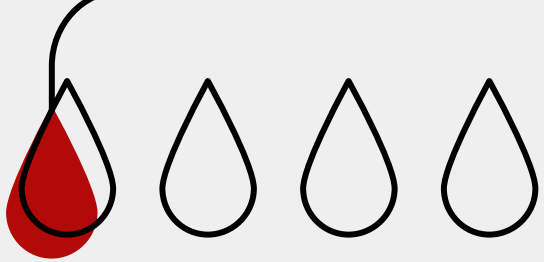
42x

Increase in Measles Cases 2022 to 2023



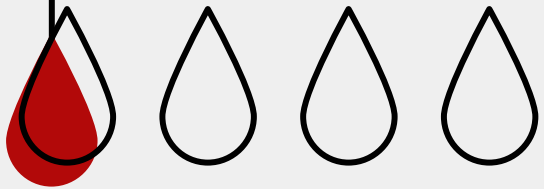
9.4 Million

Missed Cancer Screenings



Chronic Disease Treatment Suffered Major Disruptions

40% of treatments were delayed or missed



What can we do about this?

Goal: Figure out what makes some healthcare systems resilient to these disruptions.

Methodology

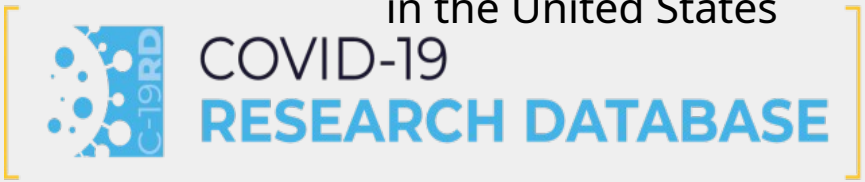
We take the largest Electronic Medical Records (EMR) dataset in the United States

COVID-19
RESEARCH DATABASE

Healthjump

Methodology

We take the largest Electronic Medical Records (EMR) dataset in the United States



Healthjump

Measure healthcare system performance using our quantification framework.

$$O(t) = P(t) - \alpha \frac{(\theta+\vartheta)^{\theta+\vartheta}}{\theta^{\theta}\vartheta^{\vartheta}} (\frac{t}{T})^{\theta} (1 - \frac{t}{T})^{\vartheta}$$

Methodology

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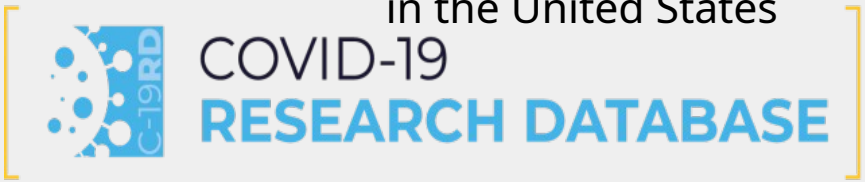

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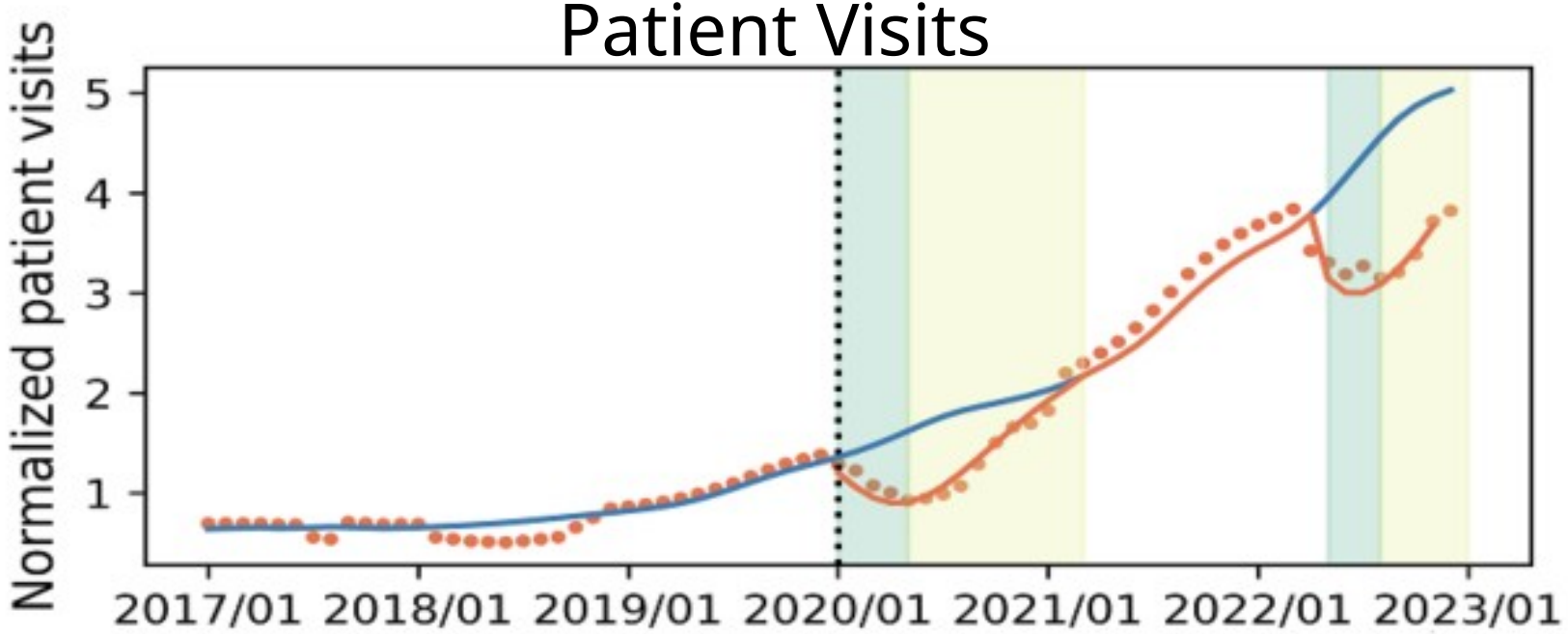
Measure healthcare system performance using our quantification framework.

