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Differences in Vaccination Coverage Rates Between the States of U.S.

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Abstract: This paper investigates vaccination rates in the US, analyzing factors behind the disparities with high-income countries. Employing economic analysis and econometrics, it aims to inform policy interventions for enhancing vaccination uptake and combating COVID-19 spread. Key aspects explored encompass trust in science, public healthcare provisioning, and COVID-19 regulations. Employing a cost-benefit model and empirical regressions, the research underscores these elements' role in shaping vaccination rates across states. Results underscore the importance of trust-building, equitable healthcare access, and effective regulations in guiding vaccination decisions. Through rigorous literature review, conceptual framework development, and meticulous data curation, the research provides insights into vaccination dynamics. It demonstrates that fostering trust, ensuring inclusive healthcare, and implementing robust regulations are essential for successful vaccination campaigns. In summary, this comprehensive examination of vaccination rates marries economic analysis, empirical insights, and strategic recommendations, offering a foundation for targeted measures to boost vaccination rates and enhance public health resilience.

Keywords: vaccination rates, public healthcare, data analysis, policy recommendations

1. Introduction

Vaccination rates in the US, while comparatively high in early-2021, have fallen behind other high-income countries [1]. This is despite the huge amount of stimulus that has been targeted towards increasing vaccination rates, such as the $10bn in vaccine-expansion funding in May 2021 and a further request for $22.5bn this May 2022 [2] [3]. Examination of the economic and social factors causing the US to lag behind is crucial for designing for more targeted policy recommendations to boost vaccination uptake and limit further outbreaks of COVID-19.

This paper proposes a cost-benefit model to explain the variations in vaccination rates across US states, then tests this empirically through a series of regression specifications. The results lend support to the model, namely that higher degrees of (1) trust in science, (2) publicly provided healthcare, and (3) stringent regulation surrounding COVID-19 are significant in raising average vaccination rates within states.

2. Literature Review

Vaccination patterns and disparities are critical aspects of public health that have gained significant attention in recent years. Bag et al (2020) identified positive spatial autocorrelation in COVID-19 spread in India, prompting an examination of vaccination disparities within US states [4]. Similarly, Phadke et al (2020) highlighted the resurgence of measles outbreaks due to vaccine refusal, emphasizing the need to address disparities in childhood immunity to vaccine-preventable diseases as evidenced by Glasser et al (2020) [5]. The heterogeneity in childhood immunity and the low uptake of non-COVID-19 vaccinations serve as reflections of diminished trust in science, a proxy useful for your model's trust component.

Trust plays a pivotal role in vaccination behaviors. Kennedy et al (2022) demonstrated that trust in scientists varies based on demographics and political affiliations. This observation aligns with Eichen-green et al (2020), which underscored the link between lower trust in science and limited prior scientific knowledge [6] [7]. The work of Wang et al (2020)* utilizing Health Belief Models shed light on determinants of pneumococcal vaccine uptake. Drawing from Michie et al (2008), theory-based interventions emerged as effective tools for influencing vaccination behavior [8].

Vaccination policies and incentives are essential considerations for increasing vaccine uptake. Archarya and Dhakal (2021) examined vaccination lotteries as incentives, revealing their broad success in enhancing vaccination rates, although outcomes varied across states [9]. This aligns with the nuanced findings of recent studies by Sehgal (2021) and Barber and West (2022), which highlighted the mixed results of vaccination lotteries [10]. Your model's incorporation of vaccination lotteries as control variables is an essential step in capturing their influence.

Methodological approaches underpinning these studies reflect diverse strategies. The usage of robustness checks, as seen in Yunwei et al (2017)*, is crucial for ensuring the validity of findings [11]. Such checks help establish the robustness of relationships between vaccination and unemployment rates. These methods, alongside the theoretical models adopted by Wang et al (2020)*, provide a comprehensive foundation for understanding vaccination dynamics [12].

