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Regional Disparities in COVID-19 Vaccine Hesitancy: The Moderating Role of Social Distancing and Vaccine Rollout in the U.S.

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Abstract

This study examines the relationship between statewide contexts and individuals' COVID-19 vaccine hesitancy by using the Household Pulse Survey, a national and near real-time data timely deployed by the U.S. Census Bureau. Controlling for the individual- and state-level variables in addition to temporal effect, this study finds that racial and ethnic minorities and COVID-19-infected people are more hesitant than their counterparts to receive a vaccine. Individuals who reside in a state where more stringent social distancing measures – particularly mask mandate – are implemented and vaccine rollout conditions are better appear to be less hesitant to receive a COVID-19 vaccine. Vulnerable subpopulation groups such as people of color and COVID-19-infected individuals are more hesitant to vaccine uptake even if regional circumstances are equal. These findings suggest that the continuation and extension of vaccine campaigns at the regional as well as individual levels are all important for expediting COVID-19 vaccination and reducing vaccine hesitancy as the world is in the middle of the third year of the pandemic.

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Coronavirus (COVID-19) pandemic, vaccine hesitancy, social distancing, vaccine rollout, regional disparities

Introduction

The third year of the Coronavirus Disease 2019 (COVID-19) pandemic has raised numerous regional management and policy concerns since its first outbreak in December 2019 (Bourdin et al. 2021). Particularly in 2021, the public introduction (i.e., rollout) of COVID-19 vaccines, as well as public awareness and attitude towards the new vaccine, have been the subject of extensive news coverage and pandemic policy discourses in the United States and many other countries around the globe (Anderson et al. 2021; Dabla-Norris et al. 2021; Ivory et al. 2021; Leonhardt 2021). COVID-19 vaccination landscape is complex and context-specific substantially varying across different places (World Health Organization 2019). Previous COVID-19 research has primarily focused on individuals' cognitive and behavioral considerations for acceptance and uptake of COVID-19 vaccines, which undeniably call for urgent policy responses. Yet how regional and spatially contextual factors are related to individuals' attitudes is arguably as important and most amenable to regional public health policies but is relatively less studied. Also neglected is a potentially unequal effect of the regional contexts among socioeconomically vulnerable subpopulations who are in most need of public assistance during and beyond the ongoing pandemic.

COVID-19 is a contagious respiratory disease which spreads between individuals through droplets released when an infected person coughs and sneezes (Centers for Disease Control and Prevention 2021). To slow the spread of the virus, many governments in the world have been mandating or recommending a variety of public measures – social distancing – in regions affected by the pandemic (Lobinska et al. 2022). Social distancing is the practice of maintaining an adequate and safe distance (e.g., six feet or more) from other people or reducing close physical contact. Individuals can comply with the government's social distancing measures by staying at home, reducing outdoor travel, avoiding public places, adopting contactless greetings, and physically staying away from others.

Vaccine hesitancy, defined as "the reluctance or refusal to vaccinate despite the availability of vaccines" and long recognized as one of the ten threats to global health, has become one of the most imminent public health and regional issues during the COVID-19 pandemic (Adhikari and Cheah 2021; MacDonald 2015; World Health Organization 2019). Representing more than one-third of Americans and even more in Europe, vaccine hesitancy is a major barrier to successfully implementing vaccination programs and achieving herd immunity against COVID-19 (Wang et al. 2021). Given that identifying which subpopulations most resist vaccines has become an important topic in public health research, previous studies report a wide range of characteristics

commonly found among vaccine-hesitant people, including demographic and socio-economic characteristics (Anderson et al. 2021; Finney Rutten et al. 2021; Fisher et al. 2020; Green et al. 2021; Latkin et al. 2021), medical insurance and infection status (File and Mohanty 2021; Office of the Assistant Secretary for Planning and Evaluation 2021), vaccine misinformation and distrust in sources of information (Bogart et al. 2021; Casas et al. 2010; Latkin et al. 2021), political factors (Finney Rutten et al. 2021; Ivory et al. 2021; Latkin et al. 2021), and residential location and urbanity (Fisher et al. 2020; Office of the Assistant Secretary for Planning and Evaluation 2021). Beyond the individual person-level characteristics and a few spatially-aggregated attributes, however, there is an unanswered question of whether an individual person's vaccine hesitancy is related to statewide social distancing and vaccine rollout and, if so, whether the regional effects are unequal among historically disadvantaged populations and people at the highest risk of infection.

Employing the health belief model (HBM), a conventional theoretical framework for explaining and predicting people's health-related behaviors, this study examines the relationship of statewide social distancing and vaccine rollout with individuals' hesitancy about the COVID-19 vaccine. Within the HBM frame, a variety of internal (i.e., personal) and external (i.e., regional and environmental) factors come into play in determining people's acceptance or resistance with regard to the vaccines. To examine the relationships between the COVID-19 vaccine hesitancy and explaining factors, this study uses the U.S. Census Bureau's Household Pulse Survey (HPS), a nationally representative and near real-time COVID-19 survey. Study period covers 1 year and 4 months in 2021–2022 (January 6, 2021–May 9, 2022) given that, in January 2021, the bureau introduced a new set of vaccination-related questions and the questions continued until May 2022 (Anderson et al. 2021). The study period may consider both the first quarter of 2021 when vaccine rollouts were expedited by strong supports from the federal government and vaccination rate soared and following months throughout 2022 when the rate reached over 80 percent and plateaued. A pooled cross-sectional dataset of 236,300 respondents and regression models were built to examine the following research question:

Research Question: How are the statewide social distancing and vaccine rollout related to individuals' vaccine hesitancy during the COVID-19 pandemic?

This study first provides an overview of the COVID-19 trend and vaccinations in the U.S., which is followed by the literature review and hypothesis formulation on vaccine hesitancy and the possible roles of regional contexts in determining individuals' vaccination intention. A theoretical model extended from the health belief model (HBM) is adopted to frame relationship of environmental and regional circumstances with individuals' health behaviors in the COVID-19 pandemic. Using a set of regression models, this study examines the associations of vaccination outcomes with individual (level-1) and regional (level-2) variables, with an emphasis on the role of statewide social distancing and vaccine rollout. Interaction models follow to reveal a disproportionate effect of the regional factors among subpopulations of color and infected people. This paper concludes by discussing the regional and pandemic policy