$$O(t) = P(t) - \alpha \frac{(\theta+\vartheta)^{\theta+\vartheta}}{\theta^{\theta}\vartheta^{\vartheta}} (\frac{t}{T})^{\theta} (1 - \frac{t}{T})^{\vartheta}$$

Find out why some healthcare systems perform better by analyzing different populations.

Patient Visits



Observed patient visits O(t)

Fitted observed patient visits O'(t)

Expected patient visits if no crisis occurs P(t)

Beta Equation

$$O(t) = P(t) - \alpha \frac{(\theta+\vartheta)^{\theta+\vartheta}}{\theta^{\theta}\vartheta^{\vartheta}} (\frac{t}{T})^{\theta} (1 - \frac{t}{T})^{\vartheta}$$

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Disruption Amplitude: α

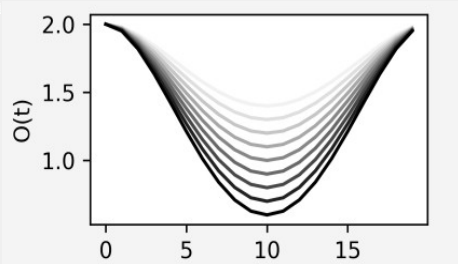
Disruption Rate: ϑ

Disruption Duration: T

Recovery Rate: Θ

Beta Equation

Disruption Amplitude: α



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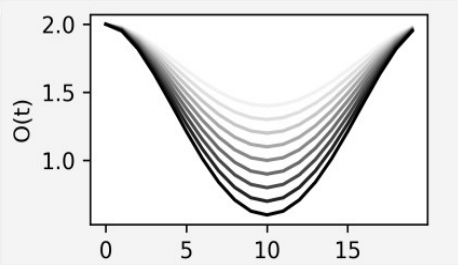

Disruption Rate: ϑ

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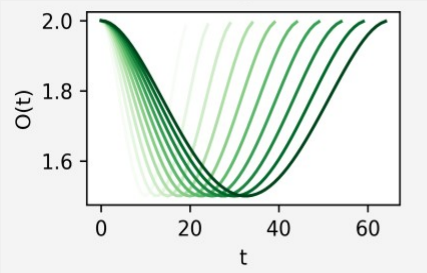

Recovery Rate: Θ

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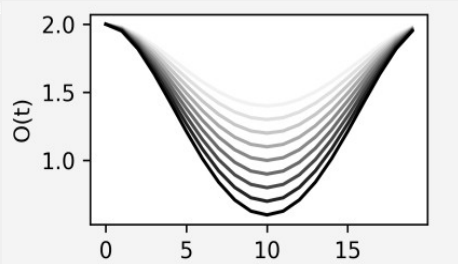

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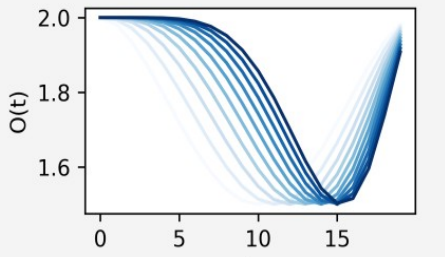
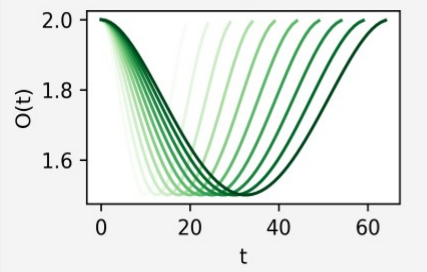