*Literature is not explicitly related to the US or COVID-19 vaccination rates, however still provides relevant methodology insights

3. Conceptual Framework

This report proposes a simple model to examine equilibrium vaccination levels in different states, namely driven by the the perceived costs for vaccination in each state. Assuming that all agents are state-representative, have von Neumann–Morgenstern preferences and are expected utility maximisers, they are faced with the following problem:

$$\max_{v_i \in [0,1]} \mathbb{E}[U] = pU[y - L(v_i) - K_i(v_i)] + (1-p)U[y - K_i(v_i)]$$

where $p \in (0,1)$ represents the exogenous probability of being exposed to COVID-19, y represents income, and $v_i \in [0,1]$ represents the agent's choice of vaccination level: assumed continuous as a state-average, where 1 is fully vaccinated and 0 is no level of vaccination. $L(v_i)$ represents the financial cost incurred when exposed to COVID-19, with $L'(v_i) < 0$ (as the probability of being infected and illness severity decreases with higher v_i); and $K_i(v_i)$ represents the cost of increasing vaccination level for high-cost (H) and low-cost (L) states: $i \in \{H, L\}$, with $K_H'(v_i) > K_L'(v_i) > 0$ and $K_H(v_i) > K_L(v_i)$. Assuming that the solution is interior (plausible as all states have a proportion

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of population vaccinated between 0 and 1) and that U(·) is strictly increasing and concave, the FOC is necessary and sufficient to find v_i^*.

Algebraically, v_i^* is the choice of v_i that satisfies:

$$\frac{\partial U}{\partial v_i} = pU'[y - L(v_i^*) - K_i(v_i^*)][-L'(v_i^*) - K_i'(v_i^*)] + (1-p)U'[y - K_i(v_i^*)][-K_i(v_i^*)] = 0$$

Intuitively, v_i^* balances the marginal benefit from lower illness severity/infection probability ($\uparrow v_i \Rightarrow\downarrow L(v_i) \Rightarrow\uparrow \mathbb{E}[U]$) with the marginal cost of vaccination ($\uparrow v_i \Rightarrow\uparrow K(v_i) \Rightarrow\downarrow \mathbb{E}[U]$).

$$\frac{\partial U}{\partial v_i} = \frac{\partial U}{\partial K_i(v_i)}\frac{\partial K_i(v_i)}{\partial v_i} + \frac{\partial U}{\partial L(v_i)}\frac{\partial L(v_i)}{\partial v_i} = 0$$

{<0 >0} {<0 <0}

positive negative

Thus, given the assumptions on $K_i(\cdot)$, and $L(\cdot)$, this model predicts $v_L^* > v_H^*$.

I identify three factors affecting the perceived cost in each state: (1) the degree of trust in vaccination science in each state ($trust_i$), (2) the degree of public healthcare provision in each state ($publichealth_i$), and (3) the stringency of COVID- 19 rules in each state ($legislation_i$). This model will be tested via the empirical strategy below, with support for the model if statistically significant and non-zero coefficients are found on $trust_i$, $publichealth_i$, and $legislation_i$.

4. Data

I used Python to clean and organise data from the US Census, CDC, and other sources to build quarterly data for 2021. Q1 2022 is excluded due to insufficient data. For data which only had an annual value, this was held constant across all quarters, given that all annually- recorded variables used had no quarterly trend (Table 2). For monthly data, if the variable was cumulative (e.g. total vaccinations), the quarterly value was taken as last month in each quarter; and if the variable fluctuated, an average value was taken for each quarter.

Table 1: List of Variables

Variables	Source	Description
vacc1	CDC	Percentage of population vaccinated against COVID- 19 with at least one dose
vacc2	CDC	Percentage of population vaccinated against COVID- 19 with a complete series of vaccine
quarter	N/A	Quarter (Q1-Q4 2021)
state	N/A	US State
region1	US Census	US Region (Northeast, Midwest, West, South)
region2	US Census	US Subregion (New England, Middle Atlantic, etc .)
educ1	US Census	Percentage of people aged 25+ who graduated high school or higher
educ2	US Census	Percentage of people aged 25+ with a Bachelor's degree or higher
confid	CDC	Percentage of people who are completely or very confident in COVID-19 vaccine safety
ffnvac	CDC	Percentage of people who have many or all friends and family vaccinated
intent	CDC	Percentage of people who are not vaccine hesitant = 100% - percentage who are probably or definitely not getting vaccinated

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Table 1: (continued).