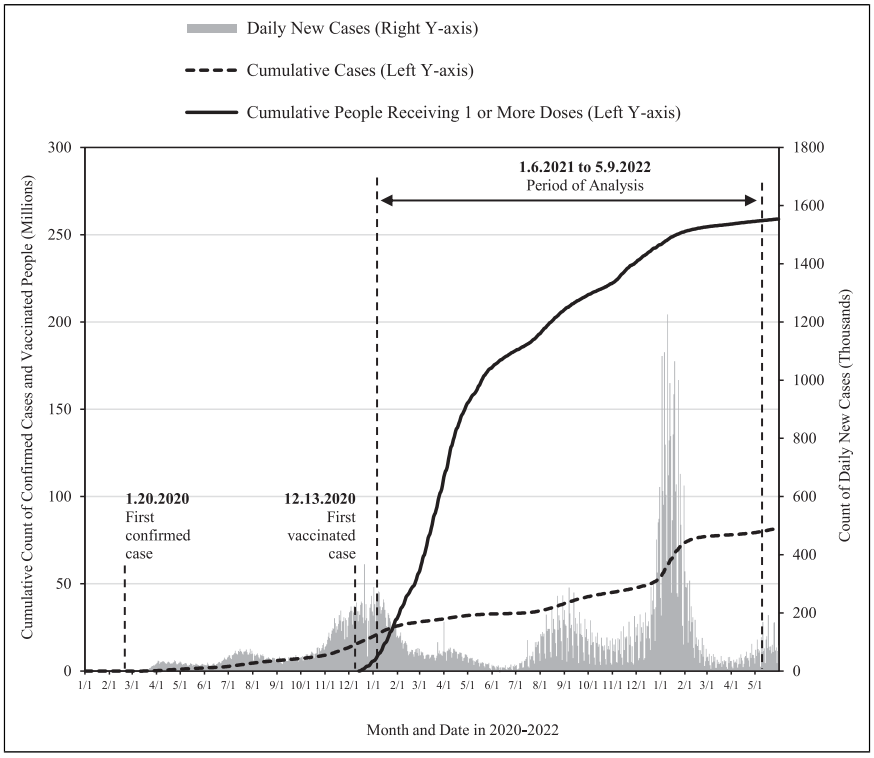

Figure 1. Day-by-Day Trends in the COVID-19 Cases and Vaccinations, United States, January 1, 2020–June 1, 2022. *Notes:* This trend is an extended version of a graph in Park (2021). *Sources:* U.S. Centers for Disease Control and Prekvention (CDC), 2020–2022.

implications to expedite vaccination and reduce vaccine hesitancy as the world enters the third year of the COVID-19 pandemic.

Background and Theoretical Framework

U.S. Trend in the COVID-19 and Vaccination

The COVID-19 was first confirmed in the United States in January 2020 and the virus spread throughout the country rapidly (see Figure 1). It did not take an year until the first COVID-19 vaccination in the U.S. took place on December 13 after the Pfizer/BioNTech vaccine received emergency-use authorization from the U.S. Food and Drug Administration (FDA). As vaccinations accelerate in early 2021, the spread of the virus sharply declined in the first and the second quarters. Soon, however, new waves of the virus have arrived in the U.S. as the Delta variant and Omicron spread across the

nation (Leonhardt 2021). The study period, as specified in Figure 1, spans 1 year and 4 months (January 6, 2021–May 9, 2022) in which the first vaccine was introduced in the U.S. and the vaccination has reached nearly 90 percent nationwide.

Literature Review and Hypotheses

There have been many discussions about who delays accepting or refuses COVID-19 vaccines despite the availability of vaccine services and what determines the vaccine hesitancy. Several streams of COVID-19 literature have focused on individuals' characteristics related to vaccine hesitancy, including demographic and socioeconomic characteristics, vaccine misinformation and distrust in sources of information, the role of political ideology and affiliation, and medical insurance and infection status. In addition to the individual variables, studies have also found that urban and regional contexts have associations with individual persons' attitudes towards vaccines (Bailey et al. 2020). A U.S. Census Bureau's new data visualization tool[1] provides a picture of regional differences in the public's attitudes and feelings about the COVID-19 vaccine in near real-time, allowing data users to track the regional dynamics of vaccine hesitancy in the U.S. (Anderson et al. 2021; Bailey et al. 2021).

Individual Factors on Public Health Behavior. Individuals generally show a wide range of attitudes and perceptions about vaccination depending on their diverse characteristics. Ample research demonstrated that a common set of demographic and socioeconomic predictors for stronger vaccination hesitancy are related to age (Anderson et al. 2021), race and Hispanic origin (File and Mohanty 2021), family and household composition (Fisher et al. 2020), education (Latkin et al. 2021), and income (Office of the Assistant Secretary for Planning and Evaluation 2021). Depending on the data source, survey period, and survey area, mixed results are found for other demographic and socioeconomic characteristics such as male (Anderson et al. 2021) versus female (Fisher et al. 2020; Latkin et al. 2021; Office of the Assistant Secretary for Planning and Evaluation 2021). An Israel research revealed a country-specific result that Jews were less hesitant about COVID-19 vaccines than Arabs due to cultural and historical reasons (Green et al. 2021).

In early January 2021 when vaccinations had proceeded for only a month, two-thirds (66.5 percent) of adults who were not covered by any type of insurance were hesitant about the COVID-19 vaccine while less than half (44.5 percent) of adults who were covered by some type of health insurance were so (File and Mohanty 2021). The overall vaccine hesitancy has substantially been lowered than the beginning of the year though the uninsured are still more hesitant to vaccinations than the insured, as reported in 9.6 percent and 19.8 percent in mid-July 2021 (Anderson et al. 2021). More specifically, private health insurance holders were least hesitant about COVID-19 vaccines, which contrasts to somewhat hesitant Medicare and Medicaid recipients and very hesitant uninsured people (Office of the Assistant Secretary for Planning and

Evaluation 2021). In addition, people who had either a flu shot or flu spray in the nose within the past year are less hesitant about COVID-19 vaccines than their counterparts (Fisher et al. 2020). In addition, Anderson et al. (2021) found that a person who has been previously diagnosed to be infected with COVID-19 resists vaccinations much more than an uninfected person, reporting the national hesitancy rate of 9.9 percent and 15.5 percent, respectively.

In sum, as for individual factors, there are varied research results regarding the acceptance of vaccination among different subpopulation groups but the general consensus is socioeconomically disadvantaged people and patients who were already infected by the COVID-19 are more hesitant about vaccination. Therefore, this study formulates the following hypotheses:

Hypothesis 1a: People of color are more hesitant than their counterparts about the COVID-19 vaccination.
Hypothesis 1b: COVID-19-infected people are more hesitant than their counterparts about the COVID-19 vaccination.

The Role of Regional Circumstances on Public Health Behavior. An individual's health-related behavior relies not only on individual factors but on a variety of environmental and regional factors. Vaccine-hesitant people locate every state in the U.S. but some states are more prevalent than others. Anderson et al. (2021) found that the most vaccine-hesitant states, way above the national average experience, are Wyoming, West Virginia, and North Dakota. Another recent study estimated hesitancy rates by county and found that there was a substantial difference in hesitancy rates across counties, with the lowest on the West Coast and in the Northeast, and highest in the South, Great Plains, and Alaska (Office of the Assistant Secretary for Planning and Evaluation 2021). Rural residents are reported more hesitant about getting a vaccine than urban residents (Fisher et al. 2020).

Political scientists have revealed the influence of political ideology and attitudes on COVID-19 vaccine hesitancy wherein political motives increase public mistrust (Finney Rutten et al. 2021). Particularly in the context of the U.S., one of the main factors driving differences in COVID-19 vaccination rates across the country is partisanship. Many news reports and research consistently find that Democrats are much more like to report having vaccinated than Republicans, and Republicans are much more likely to say that they do not want to get vaccinated (Finney Rutten et al. 2021; Ivory et al. 2021). Latkin et al. (2021) also found that not only political affiliations (i.e., Republican, Democrat, independent, and other) but conceptual ideology (i.e., a range of political ideas from very conservative to very liberal) show a consistent result on the vaccine hesitancy in that liberal and/or democratic people are less hesitant about vaccines compared to conservative and/or republican people.

Public policies, particularly a series of social distancing, have been mainly led by the state government and affected people's outdoor socializations and attitudes towards

vaccination. A recent COVID-19 study published in the *Nature* noted that a lifted level of social distancing may expedite the spread of the virus and increase selection pressures between peers because of vaccination, resulting in the rise of vaccine hesitancy (Lobinska et al. 2022). The research team found that, under the condition of slow vaccination, vaccine hesitancy emerges even though social distancing continues. In contrast, under the condition of rapid vaccination, the advent of COVID-19 mutants may be prevented when social distancing is implemented. Another COVID-19 study found that the determinants of vaccine hesitancy among people who kept wearing mask were similar to those among others who complied with other types of social distancing measures (Muhajarine et al. 2021).

