The impact of vaccinations and chronic disease on COVID death rates

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Abstract

This study presents a theoretical and empirical regression model to measure the efficacy of vaccinations in reducing COVID death rates across states over the 3/10/21 to 12/28/22 period. During that period, it was estimated that the availability of vaccinations resulted in a reduction of 427,000 COVID deaths in the nation. To arrive at that estimate, other covariants were held constant. In particular, it was found that chronic disease should be included as an explanatory variable to arrive at unbiased measures of the efficacy of vaccinations in reducing deaths. In addition, the percentage of people over the age of 65 was found to be highly significant. The only ethnic/racial characteristic that was significant in explaining COVID deaths was the percentage of American Indians/Alaska Natives residing in a state. Other ethnic/racial characteristics, as well as variables representing population, density, governmental stringency, and income, were not significant over the period tested.

1 Introduction

Cumulative fatalities in the U.S. from the severe acute respiratory syndrome coronavirus 2 (SARS-COV-2) reached 1,085,000 from January 1, 2020, through the year-end of December 2022. About half of those deaths (540,000) occurred after 3/10/21 when COVID vaccinations first became generally available.
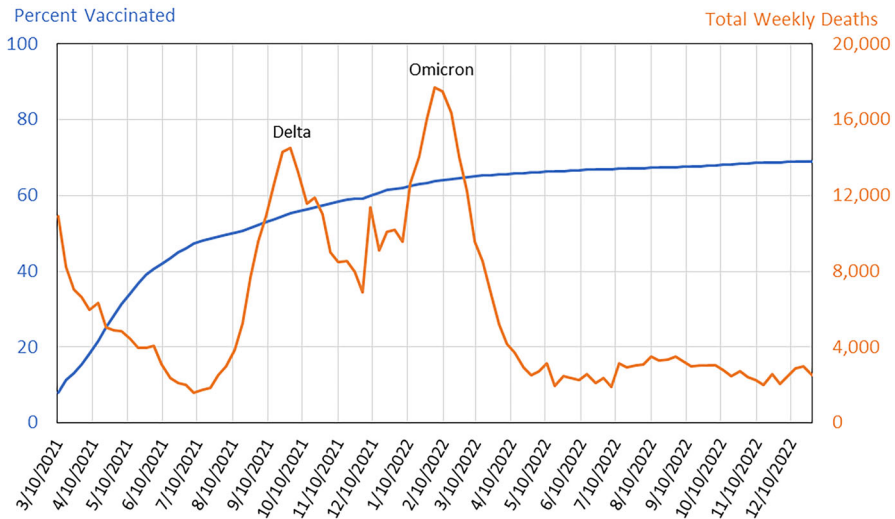
Figure 1 shows that the weekly mean cumulative rate of fully vaccinated people in

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Percent Fully Vaccinated Versus Total Weekly COVID Deaths in the U.S.

Fig. 1 Percent fully vaccinated versus total weekly COVID deaths in the U.S

the U.S. increased from 8 percent on 3/10/21 to 69 percent on 12/28/22. During that 21-month period, the total number of weekly COVID fatalities experienced two peaks during the spread of the highly contagious Delta and Omicron variants. Following the Omicron peak, the weekly average COVID fatalities dropped sharply from a high of 17,701 during the week of 2/22/22 to 2,505 only two months later on 4/27/22. For the rest of 2022, the weekly average death rates hovered at relatively low levels in a narrow range between 2000 and 4000.

While one might argue that the relatively low number of weekly COVID fatalities after 4/10/22 was the result of increasing cumulative vaccination rates, the sharp increases in COVID deaths during the Delta and Omicron outbreaks occurred after mean vaccination rates exceeded 50 percent.

A number of academic papers have studied the impact of vaccinations on COVID death rates. Few, however, have investigated differences in COVID deaths across states and how those differences can be used to estimate the efficacy of COVID vaccinations.

A study that is similar to analyzing differences across states examines diverging patterns of COVID-19 cases in seven countries with high vaccination rates (Bukhari et al., 2021). The study concludes somewhat ambiguously that "the number of cases and deaths have declined significantly (with vaccinations ≥ 50%), whereas in others they have increased compared to pre-vaccination levels" (Bukhari et al., 2021, p. 1). More problematic is the fact that the period of testing in this paper ends on May 30, 2021, and it does not account for covariates that could bias the estimates.

A study that compares U.S. COVID mortality with the ten most- and least-vaccinated states, as well as 20 OECD countries, concludes that the U.S. would have averted 122,304 deaths if COVID-19 mortality matched that of the ten most-vaccinated states (Bilinski et al., 2023). This finding was based on mortality rates over the Delta

and Omicron periods from 6/27/21 to 3/26/22. Not only does the aggregation of the ten most-vaccinated states as a comparison group constrain the sample, but the initial period tested starts on 6/27/21 when the average vaccination rate had already reached 46 percent. The sample period ends on 3/26/22 and therefore excludes any empirical findings relating to the 108,000 deaths that occurred after that date.

Robert J. Barro uses differences across states' vaccination rates and instrumental variables to analyze vaccine efficacy. He argues, "If vaccinations are effective at reducing infections and deaths, these differences should map into differences in COVID-related deaths, hospitalizations, and cases." (Barro, 2022). Barro divides his sample into five periods over the 3/19/21 to 5/22/22 period. It uses cross-sectional regressions to measure the effects of vaccinations on COVID-related outcomes. He concludes that "one expected life saved requires 248 additional doses." No estimation is given for the total number of lives saved during the period tested. The period tested ended on 5/22/22, after which 85,000 more COVID deaths occurred during the remainder of the year. Barro's methodology does not directly include an instrumental variable representing chronic disease to hold differences across states in this variable constant. It might be argued that his use of a life expectancy variable could serve as a proxy for chronic disease. But as will be shown later in this study, life expectancy is an inferior measure as compared to directly including a chronic disease variable in explaining COVID death rates.

In the study to follow, the efficacy of mean vaccinations across states from 3/10/21 to 12/28/22 will be examined. A regression model similar to those undertaken by (Doti 2021a, b) will be used to measure the efficacy of vaccinations in reducing COVID mortality. The study will hold constant other covariants such as population, density, income, stringency, age, chronic disease, and differences in racial/ethnic composition across states. In addition, the study will estimate the impact of each state's mean vaccination rate on its mean death rate, thereby allowing for an estimation of the total number of lives saved as a result of vaccinations.

A particularly important aspect of this study is the inclusion of a chronic disease variable into the estimation. No known study on the efficacy of COVID vaccinations includes chronic disease as an explanatory variable. It will be shown that including such a variable in regression tests results in more accurate estimates of the efficacy of vaccination in reducing COVID death rates. The present study will also show that excluding chronic disease as an explanatory variable results in unreliably high estimates of lives saved due to COVID vaccinations.

2 Theoretical model

Although mean weekly vaccination rates in the U.S. reached asymptotic peaks of 70 percent by year-end 2022, Fig. 2 shows that there was a relatively wide range in statewide cumulative vaccination rates, with Rhode Island registering the highest at 89.6 percent and Wyoming the lowest at 53.0 percent as of year-end 2022. In comparing weekly average statewide vaccination rates over the 3/10/21 to 12/28/22 period, Vermont was highest at 70.9, and Alabama was lowest at 43.3 (See Table 1).

Comparison of Vaccination Rates
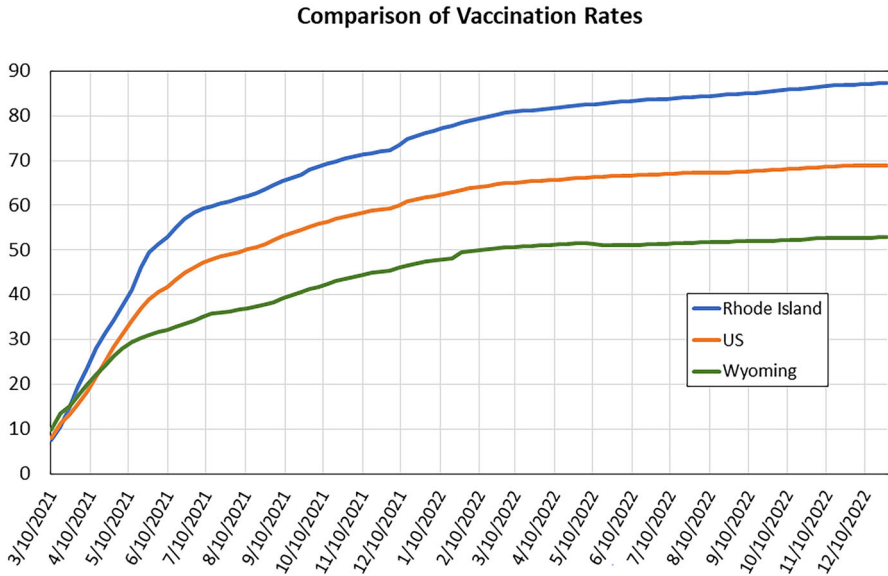
Fig. 2 Comparison of vaccination rates

These wide differences in statewide averages suggest a potential theoretical approach in measuring the benefits of higher cumulative vaccination rates.

