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COVID-19 vaccine hesitancy cannot fully explain disparities in vaccination coverage across the contiguous United States

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ABSTRACT

Vaccine hesitancy has been identified as a major obstacle preventing comprehensive coverage against the COVID-19 pandemic. However, few studies have analyzed the association between ex-ante vaccine hesitancy and ex-post vaccination coverage. This study leveraged one-year county-level data across the contiguous United States to examine whether the prospective vaccine hesitancy eventually translates into differential vaccination rates, and whether vaccine hesitancy can explain socioeconomic, racial, and partisan disparities in vaccine uptake. A set of structural equation modeling was fitted with vaccine hesitancy and vaccination rate as endogenous variables, controlling for various potential confounders. The results demonstrated a significant negative link between vaccine hesitancy and vaccination rate, with the difference between the two continuously widening over time. Counties with higher socioeconomic statuses, more Asian and Hispanic populations, more elderly residents, greater health insurance coverage, and more Democrats presented lower vaccine hesitancy and higher vaccination rates. However, underlying determinants of vaccination coverage and vaccine hesitancy were divergent regarding their different associations with exogenous variables. Mediation analysis further demonstrated that indirect effects from exogenous variables to vaccination coverage via vaccine hesitancy only partially explained corresponding total effects, challenging the popular narrative that portrays vaccine hesitancy as a root cause of disparities in vaccination. Our study highlights the need of well-funded, targeted, and ongoing initiatives to reduce persisting vaccination inequities.

1. Introduction

The United States (US) has been a major epicenter of the Coronavirus disease 2019 (COVID-19) pandemic since early 2020, reporting the highest number of total infections and deaths worldwide [16]. Safe and effective prophylactic vaccines are considered a critical solution to bring the pandemic to an end, with the expectation that vaccines will mitigate disease severity and slow down the transmission of the virus. Aided by the rapid development and testing, the COVID-19 vaccine rollout has been seen in the US since late 2020 [45]. On December 11, 2020, the first Emergency Use Authorization was issued for Pfizer/BioNTech (BNT162b2) by the US Food and Drug Administration (FDA). As of May 2021, two other COVID-19 vaccines have been authorized in the US, including Moderna (mRNA-1273) and Johnson & Johnson's Janssen (AD26.COV2.S). Phase III clinical trials have provided strong evidence of vaccine efficacy [3,36,40]. Post-approval observational studies also proven that the initial rollout of the COVID-19 vaccination program was related to substantial reductions in COVID-19 deaths and hospital admissions [27,34,43,44].

Although clinical trials and real-world observational studies have affirmed the efficacy, effectiveness, and safety of FDA-authorized COVID-19 vaccines, a proportion of people still forgo vaccination [24,39,41]. The vaccination refusal can be directly reflected by the failure in reaching complete vaccination coverage. By January 31, 2022, one year after the initial vaccine rollout, the percentage of people fully vaccinated in the US only reached 63.8 % [13], which was far not enough to achieve population-level protection against COVID-19, particularly under the devastating outbreak of Omicron variants. Besides the insufficient vaccination coverage, another well-documented issue is the inequity in COVID-19 vaccination coverage [7,10,24,39,48]. Given that all US residents aged over 12 years have been eligible to receive vaccines since May 2021, and there is currently an excess of vaccines in

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supply, the roots of inequity in vaccination coverage should be traced to other structural barriers, such as socioeconomic privilege [4,10,32], political ideology [48], racial disparity [1,20], and vaccine hesitancy [26,46]. Broadly, studies claimed that communities with lower vaccine hesitancy, higher socioeconomic statuses (e.g. higher median income, more educated populations, lower unemployment rates), greater shares of Whites and Asians, and higher vote shares for the Democrat party were associated with significantly higher vaccination coverage [1,4,24].

The insufficient and uneven vaccination coverage has been anticipated by researchers due to a long-standing knowledge of vaccine hesitancy, a concern that existed before the COVID-19 pandemic as evidenced by influenza vaccine hesitancy [11,19,42]. By the World Health Organization (WHO), vaccine hesitancy is the "delay in acceptance or refusal of vaccination despite the availability of vaccination services", and is widely considered the main barrier to achieving full vaccination coverage [30]. A "5C" framework was constructed to describe individual-level determinants of vaccine hesitancy from five aspects: confidence, convenience, complacency, collective responsibility, and risk calculation [6,31]. A set of surveys has also been conducted before the rollout of COVID-19 vaccines to examine specific factors related to vaccine hesitancy during COVID-19 [5,18,26,29,37,38,46]. Similar to vaccination coverage, significant disparities have been observed in vaccine hesitancy. Overall, vaccine hesitancy was notably higher among participants who were Black, female, low-educated, low income, or voted for the Republican party in 2020 [11,26,29,46], and such relationships may vary across the pandemic [15,18,23].

Although vaccine hesitancy and vaccination coverage have been explored in previous studies, most studies examined them separately [28]. Vaccine hesitancy is derived from surveys describing prospective intentions, which may not always translate into vaccine uptake in the real world [33]. Current studies focusing on associations between ex-ante vaccine hesitancy and ex-post vaccination coverage are limited, and few have considered the time-varying patterns of the associations. Also, few studies have jointly analyzed the associations among vaccine hesitancy, vaccination coverage, and various confounders under one model framework. It remains unclear whether vaccine intention finally translates into differential vaccination coverage in the real-world setting, how their relationships change over the pandemic, and to what extent vaccine hesitancy accounts for socioeconomic, racial, and partisan disparities in vaccination coverage. To this end, we designed a set of regressions based on over one-year county-level vaccine data by early 2022 across the contiguous US. A set of time-varying regressions was first built to delineate the temporal evolution of the relationship between vaccine hesitancy and vaccination rate. Then, a set of structural equation modeling (SEM) was fitted to jointly investigate intertwined relationships, using vaccine hesitancy (also served as the mediator) and vaccination rate as endogenous variables, controlling for racial makeup, industry structures, housing types, partisanship, socioeconomics, demographics, and health-related features. Our findings are reliable and timely sources to guide future efforts to increase COVID-19 vaccination willingness, reduce vaccination inequality, and ultimately end the pandemic.

2. Data and variables

2.1. Vaccination coverage and vaccine hesitancy (endogenous variables)

We considered county-level vaccination coverage and vaccine hesitancy as endogenous variables. Vaccination coverage was drawn from the Centers for Disease Control and Prevention (CDC) COVID Data Tracker [13]. Since early 2021, the CDC has continuously collected national vaccination records from all vaccine partners including jurisdictional partner clinics, retail pharmacies, long-term care facilities, dialysis centers, Federal Emergency Management Agency and Health Resources and Services Administration partner sites, and federal entity facilities. In this study, we used the vaccination rate, i.e., the percentage of fully vaccinated people (with a second dose of the two-dose vaccine or one dose of the single-dose vaccine) based on the county where the recipient lives to represent county-level vaccination coverage.

Vaccine hesitancy was derived from the Household Pulse Survey (HPS) [8]. HPS was a 20-minute online survey designed by the US census bureau to quickly deploy data collected on how people's lives have been impacted by COVID-19. The first phase was started in April 2020, followed by a weekly update until now. HPS included the nationally representative information on US residents' willingness to take the COVID-19 vaccine when available. To support local communication and outreach efforts, the Office of the Assistant Secretary for Planning and Evaluation (ASPE) predicted the Public Use Microdata Areas (PUMA) level hesitancy based on HPS survey data and estimated the county-level vaccine hesitancy using a PUMA-to-county crosswalk [2]. In our study, vaccine hesitancy was approximated by the percentage of adults who describe themselves as "unsure", "probably not", or "definitely not" going to receive a COVID-19 vaccine when available, based on the county-level estimation from ASPE. For robustness check, we also conducted analogous models replacing the vaccine hesitancy with the "strong vaccine hesitancy", which is approximated by the percentage of adults who describe themselves as "definitely not" going to receive a COVID-19 vaccine when available.