Disruption Duration: T



Recovery Rate: Θ

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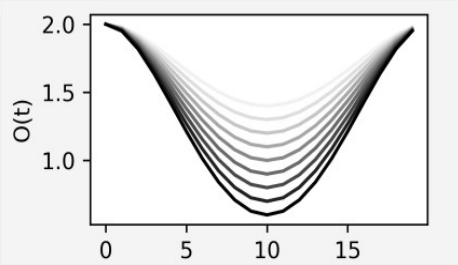
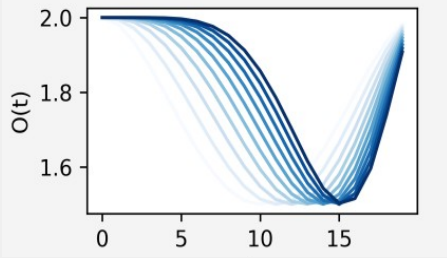
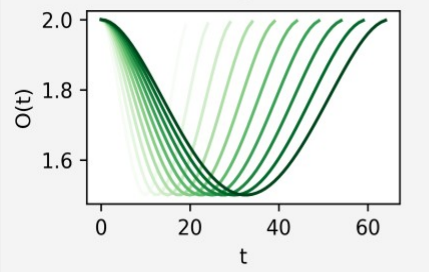


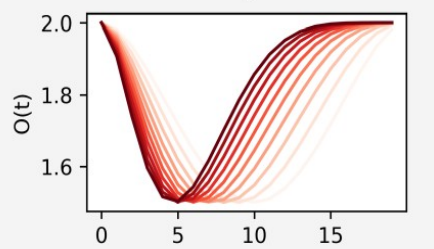
Disruption Rate: ϑ



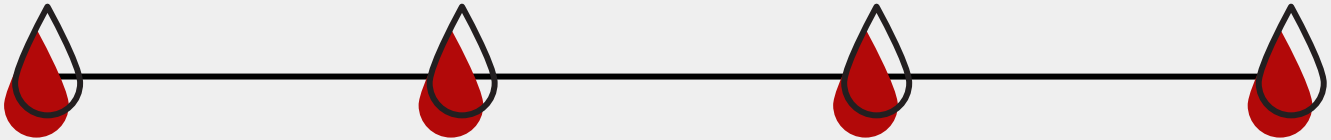
Disruption Duration: T



Recovery Rate: Θ



Metrics



Disruption Rate

Recovery Rate

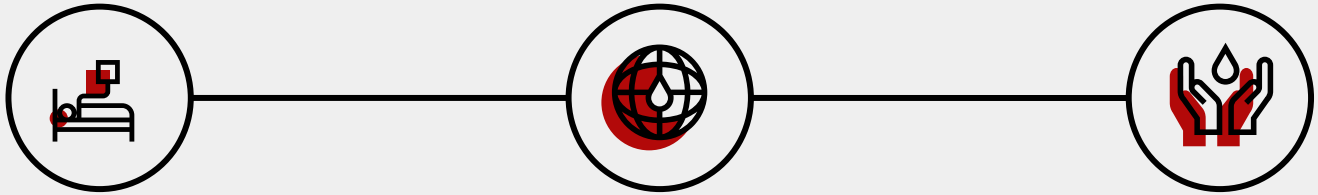
Resilience

Proportion of patient visits that were able to be kept

Adaptability

Populations Analyzed

Populations Analyzed



Chronic Diseases

Cancer, heart disease, asthma, prenatal care...

Populations Analyzed

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Geographic Areas

48 / 50 of the US states

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Asian, Black, Hispanic, White, ...

Populations Analyzed

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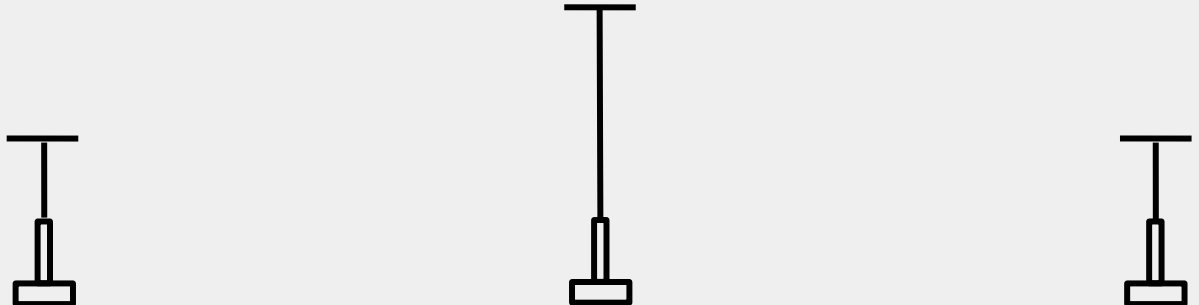
What are characteristics of healthcare systems that were resilient?

Best Predictors of Resilience



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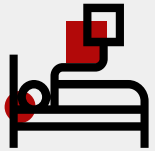
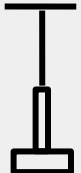
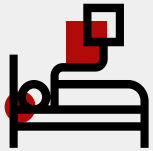


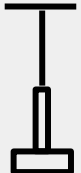


Best Predictors of Resilience

Physician Abundance

We **must** invest in our physicians going forward.





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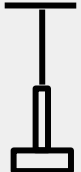

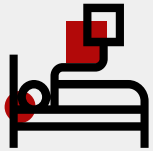

Social Vulnerability Measures

Coincides heavily with poverty rates and rates of uninsurance.

Best Predictors of Resilience

Physician Abundance

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Social Vulnerability Measures

Coincides heavily with poverty rates and rates of uninsurance.