If vaccinations reduce COVID death rates, the relationship between mean vaccination rates by state, vr_s, will be inversely related to the death rate by state, dr_s, as shown in Fig. 3.

An example of the impact of vaccinations in saving lives is depicted in Fig. 3 by comparing the state with the lowest mean vaccination rate during the 3/10/21 to 12/28/22 period (Alabama) with that of the highest (Vermont). The hypothetical efficacy of a higher vaccination rate is depicted in Fig. 3 as the difference in death rates for those two states, $dr_A - dr_V = \Delta\, dr$. The other 48 states whose vr_s range between vr_A and vr_V would theoretically have death rates (dr_s) between dr_A and dr_V.

The vr_s and dr_s for all 50 states are shown in both alpha and rank order in Table 1. These values conform approximately to a linear trendline, as shown in Fig. 4, with wide differences around that trendline. Notice that the placement of the intercepts for Alabama's and Vermont's mean vaccination rates (vr_A and vr_V) and COVID cumulative death rates (dr_A and dr_V) are similar to those hypothesized in Fig. 3.

Although the trendline shown in Fig. 3 suggests an inverse relationship between mean vaccination rates and cumulative COVID death rates by state, it is possible that other explanatory variables that are related to vaccination rates in a collinear way may lead to a misleading characterization of the efficacy of COVID vaccinations. An empirical model presented in the following section will address that issue by examining a wider set of explanatory variables in addition to vaccination rates that might significantly influence COVID death rates. It will be shown that chronic disease, in particular, has a significant impact on COVID deaths, an impact that needs to be
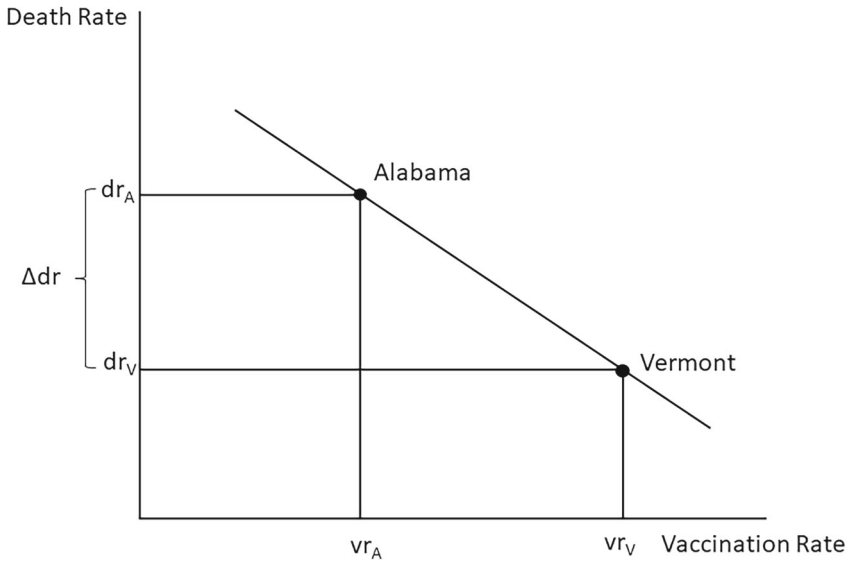
Table 1 Comparison of mean vaccination rates (vr) and cumulative covid death rates (dr) by state from 3/10/21 to 12/28/22

	Alpha order by state	vr	dr		Rank order of vr from highest to lowest	vr	dr
1	Alabama	43.3	209.5	1	Vermont	70.9	90.1
2	Alaska	53.6	157.0	2	Rhode Island	70.7	111.4
3	Arizona	52.7	216.2	3	Maine	69.5	150.7
4	Arkansas	46.2	242.6	4	Connecticut	69.1	111.4
5	California	60.9	112.5	5	Massachusetts	68.9	133.3
6	Colorado	60.6	133.2	6	New York	65.6	134.6
7	Connecticut	69.1	111.4	7	New Jersey	65.3	127.4
8	Delaware	59.4	172.3	8	Maryland	65.1	128.9
9	Florida	57.2	238.1	9	Hawaii	64.8	91.1
10	Georgia	46.4	216.9	10	Washington	62.6	128.4
11	Hawaii	64.8	91.1	11	New Mexico	62.5	235.2
12	Idaho	45.6	179.8	12	Virginia	62.5	150.2
13	Illinois	57.9	138.8	13	New Hampshire	61.2	120.0
14	Indiana	48.3	184.7	14	California	60.9	112.5
15	Iowa	54.5	151.1	15	Colorado	60.6	133.2
16	Kansas	52.9	166.7	16	Oregon	60.5	156.6
17	Kentucky	50.5	284.0	17	Minnesota	59.9	133.1
18	Louisiana	45.7	185.7	18	Delaware	59.4	172.3
19	Maine	69.5	150.7	19	Pennsylvania	59.1	188.5
20	Maryland	65.1	128.9	20	Illinois	57.9	138.8
21	Massachusetts	68.9	133.3	21	Wisconsin	57.2	146.8
22	Michigan	52.7	239.1	22	Florida	57.2	238.1
23	Minnesota	59.9	133.1	23	Nebraska	55.3	130.8
24	Mississippi	43.7	212.5	24	Iowa	54.5	151.1
25	Missouri	48.4	221.4	25	South Dakota	54.0	135.8
26	Montana	49.8	202.3	26	Alaska	53.6	157.0
27	Nebraska	55.3	130.8	27	Utah	53.0	95.7
28	Nevada	52.0	212.2	28	Kansas	52.9	166.7
29	New Hampshire	61.2	120.0	29	Arizona	52.7	216.2
30	New Jersey	65.3	127.4	30	Michigan	52.7	239.1
31	New Mexico	62.5	235.2	31	North Carolina	52.5	152.5
32	New York	65.6	134.6	32	Nevada	52.0	212.2
33	North Carolina	52.5	152.5	33	Texas	51.9	155.9
34	North Dakota	48.0	121.6	34	Ohio	51.1	188.9
35	Ohio	51.1	188.9	35	Kentucky	50.5	284.0

Table 1 (continued)

	Alpha order by state	vr	dr		Rank order of vr from highest to lowest	vr	dr
36	Oklahoma	49.1	320.6	36	Montana	49.8	202.3
37	Oregon	60.5	156.6	37	Oklahoma	49.1	320.6
38	Pennsylvania	59.1	188.5	38	South Carolina	48.7	193.9
39	Rhode Island	70.7	111.4	39	West Virginia	48.5	299.2
40	South Carolina	48.7	193.9	40	Missouri	48.4	221.4
41	South Dakota	54.0	135.8	41	Indiana	48.3	184.7
42	Tennessee	46.3	243.6	42	North Dakota	48.0	121.6
43	Texas	51.9	155.9	43	Georgia	46.4	216.9
44	Utah	53.0	95.7	44	Tennessee	46.3	243.6
45	Vermont	70.9	90.1	45	Arkansas	46.2	242.6
46	Virginia	62.5	150.2	46	Louisiana	45.7	185.7
47	Washington	62.6	128.4	47	Idaho	45.6	179.8
48	West Virginia	48.5	299.2	48	Wyoming	44.0	219.8
49	Wisconsin	57.2	146.8	49	Mississippi	43.7	212.5
50	Wyoming	44.0	219.8	50	Alabama	43.3	209.5
	Average for States	55.6	173.5		Average for States	55.6	173.5

Fig. 3 Relationship between vaccination rates and cumulative COVID death rates by state

Relationship between Mean Vaccination Rates and Cumulative COVID Death Rates by State from 3/10/21 to 12/28/22
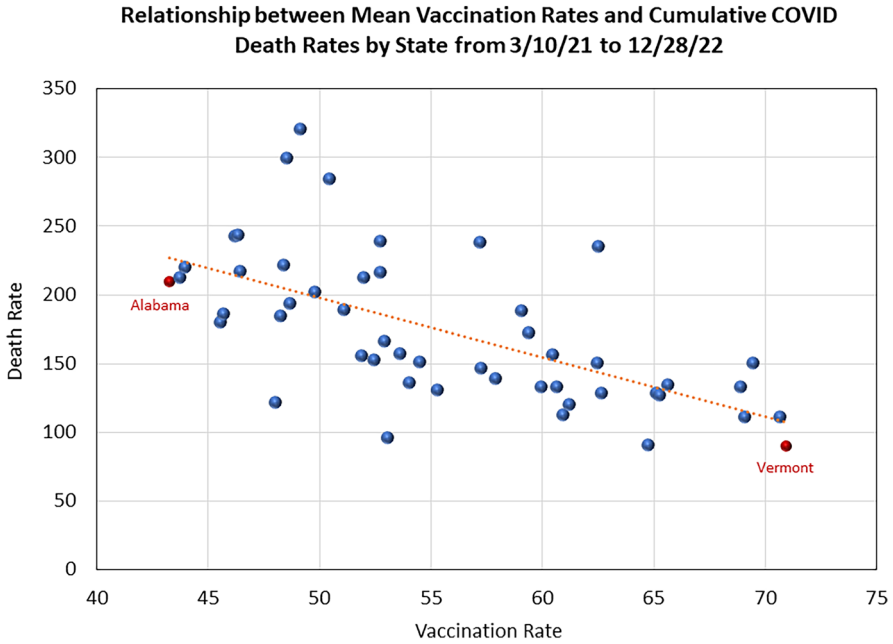
Fig. 4 Relationship between mean vaccination rates and cumulative COVID death rates by state from 3/10/21 to 12/28/22

held constant in order to derive unbiased estimates of the efficacy of vaccinations on COVID mortality.