Table 1 provides descriptive statistics for all variables. There was a substantial gap between vaccine hesitation and vaccination rate. By the end of January 2022, the percentage of people fully vaccinated was 49.052 % (county-level average), while, only 19.090 % of adults showed hesitancy in receiving vaccines, and 8.609 % of adults showed a strong refusal to vaccines from the hesitancy survey. The discrepancy indicated that survey-based vaccine hesitancy cannot accurately represent the actual vaccination rate. Some portion of respondents were either not included in the survey or were not reporting hesitancy but ultimately chose to forego the COVID 19 vaccine.

Several potential data limitations are noteworthy. First, CDC vaccination data typically had a state-specific lag time from the information shown on states' websites. This can be partially eliminated by using the weekly average. Second, data collection and transmission errors sometimes happened and correction processes were post hoc conducted each time when a state reported an error. The frequently changing dataset led to multiple versions of historical data, and some states like Texas, Colorado, and Virginia that failed to correct their historical errors have to be excluded when conducting temporal analysis. Third, the vaccine hesitancy collected from HPS only covered a small portion (60,000 respondents on average) of the whole population. Sampling biases and nonresponse errors may induce biases in model estimation outcomes [9]. However, this is currently the best vaccine hesitancy dataset that we can access.

2.2. Exogenous variables

Exogenous variables included racial/ethnic groups, industry types, socioeconomics, health-related features, housing types, demographics, partisanship, and state fixed effects. Variables were selected based on evidence from prior studies [1,22,24,47] and the C.D.C. social vulnerability index (SVI) [12], which used 15 variables grouped into four themes, including socioeconomic status, household composition & disability, minority status & language, and

Table 1
Summary of county-level variables.

		Description	Mean	SD	Median	Min.	Max.
Endogenous Variables							
Vaccination Rate		Cumulative percentage of people fully vaccinated, in %	49.052	12.279	0.000	48.143	95.000
Vaccine Hesitancy		The percentage of adults who describe themselves as "unsure", "probably not", or "definitely not" going to get a COVID-19 vaccine once one is available to them, in %	19.090	5.309	4.990	19.010	32.330
Strong Vaccine Hesitancy		The percentage of adults who describe themselves as "definitely not" going to get a COVID-19 vaccine once one is available to them, in %	8.609	3.229	1.860	8.470	18.240
Exogenous Variables							
Racial/ ethnic groups	*White*	*The percentage of Non-Hispanic Whites, in %*	76.595	19.881	0.693	83.886	100.000
	African American	The percentage of African Americans, in %	9.155	14.560	0.000	2.332	87.226
	Asian	The percentage of Asians, in %	1.301	2.390	0.000	0.621	36.467
	Hispanic	The percentage of Hispanics/Latinos, in %	9.456	13.928	0.000	4.219	99.174
	Minority	The percentage of other minorities including American Indian and Alaska Native alone, Native Hawaiian or other Pacific Islander, two or more races, and others, in %	6.240	8.269	0.000	3.929	94.782
Industry types (For the civilian employed population 16 years and over)	Finance	The percentage of finance and insurance, real estate, and rental and leasing, in %	4.550	1.931	0.000	4.287	20.141
	Technique	The percentage of professional, scientific, and technical services, in %	3.739	2.664	0.000	3.109	52.900
	Administration	The percentage of administration, business support, management of companies, and waste management services, in %	3.267	1.410	0.000	3.224	15.686
	Manufacture	The percentage of manufacturing industry, in %	12.332	7.087	0.000	11.414	46.394
	Retail	The percentage of retail trade and wholesale trade, in %	13.618	2.663	1.270	13.705	42.424
	Information	The percentage of information, in %	1.326	0.799	0.000	1.245	11.609
	Utility	The percentage of transportation, warehousing, and utilities, in %	5.575	1.992	0.000	5.336	21.849
	Education	The percentage of educational services, in %	9.335	3.213	0.000	8.736	36.123
	Health Care	The percentage of health care and social assistance, in %	13.866	3.390	0.000	13.833	38.154
	Recreation & Food	The percentage of accommodation, food, arts, entertainment, and recreation services, in %	8.310	3.600	0.000	7.937	41.368
	Agriculture & Mining	*The percentage of agriculture, forestry, fishing, hunting, construction, and mining, in %*	13.994	7.672	0.896	11.976	66.748
Socioeconomics	Median Income	The median household income (in 2019 Inflation-Adjusted Dollars), in $\$10^3$/household	53.305	14.102	21.504	51.658	142.299
	Poverty	*The percentage of households below national poverty level, in %*	14.828	5.940	2.256	13.812	48.222
	High Educated	*The percentage of residents with education attainment equal to/higher than Bachelor, in %*	21.954	9.582	0.000	19.551	77.557
	Without Vehicle	The percentage of households with no vehicle available, in %	6.192	3.604	0.000	5.600	77.000
	Unemployment Rate	The percentage of civilian (age 16+) unemployed, in %	5.231	2.562	0.000	4.904	24.863
	Single Parent	The percentage of single parent households with children under 18, in %	8.298	2.705	0.000	8.100	25.600
	Less English	*The percentage of persons (age 5+) who speak English "less than well", in %*	*1.697*	*2.786*	*0.000*	*0.700*	*30.400*
Health-related features	Cumulative Case Rate	Total number of confirmed COVID-19 cases per population	0.213	0.050	0.000	0.216	0.902
	Without Insurance	The percentage of residents with no health insurance coverage, in %	9.557	4.987	0.674	8.646	40.907
	Disability	The percentage of civilian noninstitutionalized population with a disability, in %	15.954	4.402	3.800	15.500	33.700
Housing types	Multi-unit House	The percentage of housing in structures with 10 or more units, in %	4.659	5.694	0.000	2.900	89.400
	Mobile Home	The percentage of mobile homes, in %	13.025	9.618	0.000	11.050	59.300
	Crowd Home	The percentage of occupied housing units with more people than rooms, in %	2.331	1.919	0.000	1.900	33.800
	Group Quarters	The percentage of persons in group quarters, in %	3.481	4.473	0.000	1.900	55.700
Demographics	Population Density	Population density, in 10^2 persons/sq. mile	2.738	18.121	0.001	0.451	720.192
	Urbanicity	The percentage of residents in urbanized areas, in %	18.576	33.330	0.000	0.000	100.000
	Age over 65	The percentage of persons aged 65 and older, in %	18.849	4.614	3.201	18.475	56.714
	Age under 18	The percentage of persons aged 17 and younger, in %	22.232	3.457	7.269	22.237	41.795
	Male	The percentage of male, in %	50.051	2.318	42.813	49.626	72.720
Partisanship	Democrat	The percentage of Democrats in 2020 presidential candidate vote totals, in %	33.184	15.861	3.091	29.953	89.256
	Republican	*The percentage of Republicans in 2020 presidential candidate vote totals, in %*	65.056	16.031	8.730	68.319	96.182

Notes:
a. Statistical description only considers data during January 21–27, 2022. Samples comprise 3,108 contiguous US counties.
b. Variables in *Italic* are excluded from the models due to the high multicollinearity.
c. Data sources of exogenous variables are as follows: Racial/ethnic groups, socioeconomics, demographics, industry types, housing types, and part of health-related features like *Without Insurance* and *Disability* are from the Census Bureau's 2015–2019 ACS 5-year estimates; Partisanship is from the 2020 presidential election result from the MIT election lab [35]; Cumulative case rate is from COVID-19 Data Repository by the Center for Systems Science and Engineering (CSSE) at Johns Hopkins University [16].

housing type & transportation, to reflect the community's ability to prevent human suffering in the event of disaster.

Variable selection was performed to determine the final variable set. The generalized variance inflation factor ($GVIF^{1/2\cdot df}$, where df is the number of coefficients in the variable-wise subset) was calculated to test the multicollinearity, and $GVIF^{1/2\cdot df}$ greater than 2.5 was excluded. Eventually, constrained by the high multicollinearity, *White*, *Agriculture & Mining*, *Poverty*, *High Educated*, *Less English*, and *Republican* were removed from both models, and *Vaccine Hesitancy* was removed from the model of *Vaccination Rate*. The final exogenous variables included in the SEM were listed in Table 1.

An important caveat here is that most variables were calculated at an aggregate (county) level. Thus, conclusions drawn from this study should not be extrapolated to individuals due to the potential ecological fallacy. Another concern is the modifiable area unit problem (MAUP), which postulates that different aggregation units may lead to different modeling results [17]. A county-level analysis may gloss over disparities at a more localized level [20]. However, due to the inaccessibility of finer-grained variables, county-level analysis is the best study that could be conducted at this time.