NOT: Number of COVID-19 Cases

Regardless of severity, systemic issues matter more.

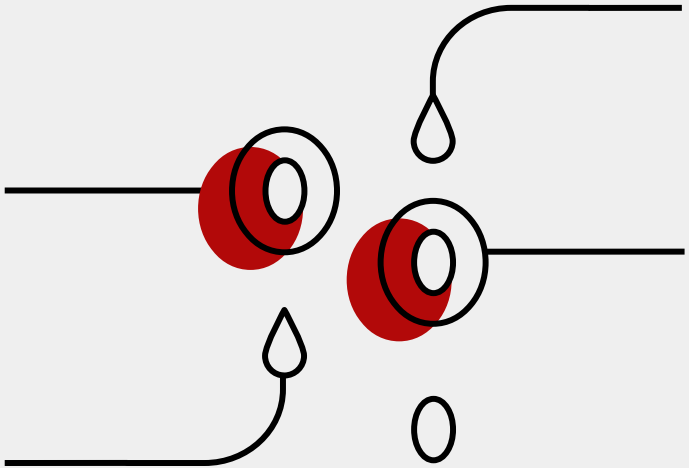
Main Results

Northern US

Had higher resilience rates than the southern part of the US.

Asian Populations

Had the highest levels fo resilience.



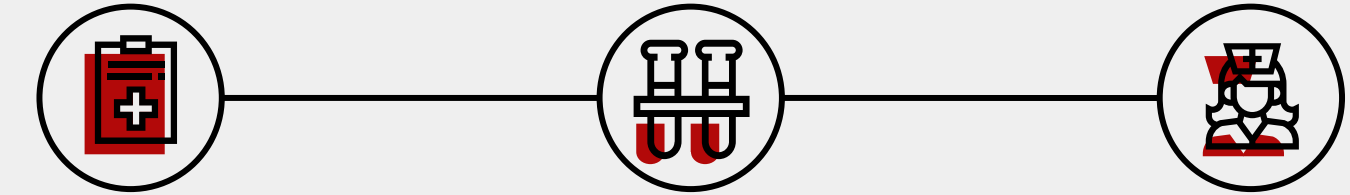
90% of States

Faced two consecutive disruptions.

Chronic Diseases

Prenatal care and chronic health diseases really suffered.

Conclusion



EMR Data

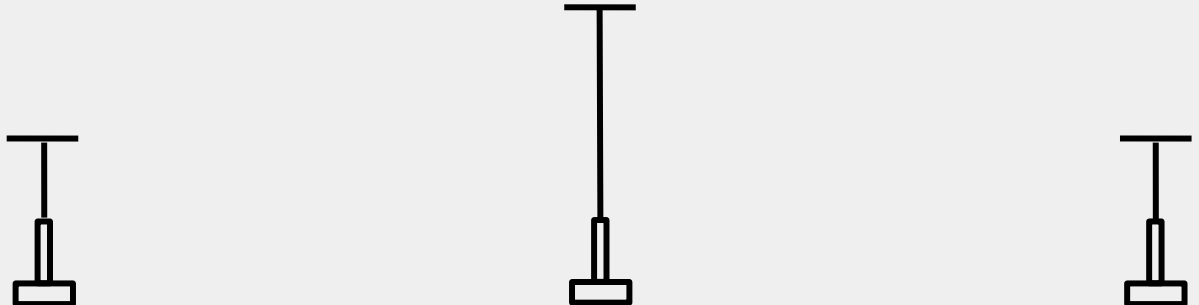
Compared System Performance

Physician Abundance

Acknowledgments

- Coauthors and advisor: Lu Zhong and Jianxi Gao
- Paper got accepted in Nature Medicine
- Funded by the C-19 Research Accelerator