Vaccine supply-and-demand circumstances determine availability of vaccines to general population and affect individuals' decisions on vaccination. A recent COVID-19 study on Africa suggests that Africans may not be willing to be vaccinated even if vaccines are supplied sufficiently due to various reasons such as religion, misinformation, and culture (Ekwebelem et al. 2021). In the U.S. context, the federal government rapidly extended the supply chain of COVID-19 vaccines (Moderna, Pfizer, and BioNTech) in early 2021 and added one additional vaccine from Novavax in the mid-2022. Despite the extended supply of vaccines, it took long to increase the national vaccination rate because of political ideology and media misinformation, as well as government distrust (Hsing et al. 2021). Previous studies, either in developing and developed countries, show possible struggles to increase vaccination rate even if there is a sufficient production and timely supply of vaccines.

These regional and environmental factors show vaccination is not only a matter of an individual but involves a wide range of external circumstances of individuals who make decisions on vaccine uptake. Particularly, social distancing measures and vaccine rollout conditions, as well as their cross-state differences, may affect intents to get a vaccine among residents in different states. Accordingly, this study puts forward the following hypotheses:

Hypothesis 2a: A more stringent social distancing is associated with a higher COVID-19 vaccine acceptance.
Hypothesis 2b: A worse condition of vaccine rollout is associated with a lower COVID-19 vaccine acceptance.

Intersectionality Between Individuals and Regional Circumstances. Some systematic review studies suggest that vaccine hesitancy is driven by individual and environmental factors not only in separate routes but in interconnected manners (Dubé et al. 2018; Larson et al. 2014). The notion of intersectionality between individuals and environmental circumstances implies a possibility of disparities in health-related behaviors between different subpopulation groups. A recent COVID-19 research also noted that it is crucial to understand the subpopulation group's concerns and sociocultural issues that change their intentions to receive a COVID-19 vaccine (Ekwebelem et al. 2021).

On the basis of the prior studies, this study expects that the effects of social distancing and vaccine rollout on individuals' vaccination may be moderated by racial and infection-related intersectionality. Thus, this study sets the following hypotheses:

Hypothesis 3a: Vaccine acceptance is disproportionately lower among people of color even if statewide social distancing and vaccine rollout condition are equal.
Hypothesis 3b: Vaccine acceptance is disproportionately lower among COVID-19-infected people even if statewide social distancing and vaccine rollout condition are equal.

Health Belief Model and COVID-19 Vaccination

An individual accepts a public health service (e.g., vaccine) only when he or she believes in it (Janz & Becker 1984). Many internal (personal) and external (regional and environmental) factors may affect an individual's belief on and uptake of health services (Costa 2020; Wong et al. 2020; Zewdie et al. 2022). Therefore, this study employed structures from the health belief model (HBM), which explain individual-level and regional-level factors that are considered to impact acceptance (or hesitancy) of COVID-19 vaccination.

The HBM, initially designed by social psychologists working at the U.S. federal government, explains social and psychological health-promoting behaviors, especially as to acceptance (or hesitancy) of public health services such as vaccine uptake (Alhalaseh et al. 2020; Janz & Becker 1984; Zewdie et al. 2022). The HBM remains one of the most renowned theories in the field of public health behavior. In the context of the COVID-19 pandemic, the HBM posits that people's beliefs on the COVID-19 vaccine, perceived advantages of vaccination, difficulties of vaccine uptake, and self-efficacy can explain and predict acceptance (or hesitancy) of health-related behaviors (Alhalaseh et al. 2020; Carico et al. 2021; Zampetakis & Melas 2021).

The HBM suggests largely two potential channels that may affect individual's vaccination in the COVID-19 pandemic: i) internal (individual-level) channel and ii) external (regional-level) channel (Carico et al. 2021; Zampetakis & Melas 2021). A large body of COVID-19 literature emphasized the importance of individual characteristics (e.g., age group, race and Hispanic origin, political ideology) as well as environmental circumstances (e.g., social restrictions, vaccine supply and demand, public health infrastructure) regarding in relation to accepting the coronavirus vaccine (Alhalaseh et al. 2020; Costa 2020; Janz & Becker 1984; Wong et al. 2020). Some studies simply focused on the role of individual characteristics in determining vaccination acceptance. Other studies explored disparities in the COVID-19 vaccination and vaccine hesitancy across different regions and environmental contexts, particularly from descriptive and narrative perspectives (Alhalaseh et al. 2020; Wong et al. 2020). Either way, these studies failed to account for the multifaceted nature of individuals' health behavior which is determined at the intersectionality of individual-level and regional-level characteristics.

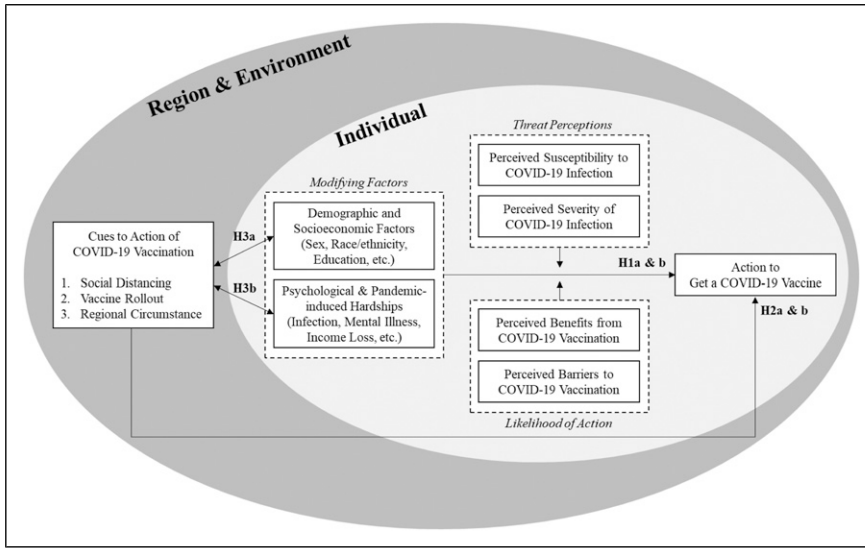

Figure 2. Conceptual Diagram of the Relationship Between Regional and Individual Factors and COVID-19 Vaccination. *Notes:* H = Hypothesis. This diagram is based on the health belief model (HBM). It is an extended and revised version of a figure in Hsing et al. (2021). Self-efficacy, one of the constructs of the HBM, was not presented in this diagram for simplicity.

This study extended previous literature by extending the health belief model (HBM) as displayed in Figure 2, which is based on the HBM and early COVID-19 studies on vaccination. By adding regional and environmental variables, this study attempts to extend the conventional form of HBM in which the external factors outside an individual's control were not considered to affect compliance to desired health behaviors (Janz & Becker 1984).

Data and Methodology

Household Pulse Survey in the COVID-19 Pandemic

The main data is the Household Pulse Survey (HPS) which is a 20-min online survey quickly and timely deployed by the U.S. Census Bureau in cooperation with 11 federal agencies (U.S. Census Bureau 2020a, 2020b; U.S. Department of Housing and Urban Development 2020).[2] The survey studies vaccination status and vaccine hesitancy among adult (age 18+) Americans, as well as the socioeconomic and health impacts of the COVID-19 pandemic (U.S. Census Bureau 2020b). It can be regarded as near real-time data because the survey is conducted every 2 weeks and released in a month. The bureau randomly chooses a certain number of addresses from across the nation, not specific residents in the address, to represent the entire population and households in the

U.S. (U.S. Census Bureau 2021)[3] The survey utilizes the Census Bureau's Master Address File (MAF) as the source of sampled housing units (see a full description of sample design on page 2 of the technical documentation of the survey; U.S. Census Bureau 2021).