3. Research design

3.1. Preliminary analysis

We first conducted a set of preliminary analyses to better understand relationships among vaccine hesitancy, vaccination rate, and exogenous variables as well as their temporal evolution. First, spatiotemporal distributions of county-level vaccine hesitancy and vaccination rate were depicted (see Appendix A1), and the differences in the mean of vaccination rates by vaccine hesitancy were compared via an unpaired *t*-test (see Appendix A2). Then, the relationship between vaccine hesitancy and vaccination rate was examined, as well as how it evolved over the course of the vaccination program, by fitting a set of time-varying fixed-effect regressions:

$$g(R_{i,t}) = \beta_{0,t} + \beta_{i,t}H_{i,t} + \theta_{i,t}S_i + \epsilon_{i,t} \quad (1)$$

where $R_{i,t}$ is the fully vaccination rate in county i by the end of week t and $g(.)$ is the link function; H_i is the vaccine hesitancy in county i by the end of week t; S_i is the state dummy variable to control differences in state-specific COVID-19 mitigation efforts and other unmeasured features; $\beta_{0,t}, \beta_{i,t}, \theta_{i,t}$ are time-varying coefficients and $\epsilon_{i,t}$ is the error term.

We included over one year of data from January 1, 2021 to January 27, 2022 to complete the temporal analysis. Both vaccine hesitancy and vaccination coverage vary along the same timeline. Note that due to different jurisdictional reporting times and issues in data collection and synchronization, the time series of daily county-level vaccination rates reported by the CDC sometimes fluctuate sharply [13]. To eliminate the oscillations, we averaged the time series weekly and excluded states (Texas, Colorado, and Virginia) with too many missing records when conducting temporal analysis.

3.2. Structural equation modeling: Mediation analysis

Prior research showed that exogenous variables were significantly associated with both vaccine hesitancy and vaccination rate [4,11,24,26,29,39]. Our preliminary research also assisted in quantifying the correlation between vaccine hesitancy and vaccination rate. However, to what extent vaccine hesitancy accounts for relations between exogenous variables and vaccination rate remains unknown. Mediation analysis was employed to this end as it is widely used to understand the underlying mechanism by which some hypothetical causal variables influence an outcome through at least one mediator.

Here we set vaccine hesitancy as the mediator between exogenous variables and vaccination rate. We assumed vaccine hesitancy could directly influence the vaccination rate, while exogenous variables could influence the vaccination rate directly (blue paths in Fig. 1) and indirectly via vaccine hesitancy (orange paths in Fig. 1). It is noteworthy that due to the high multicollinearity between vaccine hesitancy and exogenous variables, the path from vaccine hesitancy to vaccination rate ($\boldsymbol{\rho_{OM}}$) cannot coexist with paths from exogenous variables to vaccination rate ($\boldsymbol{\rho_{OP}}$) in one model. Therefore, we built two SEMs, Eq. (2) and Eq. (3), to quantify the total effects and indirect effects respectively. Specifically, Eq. (2) hypothesized that total effects from exogenous variables on vaccination rate were directly exerted and were not mediated by vaccine hesitancy. Eq. (3), on the contrary, assumed that vaccine hesitancy was a complete mediator to bridge exogenous variables with vaccination rate, i.e., exogenous variables influenced vaccination rate in a completely indirect manner through vaccine hesitancy. The difference between total effects in Eq. (2) ($\boldsymbol{\rho_{OP}}$) and indirect effects in Eq. (3) ($\boldsymbol{\rho_{MP}} \cdot \rho_{OM}$) thus represented the unsolved disparities in vaccination rate, which could not be explained by vaccine hesitancy:

$$O = \boldsymbol{\rho_{OP}}\boldsymbol{P} + E_O \quad (2)$$

$$M = \boldsymbol{\rho_{MP}}\boldsymbol{P} + E_M, O = \rho_{OM}M + E_O \quad (3)$$

$$DE := TE - IDE := \rho_{OP} - \rho_{MP} \cdot \rho_{OM} \quad (4)$$

where O is the outcome (vaccination rate); M is the mediator ((strong) vaccine hesitancy); $\boldsymbol{P}$ is the set of exogenous variables; $\boldsymbol{\rho_{MP}}, \boldsymbol{\rho_{OP}}, \rho_{OM}$ are the path coefficients between exogenous variables and mediator, between exogenous variables and outcome, and between mediator and outcome, respectively; E_M and E_O are the error terms; $\boldsymbol{TE}, \boldsymbol{DE}, \boldsymbol{IDE}$ are the total effects, direct effects, and indirect effects respectively. Since indirect effects are based on products of estimation, their estimated sampling distributions tend to be nonnormal. Thus, 95 % CIs of indirect effects and total effects are obtained through 500 bootstraps.

SEM was built using the cross-sectional data from January 21–27, 2022. The vaccine hesitancy was the average value throughout the observation and the vaccination coverage was the accumulated value by the end of the observation. The underlying assumption was that vaccine hesitancy during the whole observation period would influence the vaccination coverage by the end of the observation. Both standardized and unstandardized coefficients were estimated in this study. Following the general rules of SEM [20,25], we assumed exogenous variables covaried with each other, and there existed unobserved factors affecting all endogenous variables. Meanwhile, when estimating unstandardized path coefficients, the variances of all locally exogenous variables were considered. To avoid some variables generating extremely larger observed variances, we scaled variables with greater magnitude by dividing a constant before model fitting and resized their unstandardized estimations by multiplying that constant. The final model parameters were estimated using Maximum Likelihood Estimation.

4. Results

4.1. Preliminary analysis

A set of univariable regressions was fitted between county-level vaccination rate and vaccine hesitancy, and the temporal evolution

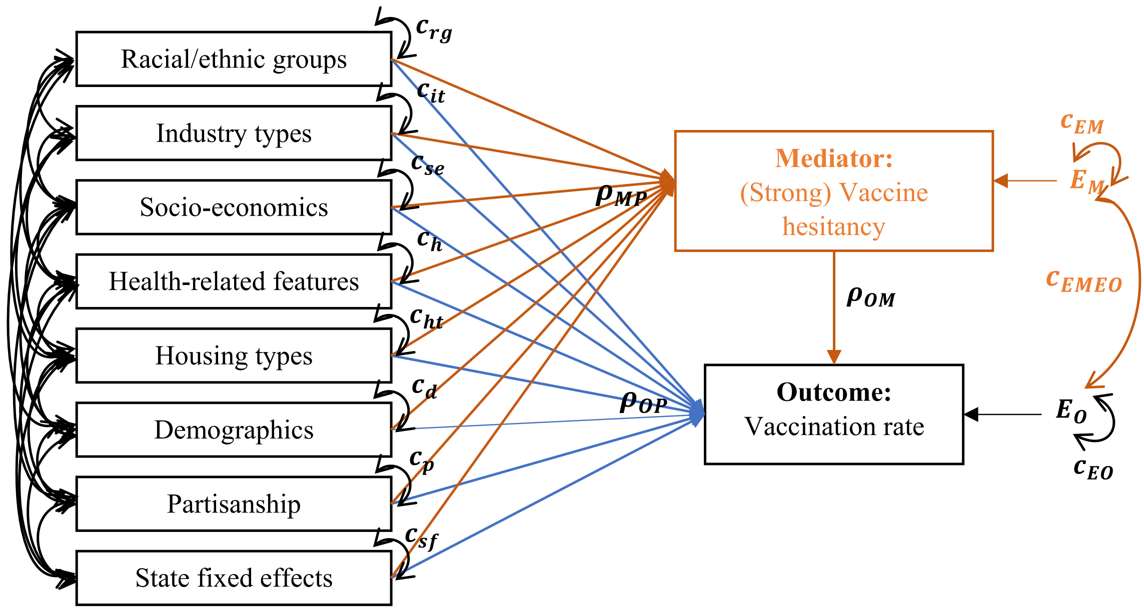

Fig. 1. Conceptual Diagrams for mediation analysis. c_{EM} means the variance of the error term of mediators; c_{EO} means the variance of the error term of outcomes; c_{rg}, c_{it}, c_{se}, c_h, c_{ht}, c_d, c_p, c_{sf} mean the variances of exogenous variables; c_{EMEO} refers to the covariance matrix between error terms of mediator and outcome.