3 Empirical model

In order to measure the impact of differences across states in vaccination rates on COVID-19 death rates, it will be necessary to hold constant other variables that may influence COVID-19 deaths as well as define more precisely the variables to be used in formulating the empirical tests.

Cumulative confirmed COVID-19 deaths per 100,000 in state population during the 3/10/21 to 12/28/22 period serves as the dependent variable in the model. A death is defined as a person who meets the clinical and epidemiological criteria for a SARS-CoV-2 death.

The structural form of the model is shown below in Eq. (1).

$$C_{i,t} = b_0 + b_1(x_{1,i}) + b_2(x_{2,i}) + \ldots + b_n(x_{n,i}) \tag{1}$$

where $C_{i,t}$ is the cumulative COVID-19 death rate per 100,000 in state i at the end of some period t. $x_1, \ldots, x_n = 1, \ldots, $ n are independent variables in state i. $b_0, b_1, \ldots, b_n$ are parameters to be estimated.

Note: Display of error terms are suppressed.

In order to control and test for the factors that explain the cumulative COVID-19 death rate by state during some time interval t, the following variables shown below in Eq. (2) were selected.

$$Death_{i,t} = b_0 + b_v\, vaccine_i + \sum_{d=1}^{2} b_{d,t} density_i + \sum_{y=1}^{2} b_{y,t} income_t$$

$$+ b_{s,t} stringency + b_{a,t} age\ 65\ + \sum_{h=1}^{3} b_{h,t} health$$

$$+ \sum_{r=1}^{4} b_{r,t} racial/ethnic \tag{2}$$

where $death_i$ is the cumulative COVID-19 death rate per 100,000 in state i during some period t. b_o, b_v, …… $b_{r,t}$, are parameters to be estimated.

The definition and descriptive statistics for the dependent and independent variables are as shown in Table 2.

4 Impact of vaccination and other variables on COVID-19 death rates

Using a regression model, the explanatory variables are added in groupings from I to VII, as shown in Table 2. The regression results are presented in Regressions 1 to 8, Table 3. Note that explanatory variables were removed if not significant at the $p < 0.10$ level (one-tailed), and the "best" fit regression, Regression (8), Tables 3, is shown in the last column.

4.1 Vaccination variable, vaccine

The estimated coefficient of − 2.28 for the vaccination coefficient shown in Table 3, Regression 8 suggests that after holding other explanatory variables constant, a state's COVID-19 death rate decreases by 2.28 deaths per 100,000 in a state's population for every increase of 1 percent in a state's average vaccine rate. The measured t statistic of − 3.75 for vaccine in Regression 8, Table 3, is highly significant at $p < 0.01$ level (one-tailed).

The empirical findings of Regression 8 can be used to estimate the reduction in COVID deaths as a result of each state's mean vaccination rate during the 3/10/21 to 12/28/22 period. This simulation that is based on a counterfactual scenario of no vaccination is shown in Table 4. For example, Alabama had a death rate of 209.5, with a mean vaccination rate of 43.3. If, as shown in Column 4, Alabama had a vaccination rate of zero, its corresponding death rate would have been 308.2. That calculation is based on the estimated coefficient of − 2.28 for the vaccination rate, vr, as shown in Table 3, Regression 8.

In order to convert the reduction of 98.7 in Alabama's death rate in Column 5 to a reduction in the number of deaths, it is necessary, as shown in Column 7, to multiply

Table 2 Dependent and independent variables used in the study

Description	Name	Mean	SD	CV	Min	Max	Obs	Source
Dependent variable								
Cumulative COVID-19 death rates from 1/1/21 to 8/10/21	dr	173.4	54.1	31.2	90.1	320.6	50	https://github.com/OxCGRT/USA-covid-policy/blob/master/data/OxCGRT_US_latest.csv
Independent variables								
I. Vaccination Rate								
Mean vaccination rate from 2/13/21 to 8/10/21 (Single dose or more)	vr	55.6	7.9	14.2	43.2	70.9	50	https://data.cdc.gov/Vaccinations/COVID-19-Vaccinations-in-the-United-States-Jurisdi/unsk-b7fc/data
II. Density variables								
Population density per square mile	Density	202.6	266.2	131.4	1.3	1207.8	50	https://worldpopulationreview.com/state-rankings/state-density-cities
Super density per square mile	Sdensity	342.9	1610.7	469.7	1.0	11,076.0	50	https://en.wikipedia.org/wiki/List_of_United_States_cities_by_population_density
III. Income variables								
Per Capita Personal Income (000)	Py	54.5	8.8	16.2	39.4	79.1	50	https://fred.stlouisfed.org/release/tables?rid=151&eid=257197
Poverty rate, percent of persons in poverty	Poverty	0.14	0.04	28.50	0.07	0.14	50	https://en.wikipedia.org/wiki/List_of_U.S._states_and_territories_by_poverty_rate
IV. Stringency Variable								
Mean Oxford Stringency Index from 1/1/21 to 8/10/21	Stringency	20.1	5.5	27.4	12.3	39.0	50	https://github.com/OxCGRT/USA-covid-policy/blob/master/data/OxCGRT_US_latest.csv

Table 2 (continued)

Description	Name	Mean	SD	CV	Min	Max	Obs	Source
V. Age Variable								
Percentage of population aged 65 or over	Age65	16.4	1.9	11.6	11.1	20.6	50	https://www.prb.org/resources/which-us-states-are-the-oldest/
VI. Health Related Variables								
Chronic Disease Indicators	Chronic	15.0	2.7	18.0	11.2	21.1	50	https://chronicdata.cdc.gov/Chronic-Disease-Indicators/U-S-Chronic-Disease-Indicators-Overarching-Conditi/7nzt-5wft
Highest Drug Use by State	Drugscore	44.6	7.9	17.7	26.1	59	50	Drug Use by State: Problem Areas (wallethub.com)
Obesity rate	Obesity	31.9	3.7	11.6	23.8	40.8	50	https://worldpopulationreview.com/state-rankings/obesity-rate-by-state
VII. Race/Ethnic Variables								
Black or African American Population as a percentage of the total population	Afram	11.0	10.0	90.9	0.1	40.0	50	https://worldpopulationreview.com/states/states-by-race
Asian population as a percentage of the total population	Asian	4.3	5.5	127.9	0.8	37.8	50	https://worldpopulationreview.com/state-rankings/asian-population
Hispanic population as a percentage of the total population	Hispan	11.7	10.3	88	1.5	48.5	50	https://worldpopulationreview.com/state-rankings/asian-population
American Indians/Alaskan Natives as a percentage of the total population	Ai/an	1.6	2.9	181.2	0.2	14.9	50	https://worldpopulationreview.com/states/states-by-race

Table 3 Regression results, dependent variable definition: mean cumulative death rate (Covid deaths per 100,000 people by state) from 3-10-21 to 12-28-22.

Dependent variable: dr	Regression 1	Regression 2	Regression 3	Regression 4	Regression 5	Regression 6	Regression 7	Regression 8
Adj. R-squared	0.38	0.36	0.58	0.60	0.64	0.75	0.77	0.77
Constant	414.18	427.42	185.9	169.54	115.25	– 19.35	– 45.88	– 61.51
	(9.57)***	(8.47) ***	(2.50)***	(2.82)***	(1.90)**	(– 0.31)	(-0.77)	(– 1.05)
I. Vaccination variable								
vr	– 4.32	– 4.62	– 2.15	– 1.95	– 2.84	– 2.84	– 2.51	– 2.28
	(– 5.61)***	(– 4.83)***	(– 2.46)***	(– 2.48)***	(– 3.46)***	(– 4.25)***	(– 3–39)***	(– 3.75)***
II. Density variables								
Density		0.01						
		(– 0.54)						
Sdensity		0.00						
		(– 0.08)						
III. Income variables								
py			– 0.36					
			(– 0.40)					
Poverty			9.86	10.80	8.90	– 2.77		
			(3.99)***	(5.18)***	(4.23)***	(– 0.84)		
IV. Stringency variable								
Stringency				– 1.28	– 0.68			
				(– 1.34)*	(– 0.72)			
V. Age variables								

Table 3 (continued)