Q & A

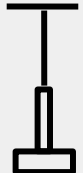


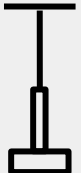
Q & A

Subgroup Analysis

Adaptability

Methodology





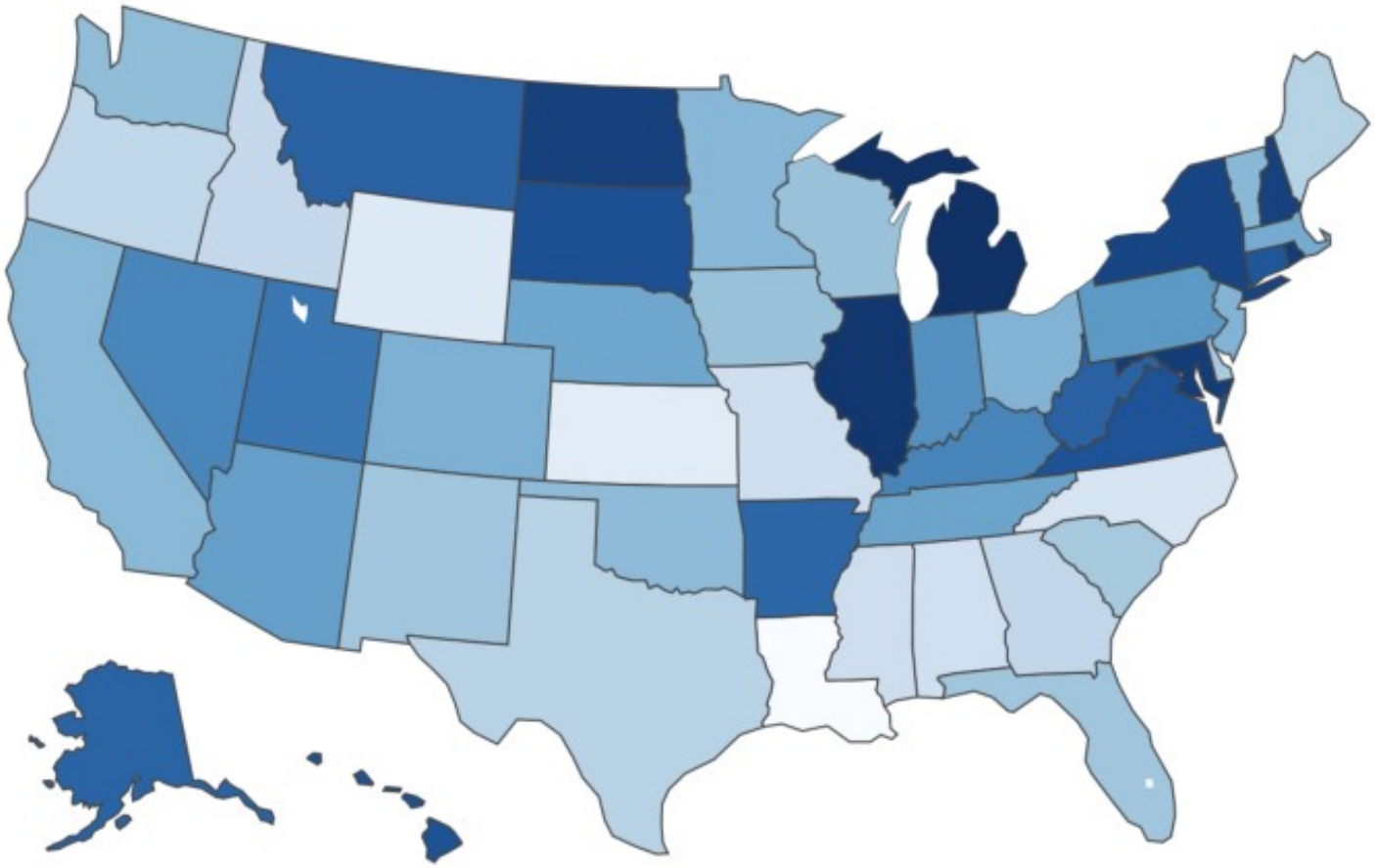
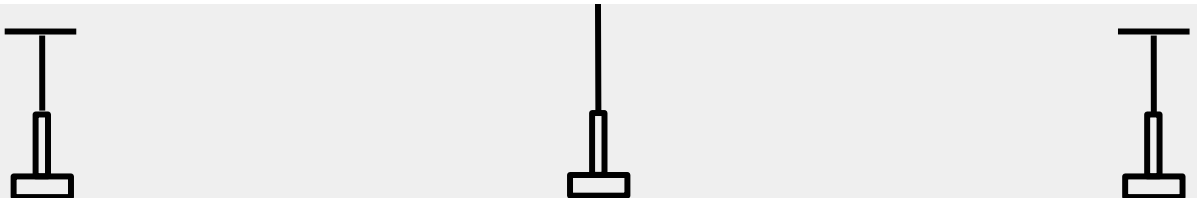
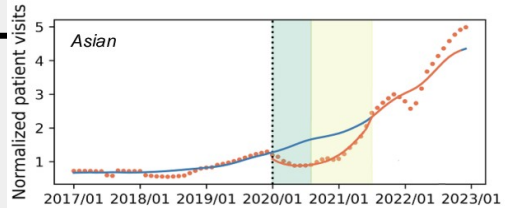
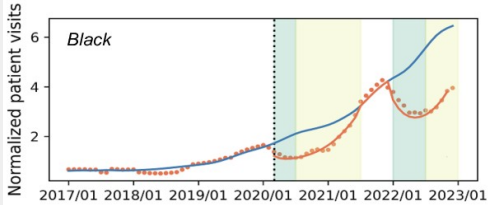


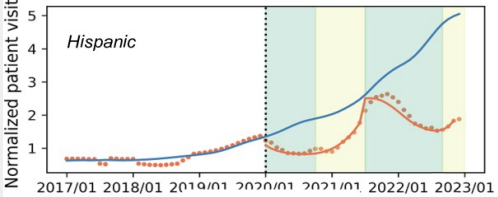
Table 2. Pearson correlation coefficients assessing the relationships between system adaptivity/resilience and pandemic severity, physician shortages, and socioeconomic factors in U.S. states. Significant correlations, indicated by a P-value less than the threshold of 0.05, are highlighted.