The finest geographic identifier available in the survey is fifty states and Washington, D.C., which may be seen as an inevitable survey design when the U.S. Census Bureau launched a nationally representative survey only in one and half months past the declaration of the national health crisis on March 13, 2020. The limited geographic availability, however, it has been widely recognized that COVID-19 vaccination and major policy responses in the U.S. vary mainly by state.

The HPS consists of different phases in the course of 2020–2022, including phase 1 (12 waves on April 23–July 21, 2020), phase 2 (5 waves on August 19–October 26, 2020), phase 3 (10 waves on October 28, 2020–March 29, 2021), and phase 3 and subsequent sub-phases (April 14, 2021–ongoing as of July 31, 2022; see Supplemental Table 1 for detailed number of replies across survey phases). Considering the availability of vaccination-related questions which were first introduced in January 2021 and continued until May 2022, this study examines January 6, 2021–May 9, 2022. Cross-sectional data in individual survey weeks were aggregated to generate a pooled cross-sectional data structure which consists of 236,300 participants. All of the individual (level-1) variables and temporal fixed-effects were derived from the HPS microdata, while regional (level-2) variables were supplemented from multiple sources (see Supplemental Table 3 for the detailed source of data, survey questionnaire, and survey answer options).

Variables

Measure of COVID-19 Vaccine Hesitancy. Before measuring COVID-19 vaccine hesitancy, this paper first identifies if a survey participant received one or more doses of the COVID-19 vaccine by using a retrospective question of "Have you received a COVID-19 vaccine?" with answer options of (1) Yes and (2) No. This paper defines that *COVID-19 vaccination* is 1 (vaccinated) if a respondent replies that he/she received a COVID-19 vaccine, and zero (not vaccinated yet) otherwise. Note that the vaccination variable is not regressed in the empirical models; rather, the vaccination variable is used as a backdrop and reference statistic when cross-state and temporal differences in the COVID-19 vaccine hesitancy are visualized in result section.

Based on the base identification of vaccination, this study specifies the *Vaccine Hesitancy* as a binary variable which is 1 (vaccine-hesitant) and zero (not vaccine-hesitant) by following the U.S. Census Bureau's definition (U.S. Census Bureau 2021). It is derived from a prospective question of "When a vaccine to prevent COVID-19 is available to you, would you…" with answers such as (1) Definitely get a vaccine, (2) Probably get a vaccine, (3) Probably not get a vaccine, and (4) Definitely not get a vaccine, which is given only to the unvaccinated respondents as a follow-up question.[4]

This study identifies respondents vaccine-hesitant when he or she replies answer options 3 and 4. Table 1 presents descriptive statistics of variables.

Individual (Level-1) Variables. This paper considers individual-level factors such as demographic factors (age, gender, race and ethnicity, marriage, children status household size and socioeconomic factors (education, income, housing tenure) (see Supplemental Table 3 for survey details).

The near 2-year pandemic induced a wide range of socioeconomic and health-related hardships among numerous Americans, affecting their decisions on COVID-19 vaccine hesitancy (Hermann and Cornelissen 2020). To reflect the effect of pandemic-induced hardships, this paper considers five binomial independent variables. First, COVID-19 infection is 1 (infection) when a respondent replies that a doctor has ever told him/her that he/she have COVID-19, and zero (no infection) otherwise. Second, loss of household income is 1 (loss) if a survey participant responds that his/her household lost at least a part of employment income, and zero (no loss) otherwise (Park and Ahn 2022). Third, housing instability is 1 (instability) when a participant answers that he/she is behind on rent or mortgage, and zero (stability) otherwise (Manville et al. 2020). Fourth, access to local grocery stores has been limited due to lockdowns and other public interventions to slow the spread of the coronavirus (Liu et al. 2021). This paper identifies that the food insufficiency is 1 (insufficiency; survey answer options 2 through 4 in Supplemental Table 3) if a participant reports that he/she was not able to secure a sufficient amount of food in the last week, and zero (sufficiency; survey answer option 1) otherwise (Bauer et al. 2020; Park et al. 2022; Schanzenbach and Pitts 2020). Lastly, as noted by research on COVID-19 and its mental health consequences (Arroyo et al. 2021), mental illness is 1 (mental problem) when at least one of the two self-reported measures of Generalized Anxiety Disorder (GAD) and Major Depressive Disorder (MDD) indicates that a participant has anxiety and/or depression symptoms in the last week, and zero (no mental problem) otherwise. (see detailed definitions in Park and Kim (2021) and Park et al. 2022)

Regional (Level-2) Variables. The most spatially fine-grained identifier in the HPS microdata is states and thus this paper includes state-level (level-2) variables such as social distancing and vaccine rollout and other regional circumstances.

Social Distancing and Vaccine Rollout. To reflect the diversity of social distancing measures implemented in the COVID-19 pandemic, this study identifies five types of social distancing – i) stay-at-home order, ii) restaurant closure (Chen et al. 2022), iii) gathering ban, iv) maks mandate, and v) bar closure – by using CDC's daily and county-level database. This study aggregates the date-county-unit measures of state social distancing, as did other COVID-19 studies (Galea et al. 2020), by allocating numeric values to multiple and ordered levels of a given social distancing measure. For example, this paper identifies stay-at-home as an ordered variable which equates to zero if a state had a category of "No order found" in a given day, 1 if "Advisory/

Table 1. Descriptive Statistics.

Variables	Full Sample (n = 236,300, % of n or Mean (SD))	COVID-19 vaccine Hesitancy	
		Yes (n = 125,052, % of n or Mean (SD))	No (n = 111,248, % of n or Mean (SD))
Regional (Level-2) variables			
Social distancing and vaccine rollout			
Stay-at-home order	0.53 (0.66)	0.49 (0.65)	0.57 (0.67)
Restaurant closure	0.79 (0.56)	0.68 (0.56)	0.92 (0.53)
Gathering ban	2.31 (2.38)	2.01 (2.33)	2.67 (2.4)
Mask mandate	0.69 (0.47)	0.61 (0.49)	0.78 (0.42)
Bar closure	0.96 (0.96)	0.83 (0.91)	1.12 (1)
Vaccine rollout index	0.59 (0.28)	0.61 (0.28)	0.56 (0.29)
Regional circumstances			
Liberal political ideology	50.77 (9.07)	49.6 (8.87)	52.63 (9.06)
COVID-19 deaths per 100 persons	0.17 (0.07)	0.19 (0.08)	0.15 (0.06)
% Monthly unemployment	5.95 (1.76)	5.56 (1.73)	6.56 (1.62)
Population density	0.03 (0.06)	0.03 (0.05)	0.03 (0.08)
% Transit commuter	4.51 (6.21)	4.03 (5.87)	5.26 (6.64)
% Less than high school	11.42 (2.51)	11.42 (2.46)	11.42 (2.58)
Individual (Level-1) variables			
Demographic characteristics			
Age			
18–24 (Ref)	8.1	8.1	8.0
25–34	23.4	25.1	20.9
35–44	24.4	26.8	20.6
45–54	18.8	19.1	18.3
55–64	15.3	13.6	17.8
65+	10.1	7.4	14.4
Gender			
Female (Ref)	50.8	52.9	47.6
Male	49.2	47.1	52.4
Race/ethnicity			
Non-Hispanic white (Ref)	63.2	63.4	62.9
Non-Hispanic black	12.0	13.7	9.3
Non-Hispanic A&PI	3.5	2.1	5.8
Non-Hispanic other	4.3	5.0	3.3
Hispanic	17.0	15.9	18.7
Marital status			
Unmarried (Ref)	47.0	48.3	45.1