Dependent variable: dr		Regression 1	Regression 2	Regression 3	Regression 4	Regression 5	Regression 6	Regression 7	Regression 8
	Age65					7.03	9.53	10.00	10.76
						(2.55)***	(3.79)***	(4.34)***	(5.19)***
	Chronic						12.58	11.2	11.97
							(3.41)***	(5.03)***	(7.04)***
	Drugscore						0.92	0.59	
							(1.56)*	(0.99)	
	Obesity						− 0.17		
							(− 0.73)		
VII. Racial/Ethnic variables									
	Afram							− 39.99	
								(− 0.81)	
	Asian							− 0.62	
								(− 0.78)	
	Hispan							0.25	
								(0.58)	
	ai/an							2.39	3.17
								(1.66)**	(2.44)***

t statistics (one-tailed test) in parentheses

* p < 0.10 ** p < 0.05 *** p < 0.01

Table 4 The impact of vaccinations in reducing Covid deaths

Column 1	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7	Column 8	Column 9
State	Death Rate with Vaccination	Vaccination Rate	Death Rate without Vaccination (Based on estimated coefficient of − 2.28 in Regression 8, Table3)	Reduction in Death Rate with Vaccination	Population	Population divided by 100,000	Reduction in the Number of Deaths	Reduction in the Number of Deaths as a % of Population
			Column 2 + (Column 3 * 2.28)	Column 4 Less Column 2		Column 6/100,000	Column 5 *Column 7	(Column 8/Column 6) *100
Alabama	209.5	43.3	308.2	98.7	5,074,296	50.7	5010	0.099
Alaska	157.0	53.6	279.2	122.2	733,583	7.3	896	0.122
Arizona	216.2	52.7	336.4	120.2	7,359,197	73.6	8843	0.120
Arkansas	242.6	46.2	347.9	105.3	3,045,637	30.5	3208	0.105
California	112.5	60.9	251.4	138.9	39,029,342	390.3	54,193	0.139
Colorado	133.2	60.6	271.4	138.2	5,839,926	58.4	8069	0.138
Connecticut	111.4	69.1	268.9	157.5	3,626,205	36.3	5713	0.158
Delaware	172.3	59.4	307.7	135.4	1,018,396	10.2	1379	0.135
Florida	238.1	57.2	368.5	130.4	22,244,823	222.4	29,011	0.130
Georgia	216.9	46.4	322.7	105.8	10,912,876	109.1	11,545	0.106
Hawaii	91.1	64.8	238.8	147.7	1,440,196	14.4	2128	0.148
Idaho	179.8	45.6	283.8	104.0	1,939,033	19.4	2016	0.104

Table 4 (continued)

Column 1	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7	Column 8	Column 9
Illinois	138.8	57.9	270.8	132.0	12,582,032	125.8	16,610	0.132
Indiana	184.7	48.3	294.8	110.1	6,833,037	68.3	7525	0.110
Iowa	151.1	54.5	275.4	124.3	3,200,517	32.0	3977	0.124
Kansas	166.7	52.9	287.3	120.6	2,937,150	29.4	3543	0.121
Kentucky	284.0	50.5	399.1	115.1	4,512,310	45.1	5195	0.115
Louisiana	185.7	45.7	289.9	104.2	4,590,241	45.9	4783	0.104
Maine	150.7	69.5	309.2	158.5	1,385,340	13.9	2195	0.158
Maryland	128.9	65.1	277.3	148.4	6,164,660	61.6	9150	0.148
Massachusetts	133.3	68.9	290.4	157.1	6,981,974	69.8	10,968	0.157
Michigan	239.1	52.7	359.3	120.2	10,034,113	100.3	12,057	0.120
Minnesota	133.1	59.9	269.7	136.6	5,717,184	57.2	7808	0.137
Mississippi	212.5	43.7	312.1	99.6	2,940,057	29.4	2929	0.100
Missouri	221.4	48.4	331.8	110.4	6,177,957	61.8	6817	0.110
Montana	202.3	49.8	315.8	113.5	1,122,867	11.2	1275	0.114
Nebraska	130.8	55.3	256.9	126.1	1,967,923	19.7	2481	0.126
Nevada	212.2	52.0	330.8	118.6	3,177,772	31.8	3768	0.119
New Hampshire	120.0	61.2	259.5	139.5	1,395,231	14.0	1947	0.140
New Jersey	127.4	65.3	276.3	148.9	9,261,699	92.6	13,789	0.149
New Mexico	235.2	62.5	377.7	142.5	2,113,344	21.1	3012	0.143
New York	134.6	65.6	284.2	149.6	19,677,151	196.8	29,431	0.150
North Carolina	152.5	52.5	272.2	119.7	10,698,973	107.0	12,807	0.120

Table 4 (continued)

Column 1	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7	Column 8	Column 9
North Dakota	121.6	48.0	231.0	109.4	779,261	7.8	853	0.109
Ohio	188.9	51.1	305.4	116.5	11,756,058	117.6	13,697	0.117
Oklahoma	320.6	49.1	432.5	111.9	4,019,800	40.2	4500	0.112
Oregon	156.6	60.5	294.5	137.9	4,240,137	42.4	5849	0.138
Pennsylvania	188.5	59.1	323.2	134.7	12,972,008	129.7	17,480	0.135
Rhode Island	111.4	70.7	272.6	161.2	1,093,734	10.9	1763	0.161
South Carolina	193.9	48.7	304.9	111.0	5,282,634	52.8	5866	0.111
South Dakota	135.8	54.0	258.9	123.1	909,824	9.1	1120	0.123
Tennessee	243.6	46.3	349.2	105.6	7,051,339	70.5	7444	0.106
Texas	155.9	51.9	274.2	118.3	30,029,572	300.3	35,535	0.118
Utah	95.7	53.0	216.5	120.8	3,380,800	33.8	4085	0.121
Vermont	90.1	70.9	251.8	161.7	647,064	6.5	1046	0.162
Virginia	150.2	62.5	292.7	142.5	8,683,619	86.8	12,374	0.143
Washington	128.4	62.6	271.1	142.7	7,785,786	77.9	11,112	0.143
West Virginia	299.2	48.5	409.8	110.6	1,775,156	17.8	1963	0.111
Wisconsin	146.8	57.2	277.2	130.4	5,892,539	58.9	7685	0.130
Wyoming	219.8	44.0	320.1	100.3	581,381	5.8	583	0.100
Total					332,615,754		427,000	0.128

98.7 by its population divided by 100,000. The resulting estimate of 5,010 fewer deaths is presented in Column 8. To express that number as a percentage of Alabama's population, the ratio of the reduction in deaths (Column 8) is divided by its population (Column 6) and then multiplied by 100, as shown in Column 9. The resulting estimate of 0.099 suggests that Alabama's COVID death rate was reduced by about a tenth of a percent of its population, given its mean vaccination rate of 43.3 percent.

That estimate can be compared to Vermont, the state with the highest vaccination rate of 70.9 percent. As shown in Column 9 of Table 4, Vermont's high rate of vaccination resulted in a COVID death rate that was reduced by 0.162 percent, considerably higher than Alabama's estimated reduction of 0.099 percent.

For all 50 states, the estimated reduction in COVID deaths resulting from vaccinations is estimated at 427,000 or 0.128 percent of the nation's population. Since the actual number of COVID deaths during the 3/10/21 to 12/28/22 period was 577,000, the estimated reduction of 427,000 in COVID deaths suggests that had vaccinations not been available, COVID deaths in the U.S. during that period would have reached about 1 million (Actual COVID deaths of 577,000 plus reduction in COVID deaths of 427,000) or 0.301 percent of its population. That compares to an actual percentage of 0.173 deaths as a percent of the nation's population. The decline in the nation's death rate of 0.128 (0.301 less 0.173) is the value shown in the total row of Table 4.

Table 5 shows a listing of states in rank order of the reduction in COVID deaths as compared to each state's mean vaccination rate. Figure 5 represents the data shown in Table 5 arranged in quintiles from the 10 states with the highest mean vaccination rate down to the 10 states with the lowest vaccination rates. For example, the l0 states with the highest vaccination rate had a mean vaccination rate of 67.3 percent and a mean reduction in the death rate of 0.153. Those 10 states with the lowest mean vaccination rate (45.8 percent) experienced a 0.104 reduction in its mean death rate.

4.2 Density variables, density and sdensity

In addition to a state's population density, a super density (sdensity) variable was added to the regression tests. Since density is a measure of a state's population divided by its total geographical area, it does not capture the impact of those states where a highly populated metropolitan area, like New York City, exhibits extremely high density. That impact can be captured by a super density variable where all cities in the nation with a population of 300,000 or more and had a population density of at least 10,000 people per square mile were identified and measured as a ratio of each state's total population. The resulting ratio, in turn, was multiplied by the density of the metropolitan areas that met the selection criteria described above. In the structural form of the model, this super density variable (sdensity) is given by

$$\text{Sdensity}_{i,t} = \sum_{k=1}^{n_1} p_{k,i}/p_{i,t} * \text{density}_{i,t}$$

where $p_{k,i}$ is population of the kth city in state i with a population > 300,000 and density > 10,000 per mile^2. n_i is number of cities in state i with population > 300,000
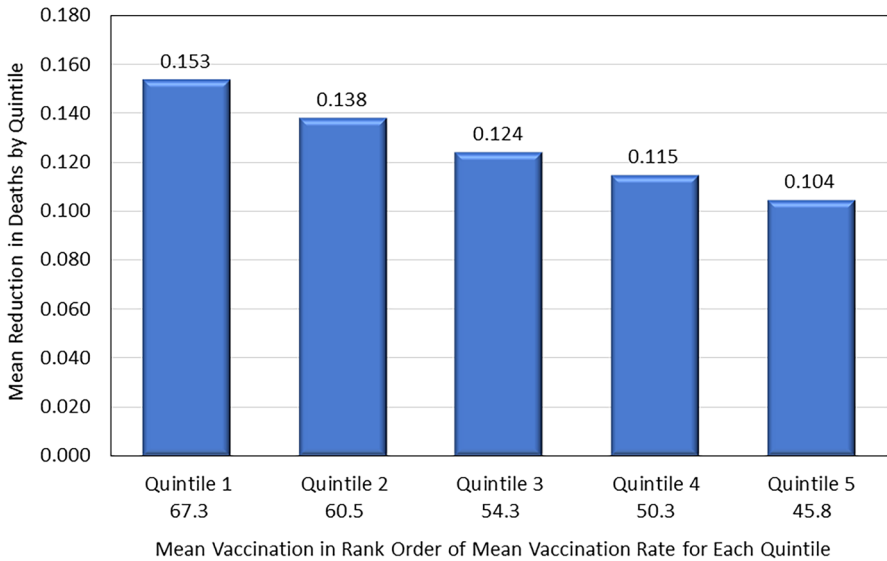
Table 5 A listing of states in rank order of the reduction in Covid deaths as a percentage of each state's population