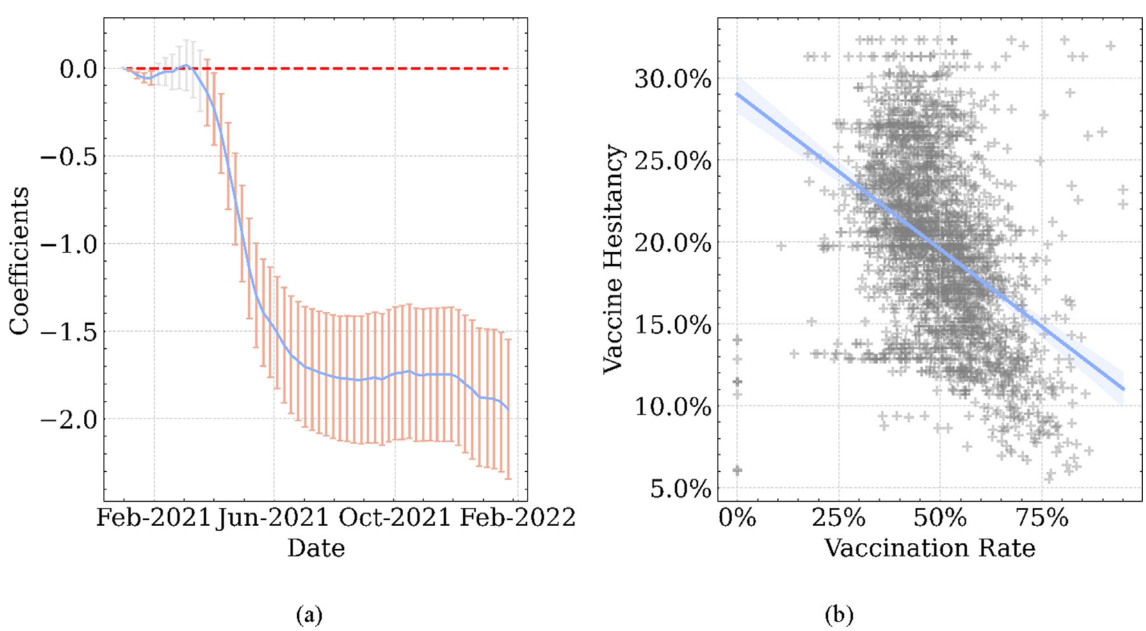

Fig. 2. Temporal evolution of coefficients of univariable regressions (a) and scatter plot of vaccine hesitancy versus vaccination rate. Panel (a) covers data from 2021-01-01 to 2022-01-27 on a weekly average basis. The error bar depicts the robust 95 % CI. Panel (b) was plotted based on data during January 21–27, 2022. Each spot represents one county in the contiguous US.

of coefficients ($\beta_{i,t}$ in Eq. (1)) was depicted in Fig. 2 (a). As shown, the evolution pattern of $\beta_{i,t}$ was highly consistent with the T-test results shown in Fig. A3. The relationship between vaccination rate and vaccine hesitancy was not significant at first but became significantly negative and dropped rapidly from March to June 2021, followed by a stable plateau until the end. By the end of January 2022, a 1 % increase in vaccine hesitancy is associated with a 1.94 % (95 % CI: 1.55, 2.41) decrease in the percentage of fully vaccinated people.

Fig. 2 (b) shows the scatter plot of vaccine hesitancy versus vaccination rate. Although a pronounced negative relationship was observed, there are still several counties showing counterintuitive patterns. For example, spots located at the upper right corner denote counties reporting lower vaccination willingness but exhibiting higher vaccination rates, while spots located at the lower-left corner denote counties reporting higher vaccination willingness but exhibiting lower vaccination rates. These contradictory patterns can be explained by confounding effects from determinants other than vaccine hesitancy.

Last, we calculated the Pearson correlation among all variables based on data from January 21 to 27 in 2022. Variables ranking in the top 15 in terms of their correlations with vaccination rate and vaccine hesitancy were reported in Table 2. As shown, counties with more Democrats, more multi-unit housing, fewer mobile

Table 2
Pearson correlation matrix.

	Vaccination Rate		Vaccine Hesitancy
Republican	−0.599	Median Income	−0.533
Democrat	0.593	Mobile Home	0.481
High Educated	0.503	Poverty	0.475
Technique	0.423	High Educated	−0.471
Multi-unit House	0.407	Technique	−0.408
Urbanicity	0.397	Disability	0.378
Median Income	0.377	**Vaccination Rate**	−0.359
Asian	0.376	Multi-unit House	−0.359
Vaccine Hesitancy	−0.359	Asian	−0.352
Mobile Home	−0.342	Without Insurance	0.329
Agriculture & Mining	−0.331	Republican	0.329
Finance	0.325	Democrat	−0.320
Disability	−0.287	Urbanicity	−0.300
Recreation & Food	0.279	African American	0.294
Without Insurance	−0.250	Finance	−0.291

Notes: All correlations have P-value < 0.01. Each column is ascendingly sorted by the absolute value accordingly.

home, more Asians, more people with disabilities, and higher socioeconomic statuses, were associated with higher vaccination rates and lower vaccine hesitancy. A negative correlation (-0.359) between vaccination rate and vaccine hesitancy was documented. However, it is important to note that vaccine hesitancy did not have the strongest correlation with the vaccination rate. In addition, rankings of exogenous variables regarding their correlations with vaccination rates were different from vaccine hesitancy. Partisanship presented the strongest correlation with vaccination rate but ranked out of the top 10 regarding its correlation with vaccine hesitancy. Median household income showed the greatest correlation with vaccine hesitancy but ranked 7th regarding its correlation with vaccination rate. These discrepancies further substantiate that the underlying determinants of vaccine hesitancy and vaccination rate are different. Counties with lower vaccination rates may not be fully caused by the residents' unwillingness to receive COVID-19 vaccines. Other factors, such as political ideologies, structural inequalities, and socioeconomic disparities, may be significantly more challenging.

4.2. Outcomes of mediation analysis

Outputs of SEMs with both standardized and unstandardized coefficients were reported in Table 3. State fixed effects were controlled but not reported. Several SEM fit measures were employed, including root mean square error of approximation (RMSEA), Tucker-Lewis index (TLI), and Comparative fit index (CFI) to evaluate the SEM goodness-of-fit. All models showed reasonable model goodness-of-fit according to rules of thumb guidelines, including RMSEA $\leq$ 0.06, TLI $\geq$0.95, and CFI $\geq$0.95. Since the degree of freedom of the model with no mediator is 0, their SEM fit measures all reach the upbound. Besides SEM fit measures, we also reported regression measures, the adjusted R^2, for each of the two regressions. We found that the model goodness-of-fit of vaccine hesitancy (0.952) is more significant than the vaccination rate (0.611), which can be explained by the high randomness of vaccination rates in the real-world setting.

By the end of January 2022, holding others constant and using White populations as a reference, a county with 1 % more Asians was associated with a 0.058 % decrease in vaccine hesitancy and a 0.361 % increase in vaccination rate, among which 0.125 % increase in vaccination rate was caused by the decrease in vaccine hesitancy. Similarly, a county with 1 % more Hispanics was associated with a 0.043 % decrease in vaccine hesitancy and a 0.127 % increase in vaccination rate, among which 0.092 % increase in vaccination rate was traced to vaccine hesitancy. The percentage of African Americans and other minorities did not show significance in modeling vaccine hesitancy but in vaccination rate. A county with 1 % more African Americans was associated with a 0.162 % lower vaccination rate, while a county with 1 % more minority populations was associated with a 0.150 % higher vaccination rate.