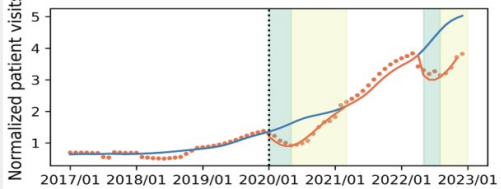
	COVID-19 cases	Physician per 100,000	Poverty percentile	Unemployment percentile	Uninsurance percentile	Age$\geq$ 65 percentile	Age$\leq$ 17 percentile	Minority percentile
Adaptivity index	0.24 (p=0.092)	**0.24 (p=0.018)**	**-0.325 (p=0.022)**	-0.176 (p=0.224)	**-0.327 (p=0.021)**	0.039 (p=0.785)	-0.132 (p=0.365)	-0.057 (p=0.697)
Resilience index	0.75 (p=0.60)	**0.34 (p=0.012)**	**-0.32 (p=0.019)**	-0.17 (p=0.220)	**-0.42 (p=0.002)**	0.13 (p=0.378)	-0.38 (p=0.086)	-0.18 (p=0.21)
Amplitude α (1st disruption)	0.17 (p=0.255)	**-0.35 (p=0.013)**	-0.013 (p=0.96)	-0.28 (p=0.076)	**0.28 (p=0.046)**	-0.090 (p=0.536)	**0.32 (p=0.028)**	-0.131 (p=0.369)
Amplitude α (2nd disruption)	0.164 (p=0.287)	**-0.25 (p=0.019)**	-0.001 (p=0.926)	-0.259 (p=0.089)	0.275 (p=0.070)	-0.080 (p=0.604)	**0.298 (p=0.049)**	-0.139 (p=0.365)











Observed patient visits O(t)

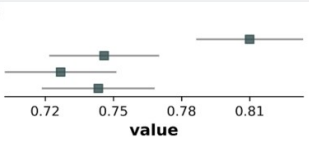
Fitted observed patient visits O'(t)

Expected patient visits if no crisis occurs P(t)

b

resilience

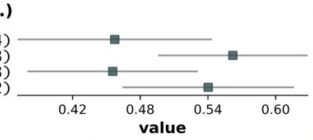
	Est.(95% Conf. Int.)
Asian	0.81(0.79 to 0.83)
Black	0.75(0.72 to 0.77)
Hispanic	0.73(0.70 to 0.75)
White	0.74(0.72 to 0.77)



c

adaptability

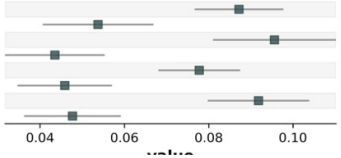
	Est.(95% Conf. Int.)
Asian	0.46(0.37 to 0.54)
Black	0.56(0.50 to 0.63)
Hispanic	0.46(0.38 to 0.53)
White	0.54(0.46 to 0.62)



d

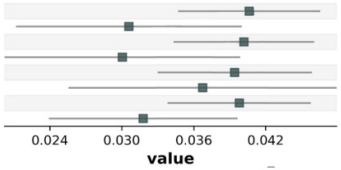
disruption rate

	Est.(95% Conf. Int.)
Asian (1st disruption)	0.09(0.08 to 0.10)
Asian (2nd disruption)	0.05(0.04 to 0.07)
Black (1st disruption)	0.10(0.08 to 0.11)
Black (2nd disruption)	0.04(0.03 to 0.06)
Hispanic (1st disruption)	0.08(0.07 to 0.09)
Hispanic (2nd disruption)	0.05(0.03 to 0.06)
White (1st disruption)	0.09(0.08 to 0.10)
White (2nd disruption)	0.05(0.04 to 0.06)



recovery rate

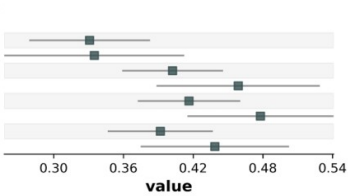
	Est.(95% Conf. Int.)
Asian (1st disruption)	0.04(0.03 to 0.05)
Asian (2nd disruption)	0.03(0.02 to 0.04)
Black (1st disruption)	0.04(0.03 to 0.05)
Black (2nd disruption)	0.03(0.02 to 0.04)
Hispanic (1st disruption)	0.04(0.03 to 0.05)
Hispanic (2nd disruption)	0.04(0.03 to 0.05)
White (1st disruption)	0.04(0.03 to 0.05)
White (2nd disruption)	0.03(0.02 to 0.04)