		Mean vaccination rate	Lives saved as a % of population
1	Vermont	70.9	0.162
2	Rhode Island	70.7	0.161
3	Maine	69.5	0.158
4	Connecticut	69.1	0.158
5	Massachusetts	68.9	0.157
6	New York	65.6	0.150
7	New Jersey	65.3	0.149
8	Maryland	65.1	0.148
9	Hawaii	64.8	0.148
10	Washington	62.6	0.143
11	New Mexico	62.5	0.143
12	Virginia	62.5	0.143
13	New Hampshire	61.2	0.140
14	California	60.9	0.139
15	Colorado	60.6	0.138
16	Oregon	60.5	0.138
17	Minnesota	59.9	0.137
18	Delaware	59.4	0.135
19	Pennsylvania	59.1	0.135
20	Illinois	57.9	0.132
21	Florida	57.2	0.130
22	Wisconsin	57.2	0.130
23	Nebraska	55.3	0.126
24	Iowa	54.5	0.124
25	South Dakota	54	0.123
26	Alaska	53.6	0.122
27	Utah	53	0.121
28	Kansas	52.9	0.121
29	Arizona	52.7	0.120
30	Michigan	52.7	0.120
31	North Carolina	52.5	0.120
32	Nevada	52	0.119
33	Texas	51.9	0.118
34	Ohio	51.1	0.117
35	Kentucky	50.5	0.115
36	Montana	49.8	0.114

Table 5 (continued)

		Mean vaccination rate	Lives saved as a % of population
37	Oklahoma	49.1	0.112
38	South Carolina	48.7	0.111
39	West Virginia	48.5	0.111
40	Missouri	48.4	0.110
41	Indiana	48.3	0.110
42	North Dakota	48	0.109
43	Georgia	46.4	0.106
44	Tennessee	46.3	0.106
45	Arkansas	46.2	0.105
46	Louisiana	45.7	0.104
47	Idaho	45.6	0.104
48	Wyoming	44	0.100
49	Mississippi	43.7	0.100
50	Alabama	43.3	0.099

Fig. 5 Mean Reduction in Deaths as a Percent of Mean Population

and density$> 10{,}000$ per mile^2. $P_{i,t}$ is population of state i as of some period t. density$_{i,t}$ is density of state i as of some period t.

Although the density and super density variables were highly significant in earlier tests conducted during the pre-vaccination period from 4/1/20 to 12/1/20 (Doti 2021a), they were not significant during the 3/10/21 to 12/28/22 period covered in the current study (See Regression 2, Table 3).

These findings suggest that while COVID hit dense states and highly dense urban areas particularly hard during the early stages of the pandemic in 2020, that impact fell away over time and was no longer significant during the time that vaccinations became available and were being administered.

4.3 Income variables, py and poverty

Because the personal income variable, py, did not pass the $p < 0.10$ significance test in Regression 3, Table 3, it was dropped from Regression 4. In sharp contrast, the poverty rate variable, poverty, was significant in Regression 3–5, Table 3. But it too was dropped in Regression 6 when the chronic disease variable, chronic, was added to Regression 6, Table 3. This will be explained in more detail in Sect. 4.6.

4.4 Stringency variable, stringency

The efficacy of a state's governmental regulations that impose mandates in order to control the spread of COVID is measured by the Oxford daily governmental stringency index (stringency). This index measures the stringency of statewide governmental mandates on a daily basis using a scale from 1 to 100 for eleven different types of governmental responses. The index measure used in this study was derived by calculating an average stringency index from the weekly averages for each state during the 3/10/21 to 12/28/22 period. The derivation is given by

$$\text{stringency}_{i,t} = \sum_{w=1}^{n} \text{stringency}_{i,\,w} / n_t$$

where stringency$_{i,t}$ is the mean stringency index in state i as of some period t, stringency$_{i,w}$ is the stringency index in state i as of a particular week, w, and n_t is the number of weeks during period t.

In a previous study, the stringency variable was found to be highly significant in reducing COVID death and case rates throughout 2020 and particularly during the 7/1/20 to 12/31/20 period (Doti, 2021a). In fact, of all the variables tested in that study, stringency was the only explanatory variable during the second half of 2020 that had $p < 0.05$ or higher level of significance.

In the current study, however, the stringency variable exhibited no significance in reducing statewide death rates after the age65 variable was added in Regression 5, Table 3. A possible explanation for the lack of significance of the stringency variable in reducing COVID deaths during the 3/10/21 to 12/28/22 period is that states, on average, reduced their use of policy intervention, thereby leading to a sharp decline in
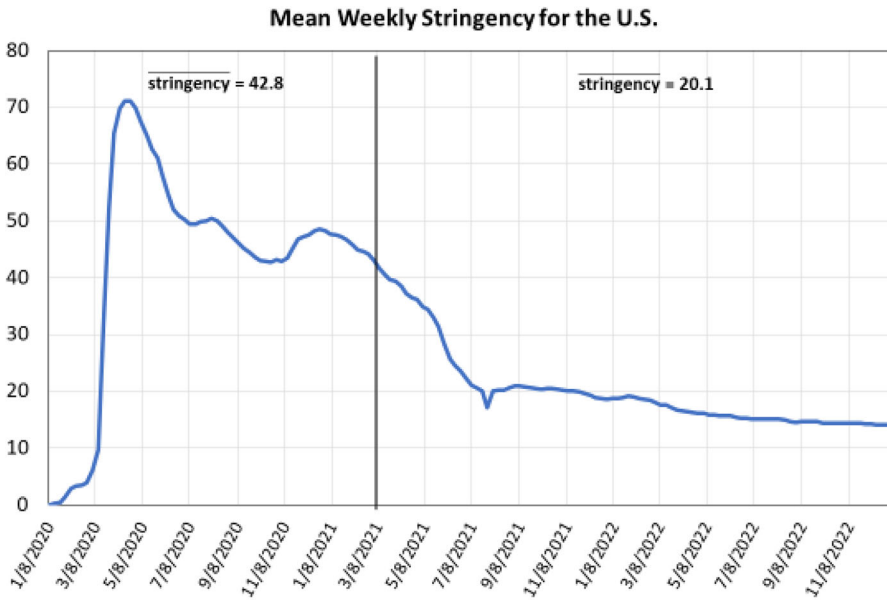
Mean Weekly Stringency for the U.S.

Fig. 6 Mean weekly stringency for the US

the Oxford stringency score. This can be seen in Fig. 6, which shows the mean weekly stringency score declined from 42.8 during the 1/8/20 to 3/10/21 period to 20.1 during the 3/10/21 to 12/28/22 period.

Figure 7 shows that the steady decline in the mean weekly stringency score during the 3/10/21 to 12/28/22 period occurred during a time when the mean death rate decreased from 218.0 at the beginning of the period to 50.5 by its end. While that may explain the accompanying decline in the efficacy of the stringency variable in reducing death rates during that period, stringency continued its steady decline even during the periods when the COVID death rate spiked as a result of the Delta and Omicron outbreaks.

It might be argued that statewide differences in stringency were effective during the period when the Delta and Omicron surges occurred. To test for that possibility, the time interval for calculating each state's mean death rate and mean stringency rate was changed to that period when death rates increased above 100 and then fell back below 100. That period is from 8/8/21 to 3/30/22. As shown in Fig. 8, no discernable relationship appears to exist between mean stringency and death rates during that period.

That finding is supported in a reestimation of Regression 6, Table 3, over the 8/8/21 to 3/30/22 period (detailed regression results not reported here). The estimated coefficient for stringency continued to be insignificant (t-statistic = − 0.43).

Finally, regression tests were conducted over the 3/10/21 to 7/14/21 period when the mean stringency rates, while falling, were still above a score of 20 (See Fig. 6).