(continued)

Table 1. (continued)

Variables	Full Sample (n = 236,300, % of n or Mean (SD))	COVID-19 vaccine Hesitancy	
		Yes (n = 125,052, % of n or Mean (SD))	No (n = 111,248, % of n or Mean (SD))
Married	53.0	51.7	54.9
Children in household			
No child (Ref)	53.3	47.7	62.1
One or more children	46.7	52.3	37.9
Household size			
Single person (Ref)	7.2	6.6	8.1
2-person	25.9	22.9	30.6
3-person	21.1	21.0	21.3
4-person	21.3	21.9	20.2
5-person	12.4	13.6	10.6
6 or more persons	12.2	14.0	9.2
Socioeconomic status			
Education			
Less than high school (Ref)	8.7	9.2	7.8
High school	32.8	37.7	25.0
Some college and AA	32.9	34.9	29.8
BA+	25.7	18.3	37.3
Household income			
Less than $25,000 (Ref)	17.8	19.9	14.5
$25,000–49,999	25.9	27.9	22.7
$50,000–74,999	18.1	18.6	17.3
$75,000–99,999	12.9	13.0	12.7
$100,000–$149,999	14.1	12.8	16.1
$150,000 and above	11.3	7.9	16.7
Housing tenure			
Renter-occupied housing (Ref)	42.0	44.0	38.9
Owner-occupied housing	58.0	55.9	61.1
Pandemic-induced hardships			
COVID-19 infection			
No (Ref)	80.2	77.1	85.2
Yes	19.8	22.9	14.8
Employment income loss			
No (Ref)	56.7	59.6	52.1
Yes	43.3	40.4	47.9

(continued)

Table 1. (continued)

Variables	Full Sample (*n* = 236,300, % of n or Mean (SD))	COVID-19 vaccine Hesitancy	
		Yes (*n* = 125,052, % of n or Mean (SD))	No (*n* = 111,248, % of n or Mean (SD))
Food insufficiency			
No (Ref)	57.6	54.6	62.4
Yes	42.4	45.3	37.6
Housing instability			
No (Ref)	85.4	83.5	88.5
Yes	14.6	16.5	11.6
Mental health problem			
No (Ref)	59.0	61.3	55.4
Yes	41.0	38.7	44.7
Temporal fixed-effects			
HPS week			
Week 22 (1.6–18, 2021, Ref)	12.7	10.1	16.8
Week 23 (1.20–2.1)	12.8	9.4	18.2
Week 24 (2.3–15)	11.6	8.5	16.5
Week 25 (2.17–3.1)	10.9	8.3	14.9
Week 26 (3.3–15)	9.5	7.3	13.1
Week 27 (3.17–29)	7.7	6.4	9.7
Week 28 (4.14–26)	3.0	3.2	2.7
Week 29 (4.28–5.10)	2.5	3.2	1.4
Week 30 (5.12–24)	2.2	3.0	0.9
Week 31 (5.26–6.7)	2.0	2.8	0.8
Week 32 (6.9–21)	1.9	2.8	0.5
Week 33 (6.23–7.5)	1.7	2.6	0.4
Week 40 (12.1–13)	1.9	2.7	0.5
Week 41 (12.29–1.10, 2022)	1.9	2.7	0.5
Week 42 (1.26–2.7)	1.8	2.6	0.5
Week 43 (3.2–14)	1.8	2.6	0.6
Week 44 (3.30–4.11)	1.8	2.8	0.4
Week 45 (4.27–5.9)	1.7	2.5	0.4

Notes: Results shown in this table were person-weighted (*pweight* in HPS microdata).

Recommendation," 2 if "Mandatory - at-risk in certain areas of state," 3 if "Mandatory - at-risk people only," 4 if "Mandatory - all people in certain areas of state," and 5 if "Mandatory - all people." This paper averages county-level values to produce a geographically aggregated state-level measure which was then temporally aggregated to match the survey weeks of HPS. The same specification process is applied to quantify the statewide stringency of the other measures such as restaurant closure, gathering ban, mask mandate, and bar closure.

In addition, this paper considers the Index of Surgo Covid-19 Vaccine Coverage (CVAC) which identifies vaccine supply- and demand-side obstacles which can delay and slow the provision of COVID-19 vaccine across states through five sub-themes: 1) historic under-vaccination, 2) sociodemographic barriers, 3) resource-constrained healthcare system, 4) healthcare accessibility barriers, and 5) irregular care-seeking behaviors (Centers for Disease Control and Prevention 2021). This paper utilizes the overall index which combines the five sub-themes and quantifies the level of concern for a difficult vaccine rollout on a range from 0 (lowest concern) to 1 (highest concern).

Regional Circumstances. This study includes proxies for political and socioeconomic contexts, as well as built-environment factors, which were measured before the pandemic hits the nation. First, the 2020 U.S. Presidential Election result is included to proxy the overall political ideology in each state. This paper utilizes Federal Election Commission (FEC)'s Official 2020 Presidential General Election Results to specify a continuous variable which identifies the voting rate (%) towards Biden in each state (Federal Election Commission 2021). Given that liberal Americans are known to accept COVID-19 vaccinations, the political ideology is hypothesized to be linked to a lower level of vaccine hesitancy.

This study considers the cumulative number of daily deaths due to the COVID-19 in each state, which is relative to the state population (per 100 persons) (U.S. Centers for Disease Control and Prevention 2020). The daily death statistics obtained from the CDC's website of COVID Data Tracker are averaged to generate a weekly database which is aligned to HPS weeks. The death toll is included in the models to reflect dynamic pandemic situations.

State-level prevalence of unemployment was considered in the models to characterize job availability and market conditions during the COVID-19 pandemic. This study used the monthly unemployment rate which has been calculated and announced by the Bureau of Labor Statistics (BLS). The monthly data was adjusted to match the weekly cycle of the HPS microdata.

Population density in the states reflects the overall built environment context and may be related to statewide vaccine hesitancy (Frank and Engelke 2005; Hamidi et al. 2020). Population density equals the total population divided by state area (square miles) in a state in 2020. A rapidly published and widely-cited urban research, though not related to vaccination and vaccine hesitancy, shows that connectivity matters more than density in the spread of the COVID-19 virus (Hamidi et al. 2020). Another recent study suggests land use patterns play a key role in determining long-term household choices of travel behavior, travel mode, and residential location in the post-pandemic era, all of which are closely related to vaccinations and vaccine hesitancy at the writing of this paper (Habib and Anik, 2021). Thus, this paper hypothesizes that dense states see a lower vaccine hesitancy rate.

Many studies highlighted sharp reductions and reallocation of outdoor travel behaviors during the COVID-19 pandemic, with a special focus on the role of public transportation (Bhin and Son 2021; Kim et al. 2021). This paper includes the rate of

transit commuters as an indicator of statewide public transportation use. It is defined as the number of age 16+ worker population who use transit for commuting divided by the total number of age 16+ worker population multiplied by 100. States with a higher dependency on transit are expected to see a lower level of vaccine hesitancy.