Several industry types showed significance in modeling vaccine hesitancy. Holding others constant and using the agriculture and mining industry as a reference, a county with 1 % more recreation and food services was associated with a 0.027 % decrease in vaccine hesitancy, leading to a 0.058 % increase in vaccination rate. Similar negative relationships with vaccine hesitancy were documented in the percentage of retail, education, manufacture, technique, and finance services, among which the percentage of technical services presented the most negative association. 1 % more technical services were associated with a 0.079 % decrease in vaccine hesitancy, rendering 0.171 % increase in vaccination rate. Last, only the health care services exhibited significance when modeling vaccination rates among all industry types. A county with 1 % more health care services was associated with a 0.331 % increase in vaccination rate.

As for socioeconomics, median household income presented significant relationships in both models. Per $\$10^3$ increase in median household income was related to a 0.043 % decrease in vaccine hesitancy and a 0.162 % increase in vaccination rate, wherein 0.094 % increase in vaccination rate was linked to vaccine hesitancy. 1 % increase in households without a vehicle was related to a 0.058 % increase in vaccine hesitancy, which could lead to a 0.125 % decrease in vaccination rate; however, its association with vaccination rate was insignificant. A similar pattern was observed in the percentage of single-parent families. 1 % increase in single-parent families was related to a 0.041 % increase in vaccine hesitancy, which could lead to a 0.088 % decrease in vaccination rate, while its association with vaccination rate was insignificant. The unemployment rate was not significantly related to vaccine hesitancy but significantly related to the vaccination rate. 1 % increase in unemployment rate linked to a 0.292 % decrease in vaccination rate.

COVID-19 case rate was only significantly related to vaccine hesitancy. One more confirmed case was associated with a 1.811 % increase in vaccine hesitancy, resulting in a 3.911 % decrease in vaccination rate. The percentage of residents without health insurance was not significantly related to vaccine hesitancy but was significantly negatively related to the vaccination rate. 1 % increase in residents without health insurance was associated with a 0.286 % decrease in vaccination rate. The percentage of civilians with a disability was only significantly related to vaccine hesitancy. 1 % increase in civilians with disability was associated with a 0.041 % increase in vaccine hesitancy, leading to a 0.089 % decrease in vaccination rate. Housing types presented limited significance. Only a percentage of mobile homes showed significance in modeling vaccine hesitancy. 1 % increase in mobile homes was associated with a 0.025 % increase in vaccine hesitancy, which could lead to a 0.055 % decrease in vaccination rate.

As for demographics, the elderly (age 65+) percentage showed significance in both models. 1 % increase in the elderly was related to a 0.116 % decrease in vaccine hesitancy and a 0.348 % increase in vaccination rate, wherein 0.251 % increase in vaccination rate was rendered by the decrease in vaccine hesitancy. The percentage of urbanized residents also presented significant relationships with vaccine hesitancy. 1 % increase in urbanized residents was associated with a 0.006 % decrease in vaccine hesitancy, which could lead to a 0.012 % increase in vaccination rate. Last, the percentage of Democrats was significant in both models. 1 % increase in Democrats was related to a 0.024 % decrease in vaccine hesitancy and

Table 3
Outcomes of SEMs: Vaccine Hesitancy as Mediator vs No Mediator.

Estimation	**Mediator: Vaccine hesitancy Outcome: Vaccination rate**				**Mediator: None Outcome: Vaccination rate**	
Variable	Direct effect on vaccine hesitancy	STD coeff.	Indirect effect on vaccination rate via vaccine hesitancy	STD coeff.	Total effect on vaccination rate	STD coeff.
(Intercept)	27.616*** (24.971, 29.858)	5.202			1.054 (−25.032, 15.548)	0.086
Racial/ethnic groups						
Asian	−0.058*** (−0.087, −0.027)	−0.026	0.125*** (0.055, 0.190)	0.024	0.361** (0.113, 0.554)	0.070
African American	0.007. (−0.001, 0.014)	0.018	−0.014. (−0.031, 0.002)	−0.017	−0.162*** (−0.214, −0.097)	−0.193
Hispanic	−0.043*** (−0.052, −0.034)	−0.112	0.092*** (0.075, 0.104)	0.104	0.127*** (0.065, 0.204)	0.144
Minority	0.012. (−0.002, 0.022)	0.019	−0.026** (−0.050, −0.010)	−0.018	0.150*** (0.077, 0.235)	0.101
Industry types						
Recreation & Food	−0.027*** (−0.043, −0.012)	−0.018	0.058*** (0.026, 0.096)	0.017	0.154 (−0.075, 0.361)	0.045
Health Care	−0.018. (−0.035, 0.006)	−0.011	0.039. (−0.012, 0.074)	0.011	0.331*** (0.131, 0.489)	0.091
Retail	−0.020* (−0.042, −0.004)	−0.010	0.043* (0.009, 0.092)	0.009	0.106 (−0.114, 0.276)	0.023
Utility	−0.009 (−0.044, 0.020)	−0.003	0.020 (−0.044, 0.089)	0.003	0.005 (−0.220, 0.232)	0.001
Education	−0.029* (−0.053, −0.002)	−0.017	0.062* (0.004, 0.121)	0.016	−0.002 (−0.146, 0.159)	−0.000
Manufacture	−0.025*** (−0.037, −0.015)	−0.034	0.055*** (0.030, 0.083)	0.032	−0.045 (−0.157, 0.077)	−0.026
Technique	−0.079** (−0.147, −0.037)	−0.040	0.171** (0.081, 0.311)	0.037	0.209 (−0.032, 0.538)	0.045
Administration	−0.003 (−0.047, 0.037)	−0.001	0.007 (−0.083, 0.099)	0.001	0.057 (−0.270, 0.434)	0.007
Finance	−0.057*** (−0.083, −0.023)	−0.021	0.124** (0.049, 0.187)	0.019	0.179 (−0.092, 0.439)	0.028
Information	−0.025 (−0.127, 0.065)	−0.004	0.054 (−0.138, 0.264)	0.004	0.045 (−0.445, 0.514)	0.003
Socioeconomic features						
Median Income	−0.043*** (−0.048, −0.028)	−0.115	0.094*** (0.062, 0.109)	0.107	0.162*** (0.099, 0.215)	0.186
Without Vehicle	0.058*** (0.026, 0.084)	0.039	−0.125*** (−0.183, −0.056)	−0.037	0.115 (−0.142, 0.346)	0.034
Unemployment Rate	0.008 (−0.017, 0.042)	0.004	−0.016 (−0.092, 0.037)	−0.003	−0.292* (−0.558, −0.020)	−0.061
Single Parent	0.041** (0.013, 0.071)	0.021	−0.088** (−0.160, −0.028)	−0.019	−0.182. (−0.404, 0.016)	−0.040
Health-related features						
Without Insurance	0.017 (−0.006, 0.036)	0.016	−0.037 (−0.078, 0.014)	−0.015	−0.286** (−0.539, −0.143)	−0.116
Cumulative Case Rate	1.811** (0.618, 3.384)	0.017	−3.911** (−6.978, −1.271)	−0.016	22.941. (7.190, 47.131)	0.094
Disability	0.041*** (0.017, 0.060)	0.034	−0.089*** (−0.141, −0.036)	−0.032	0.088 (−0.079, 0.245)	0.031
Housing types						
Multi-unit House	−0.012 (−0.024, 0.012)	−0.013	0.027 (−0.025, 0.054)	0.012	−0.098 (−0.235, 0.085)	−0.046
Mobile Home	0.025*** (0.016, 0.036)	0.046	−0.055*** (−0.081, −0.033)	−0.043	−0.053. (−0.127, 0.001)	−0.041
Crowd Home	0.018 (−0.024, 0.067)	0.007	−0.039 (−0.143, 0.051)	−0.006	0.405 (−0.280, 0.977)	0.063
Group Quarters	0.006 (−0.012, 0.021)	0.005	−0.014 (−0.048, 0.025)	−0.005	−0.112 (−0.285, 0.032)	−0.041
Demographic characteristics						
Male	−0.011 (−0.040, 0.030)	−0.005	0.024 (−0.065, 0.089)	0.005	0.197 (−0.017, 0.599)	0.037
Age over 65	−0.116*** (−0.136, −0.086)	−0.101	0.251*** (0.185, 0.305)	0.094	0.348*** (0.208, 0.586)	0.131
Age under 18	0.012 (−0.017, 0.045)	0.008	−0.025 (−0.107, 0.039)	−0.007	−0.142 (−0.406, 0.069)	−0.040
Population Density	−0.004. (−0.010, 0.000)	−0.012	0.008. (−0.001, 0.020)	0.011	−0.047 (−0.134, −0.019)	−0.070
Urbanicity	−0.006*** (−0.009, −0.003)	−0.035	0.012*** (0.007, 0.020)	0.032	−0.007 (−0.027, 0.008)	−0.018