A Comparison of Stringency and Weekly COVID Death Rates per 100,000 in the U.S. from 3/10/21 to 12/28/22
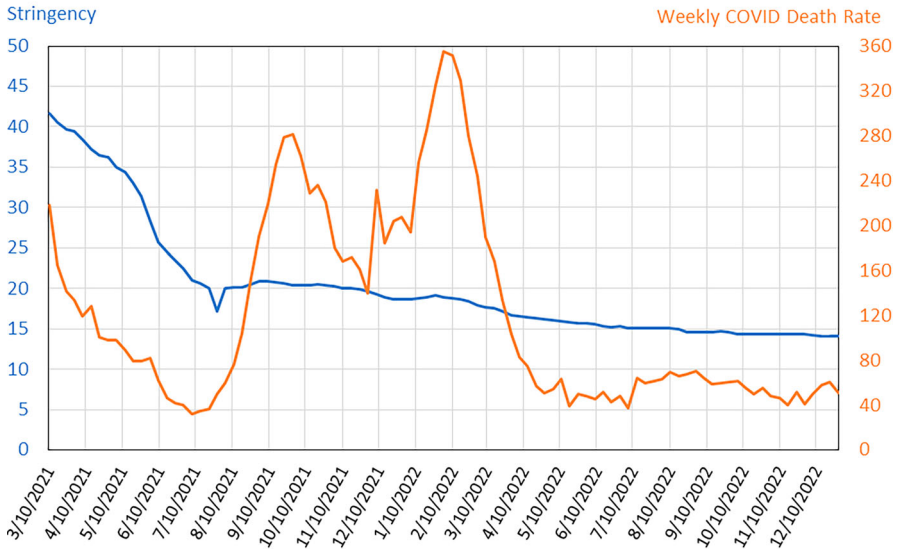
Fig. 7 A comparison of stringency and weekly COVID death rates per 100,000 in the U.S. from 3/10/21 to 12/28/22

Relationship between Mean Stringency and Cumulative COVID Death Rates by State During the Delta and Omicron Surges (8/8/21 to 3/30/22)
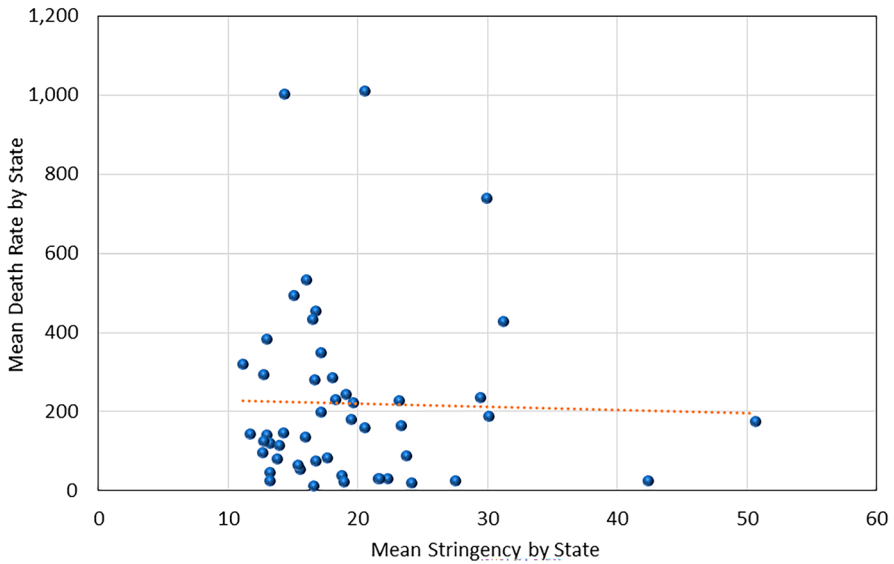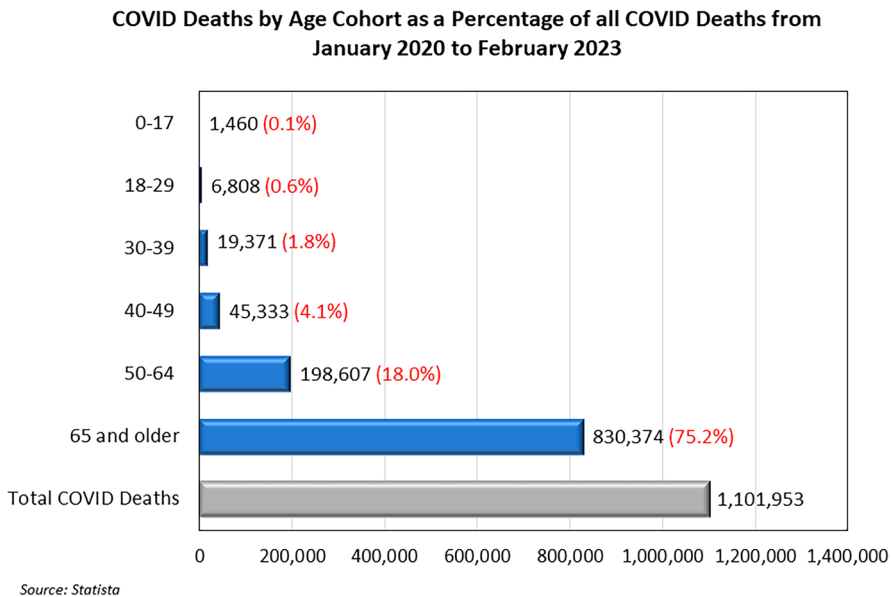
Fig. 8 Relationship between mean stringency and cumulative COVID death rates by state during the Delta and Omicron surges (8/8/21 to 3/30/22)

As in the regression tests over the longer 3/10/21 to 12/28/22 period, the coefficient for the stringency variable was insignificant (p value = 0.86).

4.5 Age variable, age65

As shown in Fig. 9, more than 75.2 percent of COVID deaths occurred over the age of 65, even though that age cohort represents only 17 percent of the total U.S. population. It is not surprising, therefore, that the coefficient for the age65 variable in Eq. (2), Table 3 was highly significant. The coefficient of 10.76 for the age65 variable in that equation suggests that a one percent increase in a state's percentage of its population over the age of 65 will lead to the 10.76 percent increase in that state's mean cumulative death rate.

The importance of including age65 as an explanatory variable can also be seen in Fig. 11, which reproduces Fig. 4 that shows the relationship between only two variables—the vaccination rate and death rate. Florida and Maine are highlighted in Fig. 10. Those two states are the only two with the age65 variable above 20 percent. It is likely, therefore, that the relatively high level of unexplained variation for Florida and Maine from the trendline in Fig. 10 is at least partially explained by a greater proportion of those state's populations being vulnerable to the lethal nature of COVID.

COVID Deaths by Age Cohort as a Percentage of all COVID Deaths from January 2020 to February 2023

Age Cohort	Deaths
0-17	1,460 (0.1%)
18-29	6,808 (0.6%)
30-39	19,371 (1.8%)
40-49	45,333 (4.1%)
50-64	198,607 (18.0%)
65 and older	830,374 (75.2%)
Total COVID Deaths	1,101,953

Source: Statista

Fig. 9 COVID deaths by age cohort as a percentage of all COVID deaths from January 2020 to February 2023
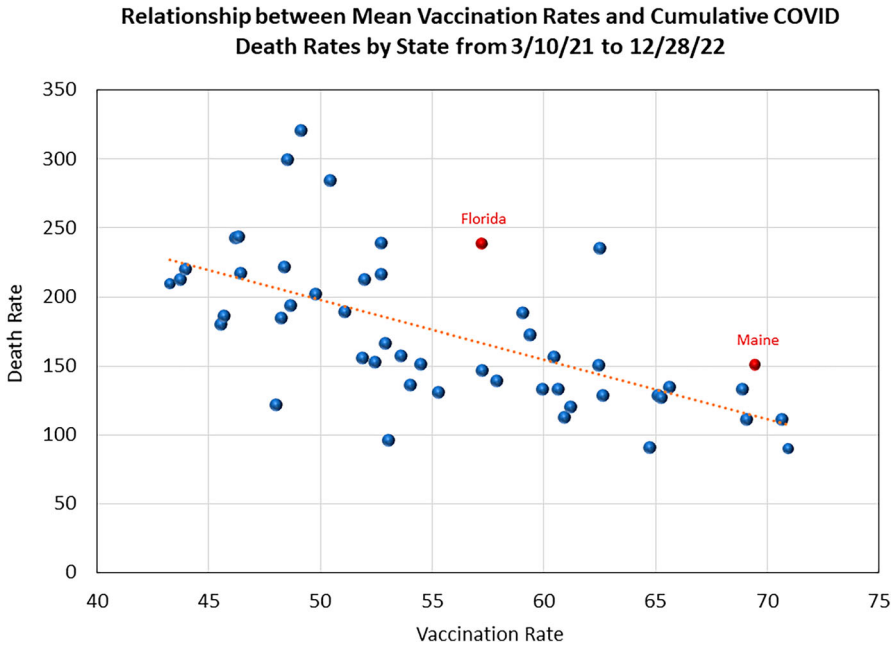
Fig. 10 Relationship between mean vaccination rates and cumulative COVID death rates by state from 3/10/21 to 12/28/22
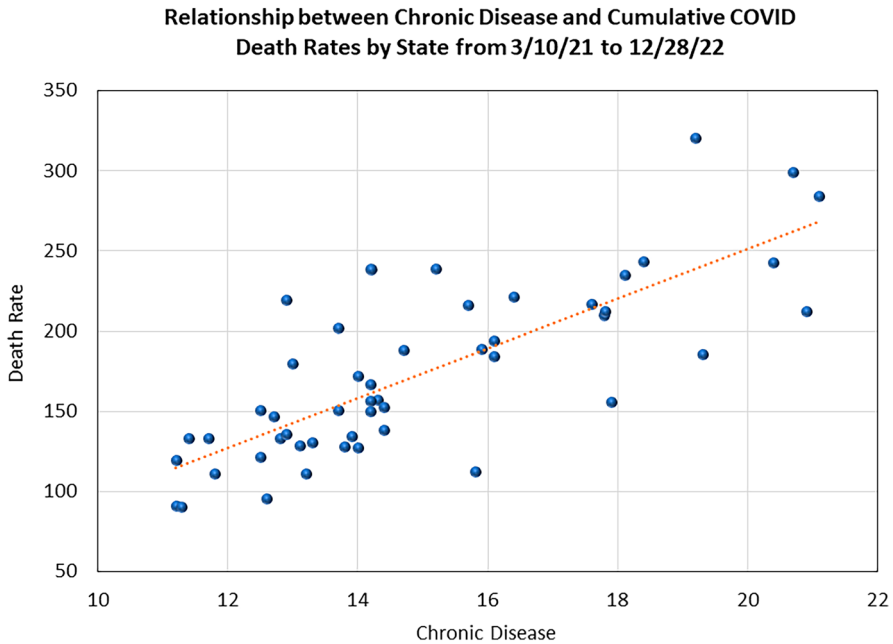
4.6 Chronic disease and other health-related variables