Lastly, this study includes the statewide education to consider state socioeconomic condition (Lee et al. 2012). The variable is derived from 2019 American Community Survey (ACS) data and computed as the count of people who are less than high school divided by the total population. It is hypothesized that the regional prevalence of less educated people is associated with a higher level of vaccine hesitancy in the region.

Temporal Effects. The national trend in the COVID-19 has evolved over weeks and this temporal volatility itself could have affected COVID-19 vaccinations and vaccine hesitancy. To control for the unmeasured time-varying (week-by-week) factors, this study specified a set of dummy variables that specifies Household Pulse Survey week at the time of response (24 waves from wave 22 to wave 45).

Multilevel Model

The HPS microdata is made up of individuals who reside in different states (the most detailed geographic level available in the survey). Therefore, this paper uses multilevel models which may be adequate to examining data with a hierarchical structure in which level-1 (individual) and level-1 (state) variables are assumed to be associated with dependent variables (*melogit* in Stata program; StataCorp 2019).

This paper regresses Y_{ijk}, a binomial dependent variable about the COVID-19 vaccine hesitancy of person i in state j in week k, on a set of level-1 and level-2 variables as shown below:

Individual (Level-1) Model

$$Y_{ijk} = \beta_{0jk} + \beta_{1k} D_{ijk} + \beta_{2jk} S_{ijk} + \beta_{3jk} P_{ijk} + \beta_{4jk} \delta_{ik} + \mu_{ijk}$$

Regional (Level-2) Model

$$\beta_{0jk} = \gamma_{0jk} + \gamma_{1jk} SD_{jk} + \gamma_{2jk} VR_{jk} + \gamma_{3jk} RC_{jk} + \varepsilon_{jk}$$

where D_{ijk} is a vector of demographic variables; S_{ijk} is a group of socioeconomic variables; P_{ijk} is a vector of pandemic-induced hardships; δ_{ik} is survey week effect; μijk is a level-1 error term; SD_{jk} is a set of statewide social distancing measures; VR_{jk} is vaccine rollout condition; RC_{jk} is a vector of regional circumstances; ε_{jk} is a level-2 error term. The level-2 error term may correlated in the same state. Accordingly, this paper adopts standard errors clustered at the state level to address heteroscedasticity. The models in this paper test correlations (not causation) between independent variables and COVID-19 vaccine hesitancy.

Results

Cross-State and Temporal Variations in COVID-19 Vaccine Hesitancy

Figure 3 shows that the national trends in the COVID-19 vaccination and vaccine hesitancy during the period of analysis (January 6, 2021–May 9, 2022). The graph highlights that the percent of adult (age 18+) Americans who received at least a dose of COVID-19 vaccines was only 10.4 percent in early January 2021. It took only 4 months to reach 80 percent in late April. Since then, the national vaccination rate nearly plateaued with slow and steady increases towards 90 percent in early May 2022. For the same period, the rate of vaccine hesitancy generally followed the trend of vaccination with a slight time-lag. The parallel trends reflect that the vaccine hesitancy among unvaccinated people are related to the overall vaccination rate. Furthermore, today's unvaccinated people (as of mid-2022) who have denied the COVID-19 vaccines for the past one and half years can be seen strongly resistant to vaccines. These estimates are based on survey self-reports and do not align precisely with published counts generated from other official sources such as CDC's COVID Data Tracker (Centers for Disease Control and Prevention 2021).

The 50 states provide a comprehensive geographic overview of the prevalence of COVID-19 vaccinations and vaccine hesitancy. Figure 4 shows the percentages of adult (ages 18+) population who received at least a dose of COVID-19 vaccine (light grey column) and who hesitates to receive vaccines (dark grey column), respectively, for the nation as a whole and states. The states are ranked within each region by their prevalence of vaccine hesitancy.

For the period of analysis in this study (January 6, 2021–May 9, 2022), 72.6 percent of the population received one or more doses of the COVID-19 vaccine while slight more than half (56.9%) of unvaccinated people are still vaccine-hesitant. Despite the national average experiences, some states showed a substantially higher or lower level of attitudes towards COVID-19 vaccines and the cross-state disparity has mostly broken down along political lines as noted by the New York Times (Ivory et al. 2021). North Dakota and Mississippi, as well as many other states in the Midwest and the South, saw a higher level of vaccine hesitancy than the national average. In contrast, half of the West states and all of the Northeast states were less vaccine-hesitant than the nation. It is notable that, unlike the large cross-state difference in vaccine hesitancy, the vaccination rates were relatively similar across states which is mainly due to the geographically balanced vaccine rollout across the nation.

Figure 5 visualizes the geographic distribution of COVID-19 vaccination and vaccine hesitancy in panel a and b, respectively. Panel a shows a relatively higher rate of vaccination in states located in the West and Northeast regions. In addition, the same states see a lower level of vaccine hesitancy as displayed in panel b. The geographic contrast tends to reflect political ideology by which more liberal states demonstrate more positive attitudes and higher rates of vaccine uptake. This study considers the political geographical factor in the empirical model.

Effects of Statewide Social Distancing and Vaccine Rollout on Individuals' Vaccine Hesitancy

In model 1 of Table 2, this study first examines the role of regional (level-2) variables in understanding the COVID-19 vaccine hesitancy by including variables of social distancing and vaccine rollout only. Model 2 also includes other regional variables such as political ideology and built environment, as well as temporal fixed-effects. These results on regional effects on individuals' vaccine hesitancy are a basis to evaluate the contribution of adding individual (level-1) variables in the following model 3.

Model 1 shows that individuals' COVID-19 vaccine hesitancy does have a significant relation with some statewide social distancing measures but not with statewide conditions of vaccine rollout. This result is partially in line with *Hypothesis 2* in which this study expected that both social distancing and vaccine rollout would be related to people's vaccine hesitancy.

A stricter implementation of stay-at-home order and restaurant closure in a state, as well as mask mandate, are related to a lower rate of vaccine hesitancy among residents in the same state. Those social distancing measures are applicable to nearly everyone regardless of age and other demographic and health characteristics. In contrast, gathering ban and bar closure are not significant in the model which is likely because the measures are less relevant to some population groups (e.g., people who do not drink alcohol and other who do not participate in a mass gathering). These findings imply that the statewide implementation of a more stringent social distancing reflects a worse pandemic situation and may motivate state residents to get vaccinated. Given the different significance among different social distancing measures, a regional implication might be that the type of statewide social distancing needs to be carefully considered as one of the key state pandemic policies to reduce vaccine hesitancy and boost uptake of COVID-19 vaccines.

Statewide vaccine supply- and demand-side obstacles in a state, as measured by the Surgo Covid-19 Vaccine Coverage Index, do not appear to be related to individuals' vaccine hesitancy in model 1. In the following models, however, the vaccine rollout variable turns significant when additional variables (especially time-fixed effects) are added. This shows that state residents are discouraged from taking COVID-19 vaccines when the overall state condition of vaccine rollout is challenging.

Turning to model 2 in which additional regional circumstances are considered, this study finds that the mask mandate is still significant and vaccine rollout turns significant which was not the case in model 1 whereas stay-at-home order and restaurant closure are no longer significant. These changes in variable significance are mainly due to the inclusion of temporal fixed-effects which control for unobservable temporal variations across Household Pulse Survey weeks. This finding implies that, among different types of social distancing measure, the general population recognizes the mask mandate as the most influential restriction in deciding vaccination.