(*continued on next page*)

Table 3 (*continued*)

Estimation Variable	**Mediator: Vaccine hesitancy Outcome: Vaccination rate** Direct effect on vaccine hesitancy	STD coeff.	Indirect effect on vaccination rate via vaccine hesitancy	STD coeff.	**Mediator: None Outcome: Vaccination rate** Total effect on vaccination rate	STD coeff.
Partisanship						
Democrat	−0.024*** (−0.034, −0.016)	−0.072	0.052*** (0.034, 0.073)	0.068	0.496*** (0.424, 0.576)	0.640
Model fit						
R-sq.(adj)	0.952				0.611	
CFI	0.987				1.000	
TLI	0.979				1.000	
RMSEA (90 % CI)	0.040 (0.030, 0.051)				0.000	

Note: Robust 95 % confidence interval (CI) is in parentheses. Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1. P-value < 0.05 is considered as statistically significant. For robustness check, we replicated an SEM analogous to Table 3 except using the strong vaccine hesitancy as a mediator (Table A1). The results were highly consistent with Table 3 regarding the significance, signs, and size of both direct and indirect effects, indicating our models are robust across different vaccine hesitancy measures.

a 0.496 % increase in vaccination rate, wherein only 0.052 % increase in vaccination rate could be sourced to vaccine hesitancy.

To compare the coefficients across variables, we now move to standardized estimations. All interpretations are based on the unit of variable's standard deviation. The rankings of the standardized estimations in different models are as follows (only consider those significant): 1) In regression with vaccine hesitancy as the dependent variable, *Mobile Home* showed the strongest positive relationship, followed by *Without Vehicle*, *Disability*, and *Single Parent*. *Median Income* presented the strongest negative relationship, followed by *Hispanic*, *Age over 65,* and *Democrats*. 2) In regression with vaccination rate as the dependent variable, *Democrat* presented the strongest positive association, followed by *Median Income*, *Hispanic*, and *Age over 65*. The *African American* presented the strongest negative association, followed by *Without Insurance, Population Density,* and *Unemployment Rate*.

5. Discussion, policy implication, and conclusion

This work evaluated vaccine hesitancy and vaccination coverage across the contiguous US to determine the extent to which vaccine hesitancy inhibited real-world vaccine uptake and how vaccine hesitancy mediated relationships between exogenous variables and vaccination coverage. Results documented a significant negative association between vaccine hesitancy and vaccination coverage, which is intuitive given that higher hesitancy indicates less willingness to uptake vaccines. However, contrary to some past studies suggesting vaccine hesitancy was the main barrier to achieving high vaccination coverage [1,4,42,46,48], we observed the negative relationship between vaccine hesitancy and vaccination rate was not predominant, particularly compared with some socioeconomic factors and partisanship. Additional efforts are needed to unravel the critical hurdle in mitigating vaccination inequality and achieving high vaccination coverage.

In alignment with previous studies, our findings substantiate that socioeconomic privilege, demographic characteristics, political ideology, and racial disparity are substantially related to both vaccination coverage [1,4,7,24,39,48] and vaccine hesitancy [5,15,18,29,31,37,38]. In general, counties with higher socioeconomic statuses, more Asians and Hispanics, higher percentages of elderly (age 65+), greater health insurance coverage, and higher percentages of Democrats presented significantly lower vaccine hesitancy and higher vaccination rates. However, unlike previous studies [11,15,26,37,38], we did not find the percentage of African Americans and males in counties have significant relationships with vaccine hesitancy. One explanation is that previous studies mainly considered the univariable correlation (similar to results in Table 2); however, after controlling for various confounders, signs and significance of coefficients may change due to the intertwined effects from other exogenous variables. Another possible reason is that vaccine hesitancy varied considerably throughout the pandemic [18], while most previous studies were based on surveys conducted at the initial stage of the vaccination campaign. For example, one recent study stated that vaccine hesitancy among African Americans and females was high in early periods but declined dramatically across time and eventually disappeared [29].

One main finding of our study is that estimated associations in modeling vaccination coverage and vaccine hesitancy are different regarding their significance, magnitude, and signs. First, some variables only showed significance in one model. For example, counties with more African Americans, fewer racial minorities, less health care services, and higher unemployment rates presented significantly lower vaccination rates, but did not show significant differences in vaccine hesitancy. On the other hand, counties with fewer recreation, food, retail, education, manufacture, technique, and financial services, more households with no vehicle, greater COVID-19 case rates, more single-parent households, more populations with disabilities, more mobile homes and group quarters, and lower urbanicity presented significant higher vaccine hesitancy, but did not show significant differences in vaccination rate. Second, the ranking of coefficients regarding their standardized magnitude in the two models is different. Among all exogenous variables, the percentage of Democrats exhibited the most robust relationship with vaccination rate, while its relationship with vaccine hesitancy ranked fourth. The percentage of African Americans exhibited the strongest negative association with vaccination rate, while its relationship with vaccine hesitancy is insignificant. Each of these differences affirms the fact that vaccination rate and vaccine hesitancy are divergent.

Mediation analysis further demonstrates that vaccine hesitancy only partially explains socioeconomic, racial, and partisan disparities in vaccination coverage. Indirect effects from many determinants to vaccination rate via vaccine hesitancy are insignificant, indicating vaccine hesitancy did not statistically account for those disparities in vaccination coverage. Among determinants showing significance in both models, indirect effects via vaccine hesitancy account for 10.484 % (the lowest) of the total effects for *Democrat* and 72.441 % (the highest) of total effects for *Hispanics*. Interestingly, political ideology presents the greatest gap between vaccine hesitancy and vaccination rate. The underlying cause is not examined in the paper. Further studies are needed to investigate whether it is caused by irreconcilable ideology, perceptions of social norms, or misinformation from leaders, to gain a more fundamental understanding.

The divergence between ex-ante vaccine hesitancy and ex-post vaccination coverage and the partial explanation power of vaccine hesitancy on vaccination coverage deserve further discussion. One potential reason is the difference between perceived willingness and real practices. The reported intention may not be eventually translated into real-world vaccine uptake because of other barriers such as inadequate vaccine supply, unavailable vaccination clinics, poor accessibility of vaccine sources, lack of eligibility due to low prioritization, and afraid of being charged [5,14]. On the other hand, the reported hesitancy may also be assuaged due to recommendations from trusted health care providers, bandwagon effects of collective vaccination behaviors, and stringent vaccine administration policies [31]. For example, in many states, people are required to wear masks or show vaccination records when entering public spaces such as restaurants, classrooms, and recreation centers. For the sake of convenience, people may compromise on vaccination even if they are not willing to. Another possible reason is the sampling biases and nonresponse biases in survey-based vaccine hesitancy. Residents presenting high mistrust in local governments are more likely to neglect a survey conducted by government agencies. In addition, since this is an online survey, those with poor accessibility to the internet or those who are unfamiliar with new techniques may have difficulties in submitting responses. The strong independent effect of partisanship on vaccine uptake may be partially sourced to this reason due to the historical mistrust of the opposing party. Last, the effects of some unobserved factors also lead to such differences. Uncontrolled factors, such as health statuses, differential exposure to media channels and social networks, social desirability and conformity, religious beliefs, and educational campaigns, all influence people's final choice of vaccination [21,48].

Several limitations exist and deserve further research. First, associations revealed in this observational study are not intended for drawing causal inferences. Second, all analyses were conducted at an aggregate level due to the limited availability of individual-level information; hence, conclusions might not reflect the actual individual behavior, considering the possibility of the ecological fallacy. Last, vaccine hesitancy examined in our models only represents the intentions of respondents participating in the survey, which may render sampling and response biases, particularly compared with the population-level vaccination rate.