The obesity variable was not significant in Regression 6, Table 3. While the drugscore variable in Regression 6, Table 3 was moderately significant in that regression (p < 0.10), it fell out of significance in Regression 7, Table 3 when the racial/ethnic variables were added to the model.

The chronic variable, however, was highly significant (p < 0.01). Its inclusion increased the adjusted R-squared value from 0.64 to 0.75. The linear relationship between COVID death rates and chronic disease is shown in Fig. 11. This measure was obtained from a self-rated survey conducted by the C.D.C.'s Division of Population Health from its Behavioral Risk Factor Surveillance System (BRFSS), which "uses complex sampling designs and weights" in surveying all states for chronic disease risk factors. (Holt et al., 2015).

The demographic group included in the 2021 survey was resident adults aged ≥ 18 years. This measure is based on self-assessment only and does not include an objective health component. The numerator for the chronic variable was all respondents, who self-reported their health status as fair or poor. The denominator included all respondents, excluding those who refused to answer, had a missing answer or answered: "don't know/not sure." (Holt et al., 2015).

Table 6 includes the percentage of those who responded as having "fair or poor" health in alpha order and rank order by state. It might be argued that the self-reporting during the survey year of 2021 is potentially biased since the respondents might have

**Relationship between Chronic Disease and Cumulative COVID
Death Rates by State from 3/10/21 to 12/28/22**

Fig. 11 Relationship between chronic disease and cumulative COVID death rates by state from 3/10/21 to 12/28/22

been inclined to report their health status as fair or poor if they recently experienced a coronavirus infection. The data, however, do not support that view. The average mean score of 14.2 for the chronic variable for the 2021 survey year, as well as that for the COVID year of 2020 survey of 12.4, were both lower than the mean chronic scores of 17.3, 16.5 and 17.3 for the 2017, 2018 and 2019 surveys, respectively. (Source: *C.D.C. U.S. Chronic Disease Indicators*).

Figure 12 reproduces Fig. 4, that shows the relationship between the vaccination rate and death rate. Notice that Oklahoma, West Virginia, and Kentucky deviated sharply from the trendline. A major reason for being statistical outliers in Fig. 12 is likely related to their high percentage of chronic disease, as reported in the C.D.C. survey. That survey, as shown in Table 6, showed that Kentucky ranked #1 in chronic disease, with West Virginia at #3 and Oklahoma at #6.

More importantly, the regression shown in Table 3 points to a clearer explanation of causality in explaining COVID mortality. When a poverty variable was added in Regression 3, Table 3, the coefficient for the vaccination variable, vr, declined sharply from − 4.32 to − 2.15, with the poverty variable showing significance at the 0.01 level. But when the chronic disease variable, chronic, was added in Regression 6, Table 3, the poverty variable was no longer significant, while the chronic variable was significant at the 0.01 level.

These empirical results suggest that poverty and chronic disease are highly correlated as reflected by a correlation coefficient of 0.62 ($p < 0.01$) as well as the scatter diagram shown in Fig. 13.

Table 6 Fair or poor self-rated health status among adults aged ≥ 18 years 2021 Data

Alpha Order by state		% of adults with fair or poor self-rated health status	Alpha Order by state		% of adults with fair or poor self-rated health status from highest to lowest
1	Alabama	17.8	1	Kentucky	21.1
2	Alaska	14.3	2	Mississippi	20.9
3	Arizona	15.7	3	West Virginia	20.7
4	Arkansas	20.4	4	Arkansas	20.4
5	California	15.8	5	Louisiana	19.3
6	Colorado	12.8	6	Oklahoma	19.2
7	Connecticut	11.8	7	Tennessee	18.4
8	Delaware	14.0	8	New Mexico	18.1
9	Florida	14.2	9	Texas	17.9
10	Georgia	17.6	10	Alabama	17.8
11	Hawaii	11.2	11	Nevada	17.8
12	Idaho	13.0	12	Georgia	17.6
13	Illinois	14.4	13	Missouri	16.4
14	Indiana	16.1	14	Indiana	16.1
15	Iowa	12.5	15	South Carolina	16.1
16	Kansas	14.2	16	Ohio	15.9
17	Kentucky	21.1	17	California	15.8
18	Louisiana	19.3	18	Arizona	15.7
19	Maine	13.7	19	Michigan	15.2
20	Maryland	13.1	20	Pennsylvania	14.7
21	Massachusetts	11.4	21	Illinois	14.4
22	Michigan	15.2	22	North Carolina	14.4
23	Minnesota	11.7	23	Alaska	14.3
24	Mississippi	20.9	24	Florida	14.2
25	Missouri	16.4	25	Kansas	14.2
26	Montana	13.7	26	Oregon	14.2
27	Nebraska	13.3	27	Virginia	14.2
28	Nevada	17.8	28	Delaware	14.0
29	New Hampshire	11.2	29	New Jersey	14.0
30	New Jersey	14.0	30	New York	13.9
31	New Mexico	18.1	31	Washington	13.8
32	New York	13.9	32	Maine	13.7

Table 6 (continued)

Alpha Order by state		% of adults with fair or poor self-rated health status	Alpha Order by state		% of adults with fair or poor self-rated health status from highest to lowest
33	North Carolina	14.4	33	Montana	13.7
34	North Dakota	12.5	34	Nebraska	13.3
35	Ohio	15.9	35	Rhode Island	13.2
36	Oklahoma	19.2	36	Maryland	13.1
37	Oregon	14.2	37	Idaho	13.0
38	Pennsylvania	14.7	38	South Dakota	12.9
39	Rhode Island	13.2	39	Wyoming	12.9
40	South Carolina	16.1	40	Colorado	12.8
41	South Dakota	12.9	41	Wisconsin	12.7
42	Tennessee	18.4	42	Utah	12.6
43	Texas	17.9	43	Iowa	12.5
44	Utah	12.6	44	North Dakota	12.5
45	Vermont	11.3	45	Connecticut	11.8
46	Virginia	14.2	46	Minnesota	11.7
47	Washington	13.8	47	Massachusetts	11.4
48	West Virginia	20.7	48	Vermont	11.3
49	Wisconsin	12.7	49	Hawaii	11.2
50	Wyoming	12.9	50	New Hampshire	11.2
	United States	14.2		Unites States	14.2

Source: https://chronicdata.cdc.gov/Chronic-Disease-Indicators/U-S-Chronic-Disease-Indicators-Overarching-Conditi/7nzt-5wft

Since the chronic disease variable displaces the poverty variable in the regression results shown in Table 3, it appears that the line of causality is as follows:

Higher Poverty → More Chronic Disease → More COVID Deaths.

While poverty might serve as a proxy for chronic disease, these empirical findings suggest that the direct impact of chronic disease on COVID mortality is more predictive than the indirect effect of poverty in explaining COVID mortality.