flu18	CDC	Percentage of people aged 18+ vaccinated against seasonal influenza
flu65	CDC	Percentage of people aged 65+ vaccinated against seasonal influenza
rcook	Cook Political	Reverse Cook Partisan Index (a measure of how Democratic a state is) = −1 × Cook Partisan Voting Index
democrat	Federal Election Commission	Dummy variable = 1 if the state voted Democrat in the last election
insured	US Census	Percentage of people under age 65 with health insurance = 100% - percentage uninsured
peraccess	CDC	Perceived ease of access to COVID- 19 vaccines: percentage who find access not at all or a little difficult
geoaccess	Ariadne Labs	Geographical ease of access to COVID- 19 vaccines . Dummy = 1 if the vast majority of unvaccinated people are in within a 30 minute drive from an active vaccination site
beds	KFF	State-/Local Government-/Non-Profit-owned Hospital Beds per 1,000
distributed	CDC	COVID- 19 vaccines distributed per 100k
religion	Pew Research	Degree of religiousity (captures religious attendance, frequency of prayer, belief in God, perceived importance of religion)
age5/18/65	US Census	Percentage of people under the age of 5/18/65
female	US Census	Percentage of females
White/Black/Asian/Hispanic	US Census	Percentage of people White/Black/Asian/Hispanic or Latino alone
foreign	US Census	Percentage of people foreign-born
household	US Census	Number of people per household
householdinc	US Census	Median household income (in 2020 dollars), 2016-2020
poverty	US Census	Percentage of people in poverty
gini	ACS	State-level Gini coefficient
unempl	BLS	Unemployment rate (seasonally adjusted)
lottery	JAMA Network	Dummy variable = 1 if there was a vaccine lottery
required	CDC	Percentage of people who are required to be vaccinated against COVID- 19 for school or work
mandate	Ballotpedia	Dummy variable = 1 if there is no ban on COVID- 19 mandates
eastcoast	N/A	Dummy variable = 1 if the state lies on the East Coast
westcoast	N/A	Dummy variable = 1 if the state lies on the West Coast
Source: CDC [13] [14] [15]; US Census [16] [17] [18] [19]; Cook Political [20]; Federal Election Commission [21]; Ariadne Lab [22]; KFF [23] [24]; Pew Research [25]; ACS [26]; BLS [27]; JAMA Network [28]; Ballotpedia [29]		

5. Empirical and Results

The regression will focus on the Q4 2021 cross-section, using vacc1 as the outcome variable:

$$\text{vacc}_{\,i} = \alpha + \beta \text{ trust}_{\,i} + \gamma \text{ publicgoods}_{\,i} + \delta \text{ legislation}_{\,i} + \mathbf{X}'\theta + \xi + \nu + u_i$$

Where trust $_i$, publichealth $_i$, and legislation $_i$ are all indices capturing our variables of interest (trust in science, provision of public healthcare, and COVID-19 stringency) respectively. X is a vector of socioeconomic control variables. ξ is a dummy variable to capture East Coast fixed effects and, similarly, ν is a dummy variable to capture West Coast fixed effects.

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5.1. Principal Component Analysis: Constructing Indices

As there are only 50 states/observations in each quarter, in order to avoid overfitting, I create three indices: $trust_i$, $publichealth_i$ and $legislation_i$, using the relevant components grouped in Table 2. These indices will be used as the explanatory variables in the regression model, which will avoid small marginal effects in regression results, thus providing a a clearer interpretation on how an overall change in an explanatory index affects vaccination rates.

Transformations were needed for each index to have a consistent interpretation. For ex- ample, as each constituent variable in the publicgoodi index increases, the index as a whole is designed to increase and, since a higher percentage of people without health insurance is reflective of poorer public health provision, the complementary percentage is used instead (per- centage with some form of health insurance).