In conclusion, our findings challenge the popular media narrative that foregrounds vaccine hesitancy as a root cause of disparities in vaccination [14]. Our study suggests that the observed disparities are a joint result of various determinants such as health care inequality, socioeconomic privilege, structural racism, medical mistrust, and partisan divide. Compared with vaccine hesitancy, these disparities may be far bigger hurdles. Governments should carefully design effective ways to achieve high and equitable vaccination coverage. Practices may include actively monitoring and addressing vaccination barriers in vulnerable communities with high priority, tailoring accessible information that is culturally and linguistically competent, guiding media to report the effectiveness and safety of vaccines, engaging local providers, professionals, and leaders who are known and trusted in the community, and expanding vaccination clinics with a more flexible schedule such as walk-in services.

Data availability

Data will be made available on request.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A

A1. Spatiotemporal distribution

Fig. A1 depicts the temporal evolutions of vaccination rates stratified by vaccine hesitancy. We observed salient disparities in vaccination rates across counties with wide-ranging levels of vaccine hesitancy. Specifically, we found that counties with stronger vaccine hesitancy persistently exhibited lower vaccination rates, and

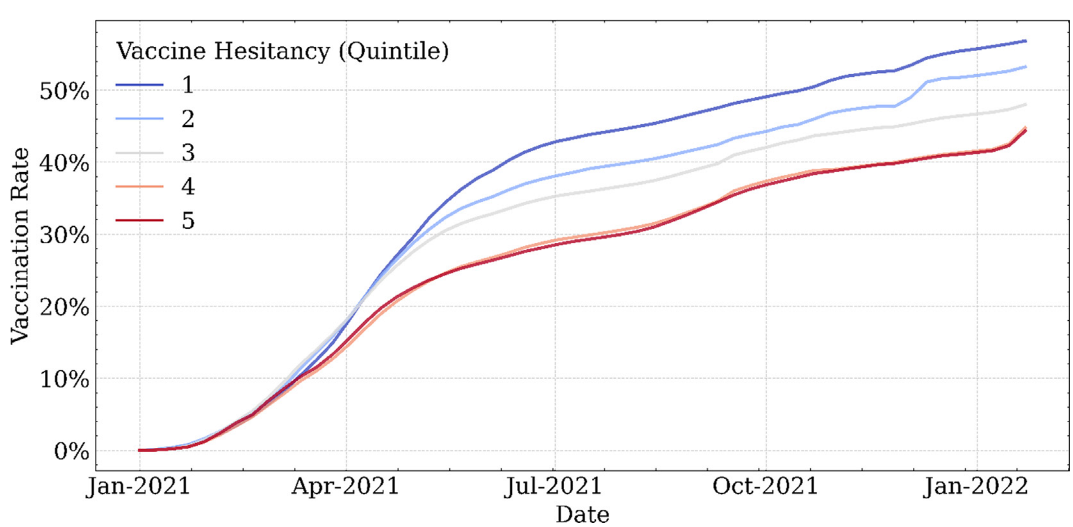

Fig. A1. Temporal evolution of fully vaccinated rate (%) across counties stratified by vaccine hesitancy. Sample comprises 2,657 contiguous US counties. Texas, Colorado, and Virginia are excluded because C.D.C. vaccination data (county level) were missing before November 2021.

the gap along vaccine hesitancy did not narrow over time. By the end of January 2022, the average percentage of people fully vaccinated in counties in the lowest hesitancy quintile (hereafter Q1 for the lowest quintile and so on) reached 56.83 % (SD: 15.98 %), counties in Q2 reached 53.23 % (SD: 11.06 %), counties in Q3 reached 47.99 % (SD: 9.51 %), counties in Q4 reached 44.76 % (SD: 11.57 %), and counties in Q5 reached 44.35 % (SD: 11.39 %). We also found that differences in vaccination rate along hesitancy quintiles were not clearly monotonic. For example, the difference between Q1 and Q2 was significant, whereas the difference between Q4 and Q5 was negligible.

Spatial distributions of county-level vaccine hesitancy and vaccination rate were mapped in Fig. A2. The two metrics showed a broadly reversed geographical pattern against each other. The West Coast and the Northeast exhibited the lowest vaccine hesitancy and highest vaccination rate, while the South, the Southern Great Plains, and the Northern Rocky Mountain presented the highest vaccine hesitancy and lowest vaccination rate. Additionally, Fig. A2 demonstrated pronounced evidence of intra-state clustering, either manifesting as the spatial concentration within states or the spatial exclusion among states, in both vaccine hesitancy and vaccination rate. Such a high spatial dependence may be

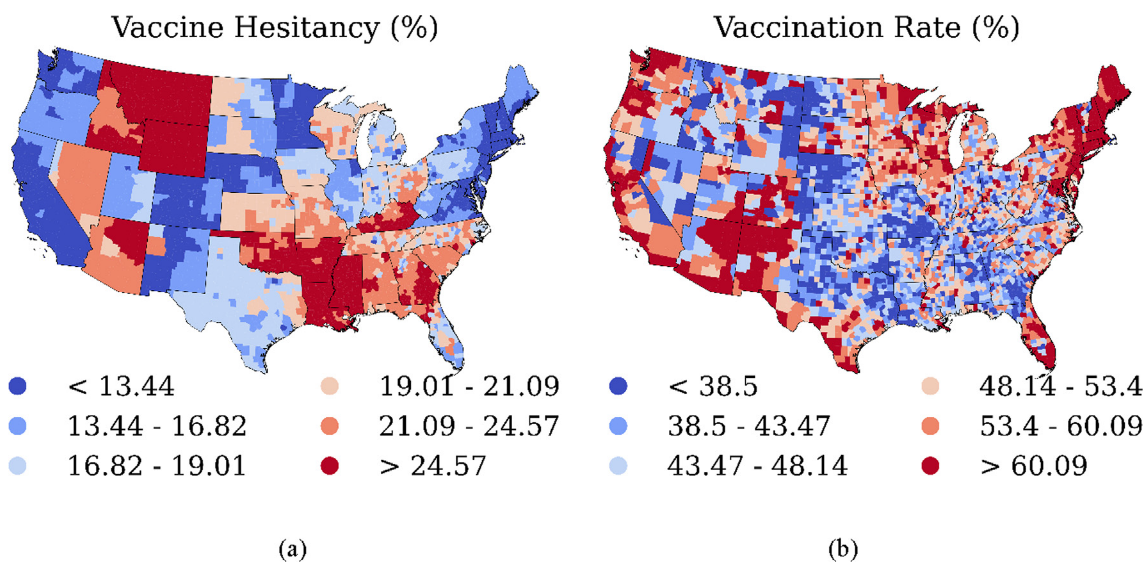

Fig. A2. Spatial distribution of county-level (a) vaccine hesitancy and (b) vaccination rate. Vaccination rate was plotted based on C.D.C. vaccination data during January 21–27, 2022.