e

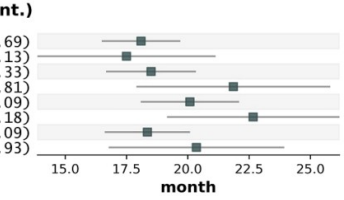
amplitude

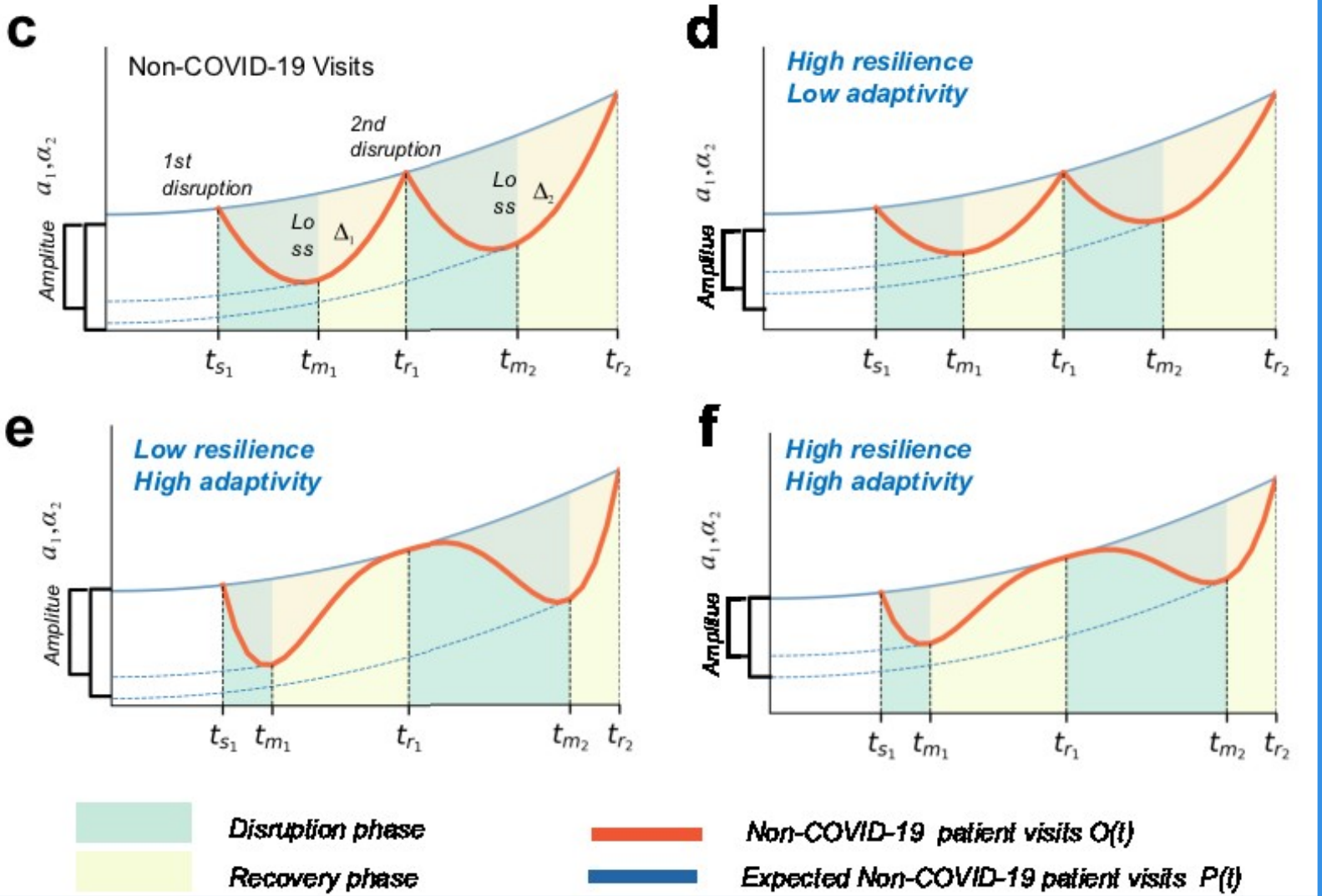
	Est.(95% Conf. Int.)
Asian (1st disruption)	0.33(0.28 to 0.38)
Asian (2nd disruption)	0.33(0.26 to 0.41)
Black (1st disruption)	0.40(0.36 to 0.45)
Black (2nd disruption)	0.46(0.39 to 0.53)
Hispanic (1st disruption)	0.42(0.37 to 0.46)
Hispanic (2nd disruption)	0.48(0.42 to 0.54)
White (1st disruption)	0.39(0.35 to 0.44)
White (2nd disruption)	0.44(0.37 to 0.50)



duration

	Est.(95% Conf. Int.)
Asian (1st disruption)	18.09(16.49 to 19.69)
Asian (2nd disruption)	17.50(13.87 to 21.13)
Black (1st disruption)	18.50(16.67 to 20.33)
Black (2nd disruption)	21.86(17.90 to 25.81)
Hispanic (1st disruption)	20.09(18.08 to 22.09)
Hispanic (2nd disruption)	22.67(19.15 to 26.18)
White (1st disruption)	18.35(16.61 to 20.09)
White (2nd disruption)	20.35(16.77 to 23.93)




c
Non-COVID-19 Visits
1st disruption
2nd disruption
Loss
Δ1
Loss
Δ2
Amplitue
a1, a2
ts1
tm1
tr1
tm2
tr2
d
High resilience
Low adaptivity
e
Low resilience
High adaptivity
f
High resilience
High adaptivity
Disruption phase
Recovery phase
Non-COVID-19 patient visits O(t)
Expected Non-COVID-19 patient visits P(t)