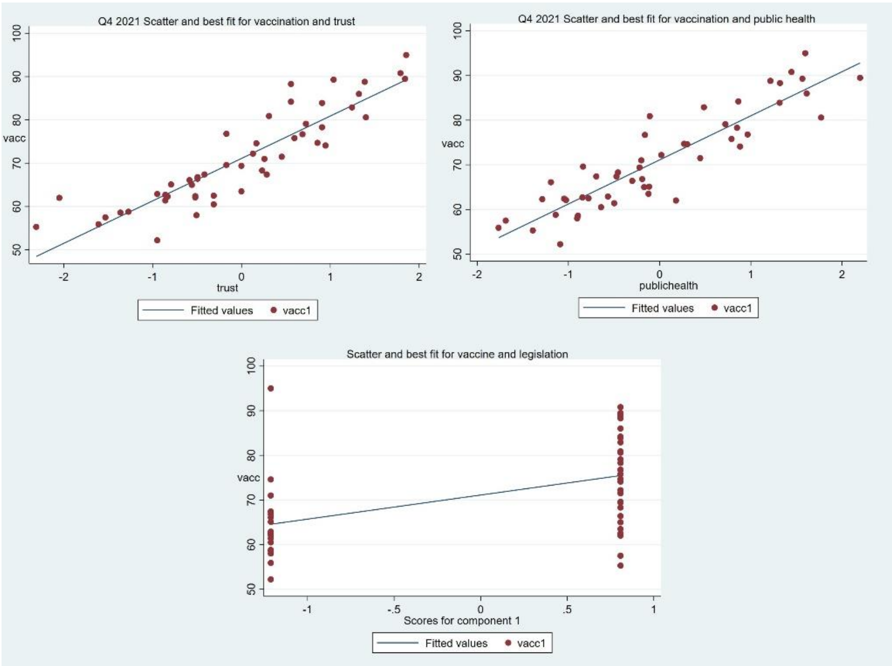

Figure 1: Initial data visualization: scatters of indices against the outcome variable in Q4 2021, with simple lines of best fit

From Figure 1, the indices for trust and public good provision look promising, both with a positive correlation with the vaccination rate: a good starting point before identifying the causal aspect of our theory. The index for legislation is assumes two values, acting as a binary variable. This is due to the lack of data on state-level stringency and $\frac{2}{3}$ of its components being dummy variables themselves. However, the positive correlation is also promising for the model's theory: the stricter the COVID-19 regulations, the higher the opportunity cost of remaining unvaccinated.

5.2. Variable Justification

5.2.1. Trust in science

Higher educational outcomes lead to a better of understanding behind vaccination science and therefore decreased vaccine skepticism. A higher percentage of friends and family being vaccinated means that agents are more likely to vaccinate themselves, due to herd mentality. Vaccinations against influenza is also a good proxy for trust, as there is unlikely to be reverse causality, as trust in vaccine

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is generally needed before making the decision to get vaccinated. Data on measels vaccines for children would have been a better proxy, as it is not subject to a high degree of seasonality and the child's vaccination decision is made by their parents, so it would be a good reflection of adult (dis)trust in science. However, this data was inaccessible.

5.2.2. Public Health Outcomes

The control variables are chosen to cover a wide range of socioeconomic factors and de- mographics. In this case, having small marginal effects from many control variables is not concerning, as the main goal is to interpret the coefficients on the indices. Two measures of ease of access to COVID- 19 vaccines are included, as perceived and actual accessibility can differ in reality. COVID- 19 vaccines distributed per 100k is also indicative of the degree of public health provision in a state.

5.2.3. COVID-19 Legislation Stringency

Vaccination lotteries are included here, as they are a form of legislation that aim to increase incentives for vaccinations. Setting the dummy as 1 if there is a lottery implies a relatively higher expected gain from vaccinations compared to other states without lotteries (holding other variables constant). Therefore, this is an indirect method for legislation to increase the opportunity cost of remaining unvaccinated. The other two mechanisms are more direct in increasing the opportunity cost, as unvaccinated agents will have barriers to access school, work, and general services or public locations.

5.3. Robustness

To check for robustness, the regression is repeated for Q1 2021, Q2 2021 and Q3 2021 (Table 3); and again for vacc2 as the outcome (Table 4). A pooled OLS combining all 2021 quarters is also run as a benchmark for both vacc1 and vacc2, along with Q4 regressions where all of the control terms in $\mathbf{X}'\theta$ are dropped (Table 5) . Finally, the Q4 regression is run again for vacc1 and vacc2, dropping one index at a time (Table 6).

Table 2: Cross-sectional regression on outcome variable vacc1:

VARIABLES	-1 Q4 2021	-2 Q3 2021	-3 Q2 2021	-4 Q1 2021
trust	4.389***	7.145***	7.405***	0.166
	-1.26	-0.571	-0.745	-0.395
publichealth	3.478**	0.775	0.365	1.402***
	-1.407	-0.527	-0.669	-0.343
legislation	1.406*	0.0336	-0.495	0.394
	-0.681	-0.542	-0.403	-0.249
religion	2.725	6.765	-2.469	-2.772
	-11.09	-4.886	-12.27	-5.364
age5	238.4	30.43	149.8	-220.9
	-351.1	-405.7	-354.7	-161
age18	-132.4	-130.6	-140.9	132.7*
	-126.5	-125.6	-105.1	-58.67
age65	-38.24	19.02	50.18	-74.70**
	-57.33	-30.89	-38.3	-26.41
female	-53.63	-114.5*	114.5	-154.4
	-159.1	-54.65	-146	-89.82