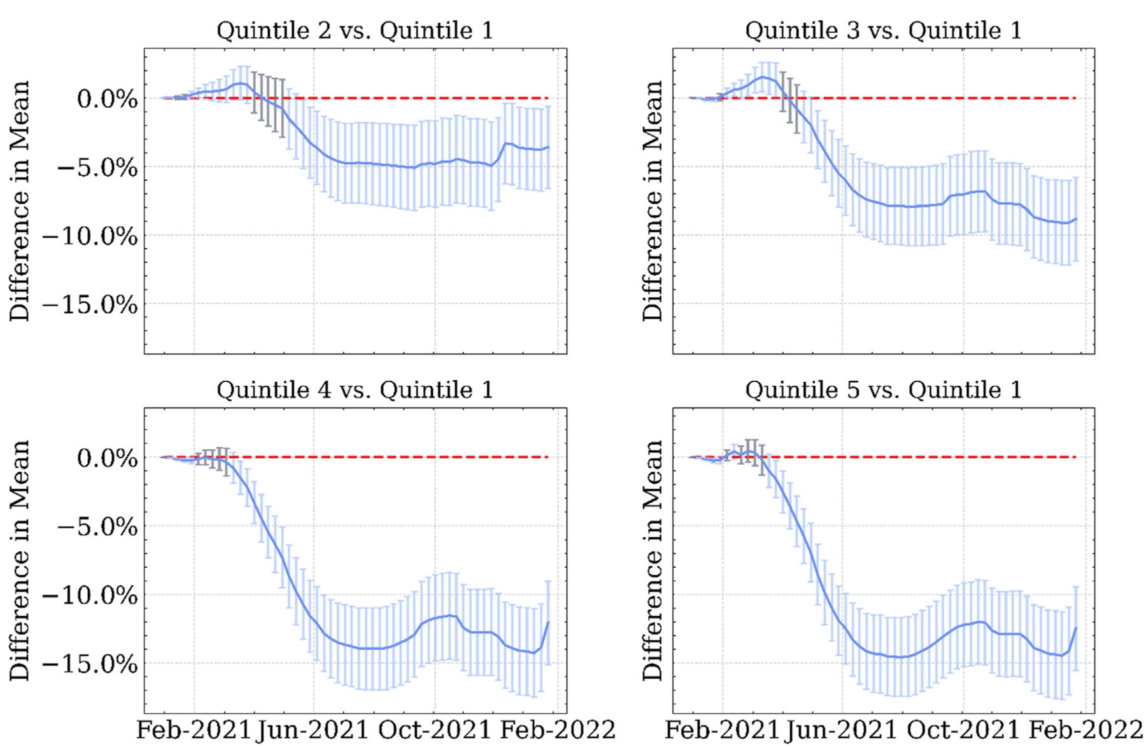

Fig. A3. Temporal evolution of difference in mean of vaccination rate between vaccine hesitancy quintiles (Q1 as reference). The error bar depicts the robust 95 % CI of the mean difference. Gray error bars denote those reporting P-values greater than 0.05 in T-tests (i.e. not significant).

because vaccine allocation, rollout, and outreach were consistently implemented at the state level. The pronounced regional dependence suggests the need for control for state effects when specifying models.

A2. T-tests of difference in vaccination rate across vaccine hesitancy strata

To quantify the differences in the mean of vaccination rates by vaccine hesitancy, we conducted unpaired T-tests across counties stratified by vaccine hesitancy with the lowest quintile as the reference (Fig. A3). T-tests were calculated on a weekly average basis to provide a time lapse displaying how the differences varied over time:

$$T_{(1,k),t} = \frac{\bar{R}_{1,t} - \bar{R}_{k,t}}{\sqrt{\left(s_{1,t}^2/n_1\right) + \left(s_{k,t}^2/n_k\right)}}, k = 2,3,4,5 \quad \text{(A1)}$$

where $T_{(1,k),t}$ is the unpaired T-test statistic between vaccination rate of counties in the lowest vaccine hesitancy quintile and the k^{th} vaccine hesitancy quintile by the end of week t; $\bar{R}_{1,t}$ is the mean of fully vaccination rates of counties in the lowest vaccine hesitancy quintile by the end of week t; $\bar{R}_{k,t}$ is the mean of fully vaccination rates of counties in the k^{th} vaccine hesitancy quintile by the end of week t; $s_{1,t}^2$ and $s_{k,t}^2$ represent the corresponding sample variance, and n_1 and n_k represent the sample sizes.

Consistent with Fig. A1, we found a decrease in vaccination rate with an increase in vaccine hesitancy. By the end of January 2022, average vaccination rate in Q1 counties was 3.60 % greater (95 % CI: 2.10, 5.10) than Q2, 8.84 % greater (95 % CI: 7.31, 10.36) than Q3, 12.07 % greater (95 % CI: 10.54, 13.59) than Q4, and 12.48 % greater (95 % CI: 10.95, 14.00) than Q5. Additionally, throughout the vaccination campaign, we found vaccination disparities among the vaccine hesitancy were not significant in the initial phase (before March 2021), but sharply increased during the mid-stage (March to June 2021), and eventually remained stable even as vaccination eligibility and access have expanded.

A3. Robustness check of mediation effects using the strong vaccine hesitancy as a mediator

Table A1

Table A1
Outcome of SEMs. Strong Vaccine Hesitancy as Mediator.

Mediator: Strong vaccine hesitancy; Outcome: Vaccination rate				
Estimation				
Variable	Direct effect on vaccine hesitancy	STD coeff.	Indirect effect on vaccination rate via vaccine hesitancy	STD coeff.
(Intercept)	15.196 (13.948, 16.245)***	4.707		
Racial/ethnic groups				
Asian	−0.015 (−0.031, −0.001)*	−0.011	0.074 (0.004, 0.152)*	0.014
African American	−0.003 (−0.007, 0.002)	−0.014	0.015 (−0.009, 0.035)	0.018
Hispanic	−0.023 (−0.027, −0.019)***	−0.100	0.111 (0.089, 0.129)***	0.126
Minority	0.006 (−0.001, 0.011)	0.015	−0.027 (−0.053, −0.002)*	−0.018
Industry types				
Recreation & Food	−0.014 (−0.022, −0.007)***	−0.016	0.067 (0.034, 0.100)***	0.020
Health Care	−0.007 (−0.017, 0.004)	−0.008	0.035 (−0.019, 0.086)	0.010
Retail	−0.010 (−0.018, 0.001)*	−0.008	0.046 (−0.002, 0.090)*	0.010
Utility	−0.003 (−0.018, 0.015)	−0.002	0.013 (−0.070, 0.080)	0.002
Education	−0.018 (−0.029, −0.008)***	−0.018	0.086 (0.040, 0.140)***	0.022
Manufacture	−0.008 (−0.013, −0.003)***	−0.018	0.039 (0.017, 0.060)***	0.022
Technique	−0.032 (−0.060, −0.012)**	−0.027	0.154 (0.060, 0.286)**	0.033
Administration	−0.002 (−0.023, 0.027)	−0.001	0.010 (−0.127, 0.109)	0.001
Finance	−0.025 (−0.041, −0.007)**	−0.015	0.121 (0.030, 0.189)**	0.019
Information	0.002 (−0.029, 0.035)	0.000	−0.008 (−0.166, 0.139)	−0.001
Socioeconomic features				
Median Income	−0.011 (−0.016, −0.006)***	−0.047	0.052 (0.030, 0.076)***	0.059
Without Vehicle	0.036 (0.024, 0.047)***	0.041	−0.174 (−0.234, −0.107)***	−0.051
Unemployment Rate	0.003 (−0.010, 0.013)	0.003	−0.016 (−0.060, 0.049)	−0.003
Single Parent	0.014 (0.001, 0.029).	0.012	−0.067 (−0.138, −0.002).	−0.015
Health-related features				
Without Insurance	0.017 (0.007, 0.031)**	0.026	−0.082 (−0.150, −0.033)**	−0.033
Cumulative Case Rate	0.954 (0.358, 1.738)**	0.015	−4.565 (−8.784, −1.724)**	−0.019
Disability	0.022 (0.011, 0.032)***	0.030	−0.105 (−0.158, −0.052)***	−0.038
Housing types				
Multi-unit House	−0.007 (−0.014, 0.001).	−0.013	0.034 (−0.003, 0.068).	0.016
Mobile Home	0.016 (0.012, 0.021)***	0.049	−0.078 (−0.103, −0.057)***	−0.061
Crowd Home	0.002 (−0.018, 0.033)	0.001	−0.010 (−0.149, 0.085)	−0.002
Group Quarters	0.013 (0.004, 0.023)**	0.018	−0.062 (−0.113, −0.018)**	−0.023
Demographic characteristics				
Male	−0.016 (−0.038, 0.001).	−0.011	0.075 (−0.006, 0.185).	0.014
Age over 65	−0.047 (−0.056, −0.035)***	−0.067	0.226 (0.162, 0.276)***	0.085
Age under 18	0.006 (−0.010, 0.022)	0.007	−0.031 (−0.108, 0.043)	−0.009
Population Density	−0.002 (−0.004, 0.000).	−0.012	0.010 (−0.001, 0.020).	0.015
Urbanicity	−0.004 (−0.005, −0.003)***	−0.039	0.018 (0.013, 0.023)***	0.049
Partisanship				
Democrat	−0.014 (−0.018, −0.008)***	−0.068	0.066 (0.040, 0.089)***	0.085
Model fit				
R-sq.(adj)	0.947			
CFI	0.975			
TLI	0.968			
RMSEA (90 % CI)	0.054 (0.043, 0.067)			

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