Recovery Rate

$$u_i = \frac{1}{\theta_i T_i}$$

Disruption Rate

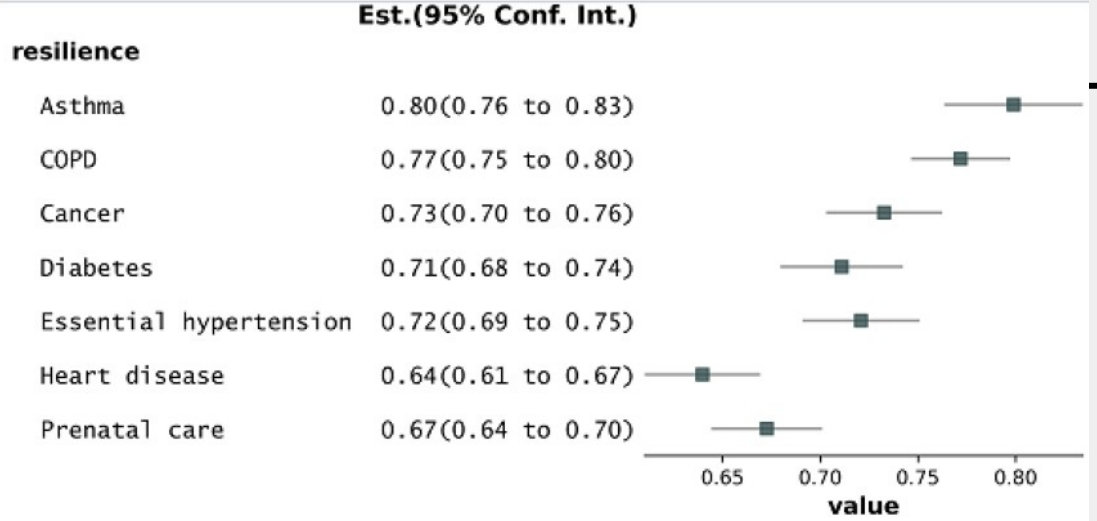
$$v_i = \frac{1}{\vartheta_i T_i}$$

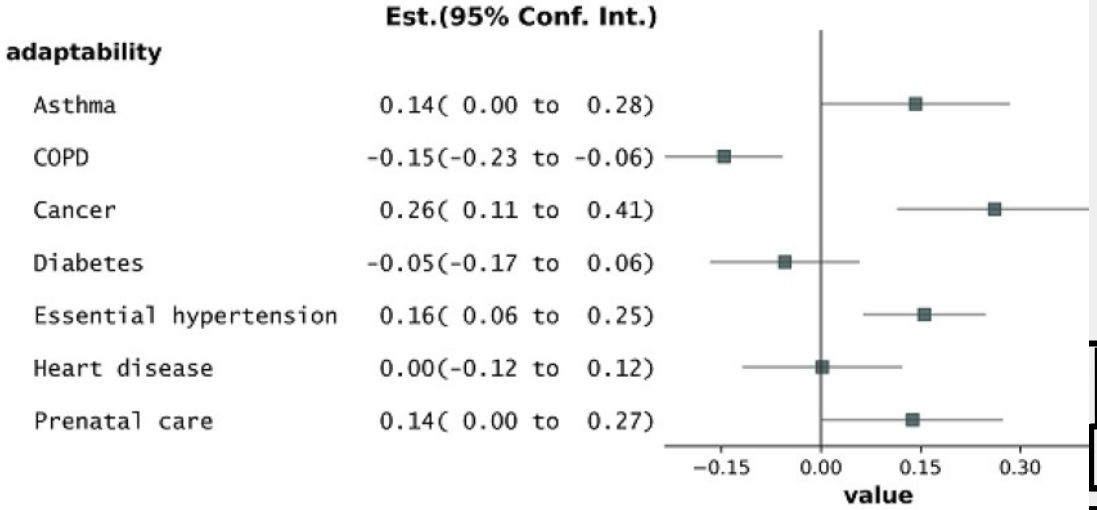
Adaptability

$$\rho = \frac{-[u_{i+1} - u_i]}{\max(u_{i+1}, u_i)}$$

Resilience

$$r = 1 - \frac{\int_{t_s}^{t_r} [P(t) - O(t)]dt}{\int_{t_s}^{t_r} [P(t)]dt}$$


Est.(95% Conf. Int.)
resilience
Asthma
0.80(0.76 to 0.83)
COPD
0.77(0.75 to 0.80)
Cancer
0.73(0.70 to 0.76)
Diabetes
0.71(0.68 to 0.74)
Essential hypertension
0.72(0.69 to 0.75)
Heart disease
0.64(0.61 to 0.67)
Prenatal care
0.67(0.64 to 0.70)
0.65
0.70
0.75
0.80
value


Est.(95% Conf. Int.)
adaptability
Asthma
0.14(0.00 to 0.28)
COPD
-0.15(-0.23 to -0.06)
Cancer
0.26(0.11 to 0.41)
Diabetes
-0.05(-0.17 to 0.06)
Essential hypertension
0.16(0.06 to 0.25)
Heart disease
0.00(-0.12 to 0.12)
Prenatal care
0.14(0.00 to 0.27)
−0.15
0.00
0.15
0.30
value