In a study by Robert Barro, the state lifespan in 2018 was used as an explanatory variable in his first-stage regression tests. Given the high correlation between chronic disease and lifespans across state, as shown in Fig. 14, it might be thought that lifespans can serve as a useful proxy for chronic disease. This, however, is not the case. When that lifespan variable was substituted in the present study in place of chronic disease in Regression 8, Table 3, the adjusted R^2 value fell from 0.77 to 0.63.
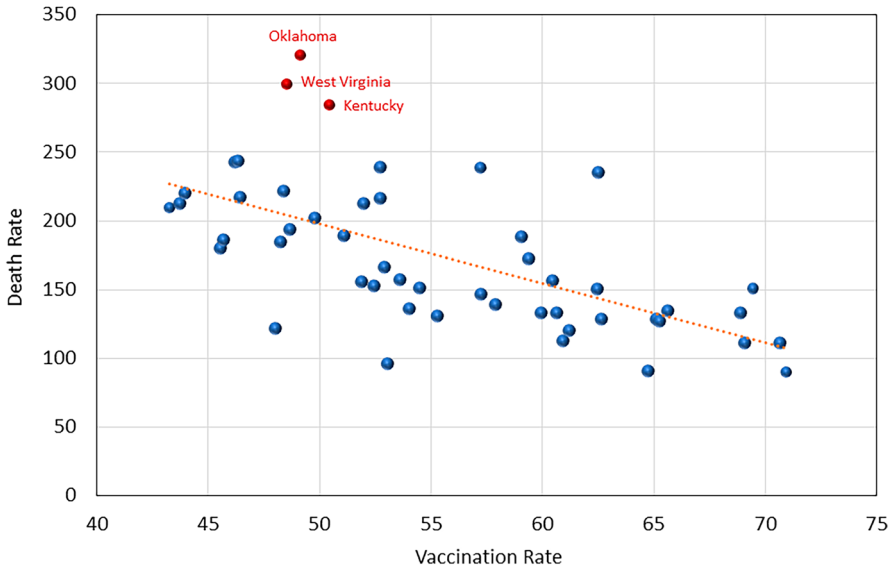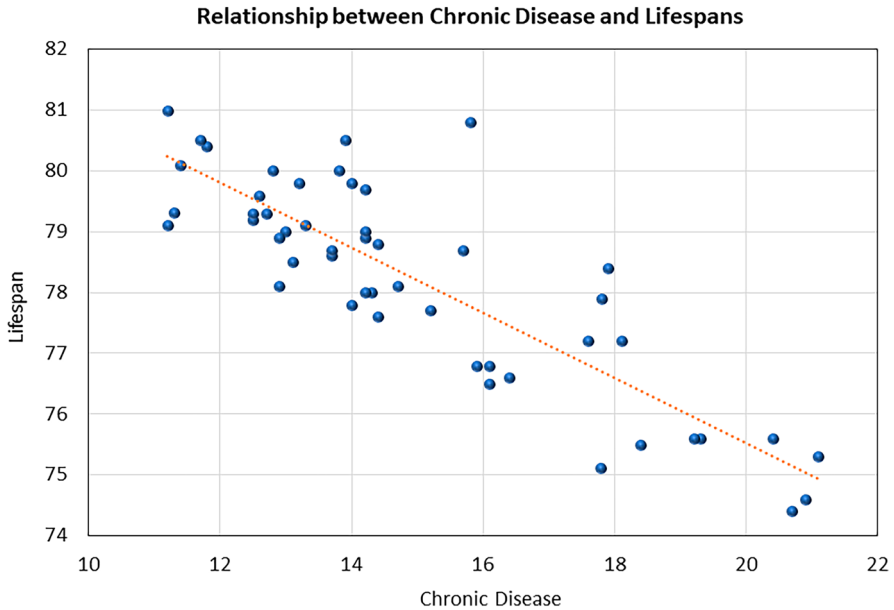
Fig. 12 Relationship between Mean Vaccination Rates and Cumulative COVID Death Rates by State from 3/10/21 to 12/28/22

Fig. 13 Relationship between Poverty Rates and Chronic Disease Rates

Fig. 14 Relationship between Chronic Disease and Lifespans

The measured t statistic for the life span variable was -3.31 as compared to 7.04 for the chronic disease variable.

These findings point to the critical importance of using a chronic disease variable in any regression tests across states. Excluding the direct impact of chronic disease in explaining COVID deaths will bias upwards the efficacy of COVID vaccinations in reducing death rates. The reason for this is that states with lower vaccination rates also tend to have higher rates of chronic disease. That means the exclusion of chronic disease from the equation will incorrectly lead to a higher estimated number of lives saved from COVID vaccinations. In reality, when vaccination rates are low, many of the deaths in a state occur not necessarily because of the low rates of vaccination but because that state has a higher rate of chronic disease. Similarly, states with relatively higher rates of vaccination tend to have lower rates of chronic disease. As a result, estimates of lives saved in a state because of a higher rate of vaccination will tend to attribute the lower death rate in that state exclusively to its higher vaccination rate when, in fact, a significant portion of that lower death rate is due to lower rates of chronic disease.

It should be noted that the estimated lives saved, as calculated in Table 4, were based on the estimated coefficient of − 2.28 (see Column 4, Table 3). If the chronic disease is not held constant as a regressor, the estimated coefficient for the vaccination rate would be − 4.32. Using that coefficient instead of − 2.28 would result in an inflated estimate of 809,000 lives saved instead of the 427,000 estimate in this study, as shown in Table 4.

4.7 Racial/Ethnic Variables, afram, asian, hispan, and ai/an

The only racial/ethnic variable that exhibited significance ($p < 0.01$) was for American Indians/Alaska Natives (ai/an). As shown in Regression 7, Table 3, the coefficient for ai/an was 2.39, which suggests that a one percent increase in ai/an in a state leads, on average, to a 2.39 percent increase in that state's mean cumulative COVID death rate over the 3/10/21 to 12/28/22 period.

The fact that the ai/an variable is such a significant explanatory variable is noteworthy, given the relatively low percentages of ai/an in most states. For example, 40 states have ai/an percentages within a very low range of 0.15 to 1.28 percent. These low percentages present analytic challenges in making statistical inferences about statewide differences in ai/an in regression modeling.

In spite of these challenges, the high degree of significance of the ai/an variable in Regression 8, Table 3 attests to the serious health challenges faced by the American Indian community. As stated in C.D.C.'s *Morbidity and Mortality Weekly Report*, compared with other racial/ethnic groups, American Indians/Alaskan Natives (AI/AN) have a lower life expectancy, lower quality of life and are disproportionately affected by many chronic conditions (Adakai et al., 2018). The health challenges facing American Indians are perhaps best reflected by the fact that, on average, American Indians die 12–13 years earlier than White Americans. (Gorzig et al., 2022).

Factors that help explain the health disparities for American Indians include low income, low educational attainment rates, health access, and higher crime, pollution, and injury rates. (https://www.cdc.gov/healthequity/whatis/index.html).

5 Conclusion

Much controversy has arisen over the efficacy of COVID vaccinations and the efforts taken or not taken by state governments to increase their mean vaccination rates. In spite of this, no academic papers have been published that directly examine statewide differences in vaccination rates while holding constant the impact of chronic disease. This study hopes to fill the gap by presenting a regression test that measures the hypothesized impact of vaccinations while holding chronic disease and other explanatory variables on each state's COVID death rate.

The empirical findings presented in Table 3 show that the vaccination rate, the percentage of people over age 65, the percentage of people with chronic disease, and the percentage of American Indian/Natives, are all significant at the $p < 0.01$ (one-tailed) level or higher and have the hypothesized signs of association.

On average, the regression findings suggest that a state's COVID death rate changes by -2.28 deaths per 100,000 in a state's population for every increase of one percent in a state's vaccination rate. That value, coupled with each state's mean vaccination rate over the 3/10/21 to 12/28/22 period, makes it possible to estimate the reduction in each state's COVID death rate. The resulting reduction in each state's death rate because of vaccinations can be used to solve each state's reduction in the number of COVID deaths. As shown in Table 4, the regression findings suggest that COVID vaccinations led to a reduction of about 427,000 COVID deaths. Since the actual

number of COVID deaths during the 3/10/21 to 12/28/22 period was 577,000, the estimated reduction of 427,000 COVID deaths during that same period suggests that COVID deaths would have reached about 1 million had vaccinations not been available. Similarly, the nation's COVID death rate is estimated to have declined from 0.301 deaths as a percent of the nation's population to 0.173 because of vaccinations.

The regression findings also suggest that at least over the 3/10/21 to 12/28/22 period, variables representing state population density, income, and stringency were not found to be significant in explaining COVID death rates.

The percentage of a state's population over the age of 65, age65, was highly significant in explaining statewide differences in COVID death rate. Specifically, Regression 8, Table 3, suggests that an increase of one percent in the percentage of people over the age of 65 in state leads to a 10.76 increase in that state's COVID death rate.

The only health-related variable that proved to be significant was one that measured the percentage of people in a state who self-reported as suffering from chronic disease. That chronic disease variable was highly significant and suggested a one percent increase leads to an 11.97 percent decrease in a state's COVID death rate. It was shown that the direct effect of chronic disease in determining COVID death rates across states is a more accurate regressor than indirect proxies of health such as poverty rates or lifespans across states.

Of the four racial/ethnic variables tested, only the American Indian/Native variable was significant. This empirical finding points to the serious health challenges facing American Indians.

This empirical study focused on the benefits of COVID vaccinations in reducing COVID death rates. Future research should extend these findings to measure the costs of vaccinations in order to derive a broader analysis of the relevant costs as well as benefits.

Declarations

Competing interests The authors declare no competing interests.

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