The statewide political ideology emerges as an important predictor of individuals' vaccine hesitancy. Specifically, local people who reside in a state with one percent point

higher rate of voting for Biden in the 2020 election are 2.8 percent more likely to get COVID-19 vaccines. The finding is consistent with early findings that political polarization in the U.S. has been impeding vaccination against COVID-19 and thus the lowest vaccination rates are substantively in Republican-leaning states. If political divisions on the COVID-19 vaccination become more severe and prevalent, the experience of anti-vaccine may negatively affect vaccinations in the future pandemic. Thus, the finding on political effects calls for urgent public health priorities at the regional levels.

Also, a more serious unemployment in a state appears to be related to a higher level of COVID-19 vaccine hesitancy among the state residents. This finding can be interpreted as an association between statewide job market conditions and individual residents' hesitancy against COIVD-19 vaccines.

The findings also indicate that a higher population density is associated with a higher level of COVID-19 vaccine hesitancy. This study interprets population density as a proxy for the overall frequency of face-to-face contacts in a state, which may be expected to either increase or decrease vaccination hesitancy (Henderson 1999; Garcia-López 2022). In a sense, people living in high density area may be more likely to accept vaccination to protect themselves from face-to-face contacts. From another perspective, urban areas are often filled with younger people and racially diverse population who are more hesitant to get a vaccine than their counterparts and it may result in a higher level of vaccine hesitancy in urbanized high-density areas. This study's finding supports the latter in which urban residents are more hesitant to COVID-19 vaccination. It may provide a piece of critical evidence that emphasizes a careful consideration of the statewide built environment when developing regional vaccination policies and other pandemic interventions. The other regional variables such as COVID-19 deaths per 100 persons and % transit commuter, as well as % less than high school population, do not appear to be related to vaccination outcomes.

Model 3 of Table 2 shows estimation results that include both regional and individual variables. An important finding is that the exiting regional variables continue to emerge as significant factors in explaining individuals' COVID-19 vaccine hesitancy even after individual characteristics are controlled for in the model. Another important result is that people of color and COVID-19-infected people are more hesitant about vaccination compared to their counterparts. This finding is consistent with *Hypothesis 1,* supporting that socioeconomically and health-related vulnerable people are less likely to accept vaccines uptake.

Even after controlling for level-1 variables, this paper finds that a more stringent measure of mask mandate is still related to a higher rate of vaccine hesitancy. At the same time, the vaccine rollout challenges, as measured by Surgo Covid-19 Vaccine Coverage Index, have again a significant association with a higher level of vaccine hesitancy. These persisting regional role in understanding individuals' vaccine hesitancy, as the net of individual variables, lend support to the notion that vaccine hesitancy is attributable to not only individual-level characteristics but regional contextual factors.

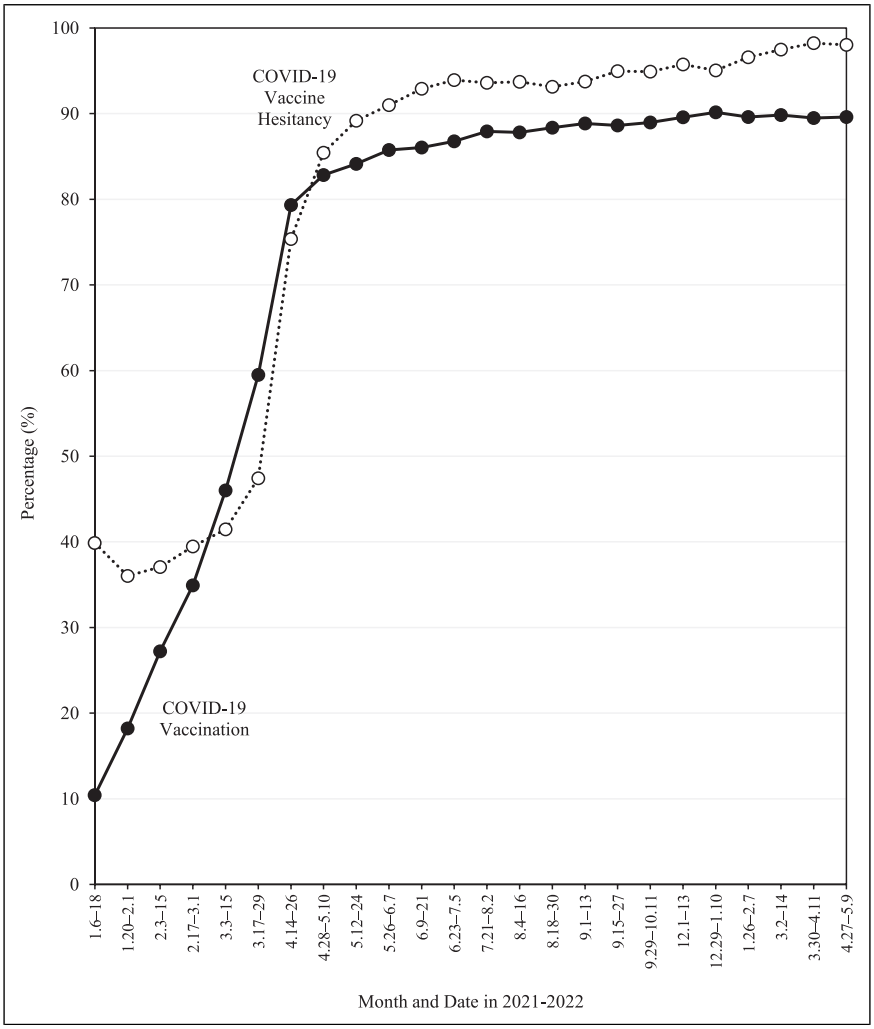

Figure 3. National Trends in the COVID-19 Vaccination and Vaccine Hesitancy, United States, January 6, 2021–May 9, 2022. *Notes:* COVID-19 vaccination rate (%) = number of age 18+ adults who were vaccinated at least one dose/number of age 18+ adults × 100. COVID-19 vaccine hesitancy rate (%) = number of age 18+ adults who answered that he/she will definitely (or probably) not get a vaccine/number of age 18+ adults who were not vaccinated yet × 100. *Sources*: U.S. Census Bureau, Household Pulse Survey (HPS), Public Use Files (PUFs).

Turning to level-1 variables, most emerge as significant predictors of COVID-19 vaccine hesitancy. On average, people who are younger ages, female, non-Hispanic Black, children in the household, greater household size, lower education, lower

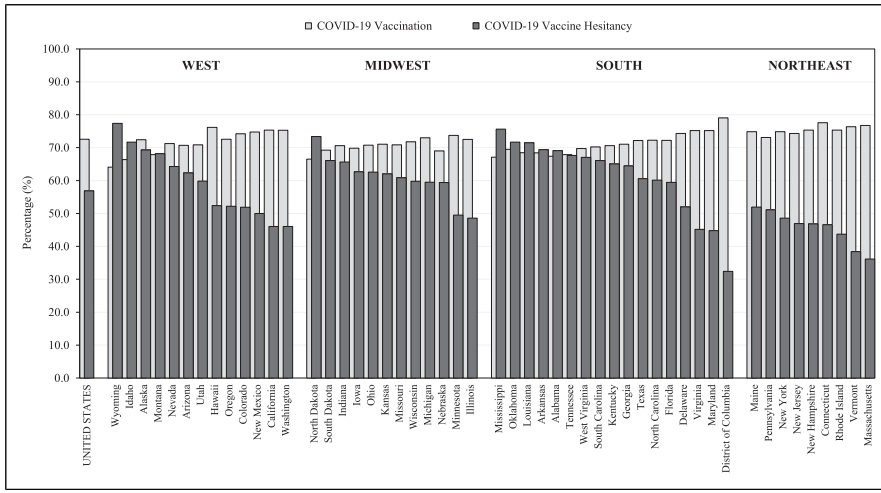

Figure 4. Cross-state Differences in the COVID-19 Vaccination and Vaccine Hesitancy, Ranked within Census Region by COVID-19 Vaccine Hesitancy, United States, January 6, 2021–May 9, 2022. *Notes:* COVID-19 vaccination rate (%) = number of age 18+ adults who were vaccinated at least one dose/number of age 18+ adults × 100. COVID-19 vaccine hesitancy rate (%) = number of age 18+ adults who answered that he/she will definitely (or probably) not get a vaccine/ number of age 18+ adults who were not vaccinated yet × 100. The entire period of analysis (January 6, 2021–May 9, 2022) is aggregated in this column graph. *Sources:* U.S. Census Bureau, Household Pulse Survey (HPS), Public Use Files (PUFs).