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Table 2: (continued).

white	-13.44	-23.41*	-2.923	-31.55***
	-16.81	-11.58	-10.38	-9.269
black	-32.03	-17.58	-7.18	-35.86***
	-17.51	-9.678	-11.87	-8.316
asian	-2.933	-18.26	23.9	-63.07***
	(31.09) 26.52**	(23.14) 20.45**	(19.55) 11.41**	(15.97) 13.94**
hispanic	-8.799	-6.117	-4.326	-4.522
foreign	-56.02**	-11.84	-13.77	-7.619
	-17.59	-17.68	-13.77	-13.37
household	9.749**	-0.92	-0.534	-6.646**
	-4.079	-2.445	-5.48	-2.636
householdinc	0.000182	-6.16E-06	-9.61E-05	0.00016
	-0.000121	-0.000124	-9.36E-05	-0.000108
poverty	4.275	3.029	-12.18	39.86
	-64.69	-58.94	-54.9	-50.22
gini	121.9*	3.832	-57.94*	29.24
	-64.92	-44.64	-30.87	-20.96
unempl	-1.136	0.302	0.926	-0.0775
	-1	-0.949	-0.617	-0.284
east	4.892**	0.99	1.248	1.703
	-1.783	-1.071	-1.54	-1.041
west	-2.32	-2.970**	-1.455***	-2.756***
	-1.326	-0.889	-0.318	-0.592
Constant	70.18	147.1***	10.05	172.5***
	-81.59	-43.3	-70.53	-42.45
Observations	50	50	50	50
R-squared	0.95	0.962	0.975	0.877
Robust standard errors in parentheses				
*** p<0.01, ** p<0.05, * p<0.1				

Table 3: Cross-sectional regression on outcome variable vacc2:

VARIABLES	-1 Q4 2021	-2 Q3 2021	-3 Q2 2021	-4 Q1 2021
trust	0.41	5.688***	6.058***	-0.398
	-0.772	-1.359	-1.516	-0.264
publichealth	4.705***	1.083	0.883	1.102***
	-1.4	-0.593	-0.861	-0.18
legislation	2.132***	-0.455	0.215	0.174*
	-0.525	-0.619	-0.254	-0.0892
religion	-9.414	-4.534	-11.44*	1.117
	-7.213	-6.687	-5.777	-3.655
age5	407.3*	-109.6	69.09	-295.8**
	-190.4	-403.1	-225.6	-127.1

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Table 3: (continued).

age18	-144.6*	-47.91	-83.51	134.2**
	-64.38	-123.3	-68.11	-44.4
age65	10.47	45.27	70.40**	-28.38
	-39.59	-31.74	-24.95	-15.46
female	219.1**	-33.69	29.29	-138.0**
	-70.91	-126.6	-145.9	-54.32
white	-24.99**	-21.82	-4.985	-26.93***
	-8.852	-12.84	-12.31	-5.311
black	-40.36***	-18.96	-8.641	-30.34***
	-11.28	-14.55	-15.62	-6.62
asian	-75.55***	-47.17*	-8.674	-45.05***
	-14.57	-24.98	-26.91	-10.41
hispanic	12.18*	15.66	6.648	8.556**
	-5.334	-10.53	-5.948	-3.216
foreign	-3.003	8.527	10.18	4.138
	-15.01	-24.15	-19.11	-9.609
household	2.971	-7.961**	-9.379**	-13.22***
	-5.292	-3.307	-2.799	-0.89
householdinc	0.000121	0.000153	4.31E-07	0.000155*
	-0.000223	-0.000194	-9.81E-05	-8.14E-05
poverty	-44.32	72.36	67.77	64.36
	-61.96	-66.92	-42.4	-37.16
gini	89.89*	-62.38	-99.76**	-26.46
	-42.97	-43.74	-31.71	-23.06
unempl	-0.905	-0.167	0.47	0.0484
	-0.66	-0.936	-0.306	-0.141
east	-0.116	1.439	3.057***	1.538***
	-1.346	-1.506	-0.82	-0.319
west	0.104	-2.766*	-1.162*	-1.691***
	-1.209	-1.207	-0.574	-0.29
Constant	-67.87*	103.7	56.15	150.2***
	-35.83	-76.66	-74.06	-31.11
Observations	50	50	50	50
R-squared	0.952	0.929	0.965	0.893
Robust standard errors in parentheses				
*** p<0.01, ** p<0.05, * p<0.1				

Table 4: Further robustness checks, pooling OLS and dropping controls for vacc1, vacc2

VARIABLES	-1 POLS 2021 vacc1	-2 POLS 2021 vacc2	-3 No controls Q4 vacc1	-4 No controls Q4 vacc2
trust	1.321	-0.269	2.925***	2.925***
	-0.808	-0.735	-0.295	-0.295
publichealth	-0.166	0.79	4.331***	4.331***

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Table 4: (continued)

	-0.768	-0.789	(0.710) 1.424**	(0.710) 1.424**
legislation	14.20*** (0.992)	14.13*** (1.063)	-0.443	-0.443
religion	-16.77	-18.08		
	-14.69	-12.65		
age5	-317.8	-433.5		
	-243.1	-291		
age18	-28.78	41.65		
	-58.89	-95.39		
age65	-90.83*	-44.67		
	-48.6	-31.33		
female	-330.6** (140.3)	-277.3** (111.3)		
white	-4.714	-3.78		
	-10.99	-10.98		
black	-4.601	-3.282		
	-5.949	-8.561		
asian	-709.4532	-56.68** (21.21)		
hispanic	15.48***	9.846		
	-3.123	-5.894		
foreign	-8.041	14.46		
	-11.77	-14		
household	15.86***	3.432		
	-1.357	-3.968		
householdinc	-0.00012	-5.30E-05		
	-0.000129	-0.000156		
poverty	-1.004	51.2		
	-49.2	-41.36		
gini	59.02	-19.04		
	-33.5	-34.08		
unempl	-2.977*** (0.772)	-3.053*** (0.879)		
east	-1.655	-1.8	1.106	1.106
	-1.622	-1.693	(1.714) 1.010* (0.496)	(1.714) 1.010* (0.496)
west	-5.175*** (1.258)	-4.808*** (1.093)	59.82*** (0.451)	59.82*** (0.451)
Constant	291.6*** (70.98)	265.0*** (50.36)		
Observations	200	200	50	50
R-squared	0.756	0.668	0.903	0.903
Robust standard errors in parentheses				
*** p<0.01, ** p<0.05, * p<0.1				

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Table 5: Further robustness checks, dropping 1 index per regression for vacc1, vacc2

VARIABLES	-1	-2	-3	-4	-5	-6
	Q4	Q4	Q4	Q4	Q4	Q4
	no legislation	no publichealth	no trust	no legislation	no publichealth	no trust
	vacc 1	vacc 1	vacc 1	vacc 2	vacc 2	vacc 2
trust	4.465***	5.690***		0.525	2.170**	
	-0.948	-1.252		-1.011	-0.859	
publichealth	4.737***		5.983***	6.614***		4.939***
	-1.309		-1.228	-1.608		-1.098
legislation		2.063***	1.483		3.021***	2.140***
		-0.571	-1.132		-0.823	-0.537
religion	2.169	4.469	-9.761	-10.26	-7.054	-10.58
	-9.686	-12.03	-10.03	-9.388	-7.646	-6.114
age5	137.1	286.4	366.6	253.7	472.3	419.3*
	-344.3	-400.1	-265.6	-323.7	-302.6	-190.1
age18	-61.12	-212.1	-186	-36.51	-252.4**	-149.6*
	-144.8	-133.1	-111.5	-109.1	-93.61	-66.63
age65	-30.15	-61.16	22.74	22.74	-20.54	16.17
	-70.05	-54.43	-72.12	-66.68	-29.05	-29.89
female	-89.14	5.251	178.1	165.3	298.8**	240.8**
	-168.1	-157.2	-215	-150.1	-103.2	-74.47
white	-3.714	-13.25	-30.16	-10.24	-24.73	-26.55***
	-14.45	-13.88	-30.06	-13.18	-18.42	-7.273
black	-18.87	-39.64**	-51.69	-20.41	-50.66**	-42.20***
	-16.91	-15.41	-30.36	-17.27	-18.21	-10.06
asian	27.82	-18.17	-24.92	-28.91	-96.17**	-77.61***
	-30.37	-27.6	-50.81	-20.13	-35.19	-15.25
hispanic	25.63**	25.56***	36.33**	10.83	10.88	13.09*
	-9.835	-7.243	-11.96	-8.374	-6.769	-5.765
foreign	-57.24***	-50.52***	-62.06**	-4.867	4.426	-3.567
	-14.8	-14.25	-25.98	-24.58	-20.39	-14.81
household	3.376	16.51**	5.942	-6.695	12.11	2.615
	-3.851	-6.142	-6.223	-7.636	-7.405	-4.752
householdinc	0.000146	0.000354*	0.000104	6.64E-05	0.000353	0.000114
	-0.000151	-0.000171	-0.0002	-0.000235	-0.000259	-0.00021
poverty	15.56	45.99	-74.17	-27.2	12.11	-51.64
	-60.33	-66.34	-107.7	-82.73	-74.79	-59.17
gini	125.8*	62.31	171.7**	95.79	9.243	94.54*
	-62.93	-62.88	-51.99	-58.21	-35.51	-44.45
unempl	-0.672	-1.084	-1.57	-0.202	-0.836	-0.946
	-1.099	-0.985	-0.933	-0.718	-0.647	-0.639
east	4.704**	5.196**	4.392***	-0.401	0.295	-0.163
	-1.548	-2.024	-0.964	-1.483	-1.031	-1.341
west	-1.575	-4.329**	-0.951	1.234	-2.614*	0.232
	-1.309	-1.426	-1.488	-1.803	-1.331	-1.07

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Table 5: (continued).

Constant	75.04	69	-68.37	-60.49	-69.47	-80.81*
	-83.77	-96.35	-113.5	-82.33	-73.35	-37.09
Observations	50	50	50	50	50	50
R-squared	0.943	0.941	0.929	0.927	0.926	0.952
Robust standard errors in parentheses						
*** p<0.01, ** p<0.05, * p<0.1						

Table 6: Summary statistics for Q4 and Q1-4 (2021)

VARIABLES	Q4	Q4	Q4	Q4	2021	2021	2021	2021
	mean	sd	min	max	mean	sd	min	max
quarter	4	0	4	4	2.5	1.121	1	4
region1	2.34	1.171	1	4	2.34	1.162	1	4
region2	5	2.407	1	9	5	2.389	1	9
vacc1	71.1	10.91	52.2	95	53.97	17.59	23.6	95
vacc2	60.35	8.431	46.3	77.5	44.45	18.04	11.4	77.5
educ1	0.9	0.0263	0.839	0.94	0.9	0.0261	0.839	0.94
educ2	0.32	0.0525	0.213	0.445	0.32	0.0521	0.213	0.445
confid	0.651	0.0771	0.473	0.794	0.622	0.078	0.455	0.794
ffvac	0.739	0.106	0.521	0.931	0.663	0.116	0.392	0.931
intent	0.882	0.0676	0.758	0.992	0.835	0.0738	0.666	0.992
flu18	0.509	0.0582	0.384	0.64	0.509	0.0577	0.384	0.64
flu65	0.751	0.0482	0.638	0.872	0.751	0.0478	0.638	0.872
rcook	-3.76	10.78	-26	15	-3.76	10.7	-26	15
democrat	0.5	0.505	0	1	0.5	0.501	0	1
insured	0.899	0.0357	0.792	0.965	0.899	0.0354	0.792	0.965
peraccess	0.872	0.0442	0.755	0.944	0.857	0.0467	0.714	0.944
geoaccess	0.7	0.463	0	1	0.7	0.459	0	1
beds	2.2	0.715	0.82	4.59	2.2	0.709	0.82	4.59
distributed	182,914	20,790	146,210	228,605	124,257	47,132	50,750	228,605
lottery	0.66	0.479	0	1	0.83	0.377	0	1
required	23.86	9.555	11	46.2	13.94	10.09	1.9	46.2
mandate	0.6	0.495	0	1	0.765	0.425	0	1
religion	0.547	0.107	0.33	0.77	0.547	0.107	0.33	0.77
age5	0.0595	0.0061	0.047	0.077	0.0595	0.00605	0.047	0.077
age18	0.222	0.0194	0.183	0.29	0.222	0.0192	0.183	0.29
age65	0.83	0.0192	0.788	0.886	0.83	0.0191	0.788	0.886
female	0.506	0.0079	0.479	0.517	0.506	0.00788	0.479	0.517
white	0.787	0.123	0.255	0.944	0.787	0.122	0.255	0.944
black	0.112	0.0963	0.006	0.378	0.112	0.0955	0.006	0.378
asian	0.0456	0.0557	0.008	0.376	0.0456	0.0553	0.008	0.376
hispanic	0.123	0.105	0.017	0.493	0.123	0.104	0.017	0.493
foreign	0.0932	0.0613	0.016	0.266	0.0932	0.0609	0.016	0.266
household	2.543	0.162	2.28	3.09	2.543	0.16	2.28	3.09
householdinc	64,529	10,525	46,511	87,063	64,529	10,445	46,511	87,063

Table 6: (continued).

poverty	0.116	0.026	0.07	0.187	0.116	0.0258	0.07	0.187
gini	0.463	0.0193	0.427	0.515	0.463	0.0191	0.427	0.515
unempl	4.046	0.972	2.3	5.9	4.703	1.318	2.3	9.2
east	0.28	0.454	0	1	0.28	0.45	0	1
west	0.22	0.418	0	1	0.22	0.415	0	1
Robust standard errors in parentheses								
*** p<0.01, ** p<0.05, * p<0.1								

5.4. Results & Analysis

Broadly, the results do lend support for the model proposed in Section 3 and provide a causal insight for the initial visualisation (Figure 1). Examining the results from the baseline model (Q4 with vacc1 as the outcome), we see that an increase in the trust index by 1 unit exerts a 4 .4pp average increase in vaccination rates, representing a ~6% increase relative to the mean, conditional on other variables. Similarly, 1 unit increases in publichealth and legislation exert 3 .5pp and 1 .4pp increases in vaccination rates respectively, representing ~6% and ~2% increases relative to the mean, conditional on other variables.

Comparing across specifications, trust seems to be a robust effect; estimated marginal effects remain broadly similar across specifications and statistically significant across the majority of robustness checks. Q1 cross-sections provide an exception: however, as this was the start of the vaccination rollout, cumulative vaccination rates were not high to begin with and so the estimated coefficients are expected to be lower in this period . When dropping the controls, the coefficient on trust goes down, suggesting the controls exert a positive effect this coefficient; while the coefficients on publicgood and legislation go up, suggesting the opposite. Almost all of the demographic variables have statistically insignificant and small coefficients, which suggests that the model is not missing any key explanatory variables. A Breusch-Pagan test is not performed, as heteroscedasticity doesn't affect the consistency or bias of the OLS estimates. Heterogeneous treatment effects are not examined in this paper, but can be explored in future work.

6. Conclusion

If I had access to richer survey data, e.g. tracking individuals' behaviour and outcomes over a long period of time, the methodology could be improved by building the analysis from the individual-level. For example, the legislation index was very hard to construct due to a lack of suitable data for explanatory variables. With richer data, the mechanisms that determine an individual's vaccination decision could then be examined with greater precision, which would also help to inform policy decisions and prevent outbreaks at the local-level.

The cross-sectional state analysis was hindered due to the small number of observations, as there are only 50 states in any given time period. However, individual-level data would not have such limitations. For example, the indices could then be broken down into many individual explanatory variables in the regression, without worrying about exceeding the number of observations and a failure of OLS. A Ramsey RESET test could also be applied to see whether the model is mis specified and if there are any interactions between explanatory variables through powers or cross-terms that should also be included. State-sourced data is also prone to measurement errors, as each state will have its own reporting methods. As seen in bibliography, even for data on racial groups and ethnicity: a demographic measurement that is highly utilised, different states will have different classifications for each group and some states may not even collect data [30]. This will lead to attenuation bias, although this is not a huge issue as if measurement errors are identifiable, coefficient estimates can be viewed as conservative due to the downwards bias.

This study proposes a simple cost-benefit model of vaccinations as insurance against COVID- 19 risk. Tested using various regression specifications, there is a broad degree of empirical support for the model: statistically significant effects of trust, public-health and legislation on vaccination outcomes. This implies a large role in policy for reducing the indirect costs of vaccination, such as working to educate and improve trust in science, providing health-related public goods in an equitable manner, and through more stringent regulations surrounding COVID- 19.

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