household income, and renter are more vaccine-hesitant than their counterparts. Married people are on average less hesitant to vaccine uptake compared to unmarried people but the difference is marginal. COVID-19-infected people and those who experienced other pandemic-induced hardships – income loss, food insufficiency, and housing instability – were also significantly related to a higher rate of vaccine hesitancy, implying that a wide range of pandemic-induced hardships have discouraged people to receive COVID-19 vaccines. Unlike other pandemic hardships, this study finds that mentally-ill people are more likely to get a vaccine which is likely because people with chronic mental health problems have been among key target of vaccination campaign and government supports.

Interactions of Key Individual Variables With Statewide Social Distancing and Vaccine Rollout

Table 3 shows results of the interaction models which test whether or not the relationships of COVID-19 vaccine hesitancy with statewide social distancing and vaccine rollout differ by subpopulation groups, particularly different racial/ethnic groups and COVID-19-infected people. This study interacts the two individual (level-1) variables

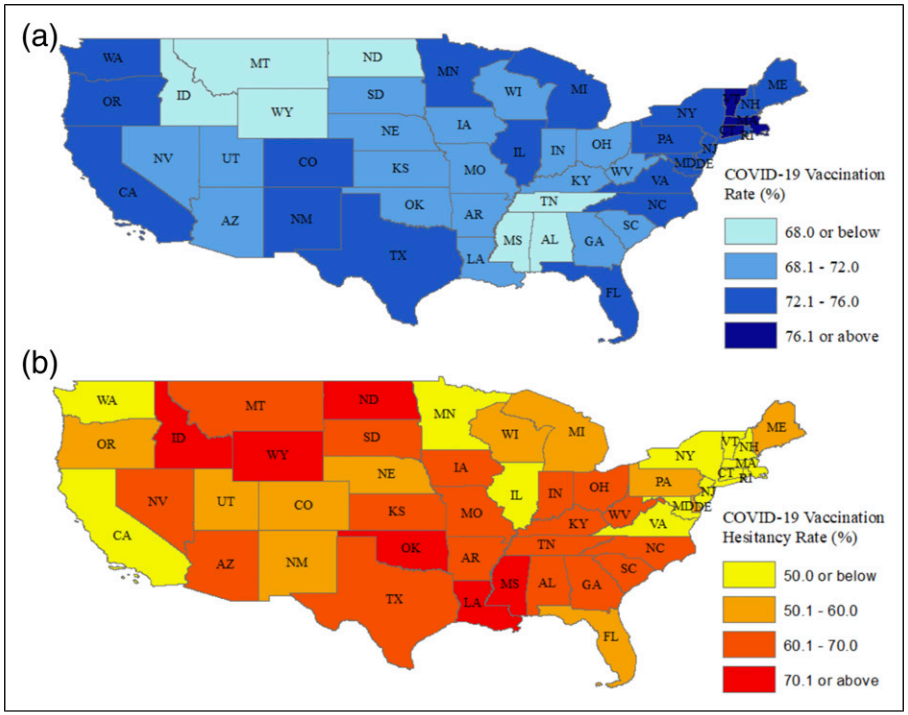

Figure 5. Geographic Distribution of COVID-19 Vaccination and Vaccine Hesitancy, United States, January 6, 2021–May 9, 2022. (a) COVID-19 Vaccination Rate (%) and (b) COVID-19 Vaccine Hesitancy Rate (%). *Notes:* COVID-19 vaccination rate (%) = number of age 18+ adults who were vaccinated at least one dose/number of age 18+ adults × 100. COVID-19 vaccine hesitancy rate (%) = number of age 18+ adults who answered that he/she will definitely (or probably) not get a vaccine/number of age 18+ adults who were not vaccinated yet × 100. The entire period of analysis (January 6, 2021–May 9, 2022) is aggregated in these maps. *Sources*: U.S. Census Bureau, Household Pulse Survey (HPS), Public Use Files (PUFs); U.S. Census Bureau Geography Division, 2021 State and Equivalent TIGER/Line Shapefiles.

— 1) race and ethnicity and 2) COVID-19 infection status – with one regional (level-2) variable at a time to separately consider the role of intersectionality between the select state characteristic and subpopulation groups. This study confirms a significant intersectionality between individuals and regional variables. This finding lends a support to *Hypothesis 3* in which this study hypothesized that the vulnerable subpopulations are more vaccine-hesitant than their counterparts even if statewide social distancing and vaccine rollout are equivalent.

As for racial/ethnic heterogeneity, the interaction results suggest that the relationships of statewide social distancing and vaccine rollout with individuals' COVID-19 vaccine hesitancy is unequal across racial and ethnic groups. This study finds that the

Table 2. Multilevel Mixed-Effect Logistic Regression Results for COVID-19 Vaccine Hesitancy, United States, January 6–August 16, 2021.

	Model (1)		Model (2)		Model (3)	
	OR	Sig.	OR	Sig.	OR	Sig.
Regional (Level-2) variables						
Social distancing and vaccine rollout						
Stay-at-home order	0.714	*	1.050		1.036	
Restaurant closure	0.519	***	0.970		0.970	
Gathering ban	0.981		0.999		1.001	
Mask mandate	0.369	***	0.886	**	0.881	***
Bar closure	0.802		1.033		1.025	
Vaccine rollout index	1.286		1.338	**	1.270	*
Regional circumstances						
Liberal political ideology			0.972	***	0.977	***
COVID-19 deaths per 100 persons			1.380		1.045	
% Monthly unemployment			1.054	+	1.051	*
Population density			1.695	**	1.373	*
% Transit commuter			0.992		0.997	
% Less than high school			0.985		0.985	
Individual (Level-1) variables						
Demographic characteristics						
Age (ref = 18–24)						
25–34					1.375	***
35–44					1.333	***
45–54					1.270	***
55–64					0.987	
65+					0.630	***
Gender (ref = female)						
Male					0.783	***
Race/ethnicity (ref = non-Hispanic white)						
Non-Hispanic black					1.572	***
Non-Hispanic A&PI					0.657	***
Non-Hispanic other					1.351	***
Hispanic					0.858	***
Marital status (ref = unmarried)						
Married					0.956	*
Children in household (ref = no child)						
One or more children					1.240	***
Household size (ref = single person)						
2-person					1.051	**
3-person					1.130	***

(continued)

Table 2. (continued)

	Model (1)		Model (2)		Model (3)	
	OR	Sig.	OR	Sig.	OR	Sig.
4-person					1.179	***
5-person					1.358	***
6 or more persons					1.607	***
Socioeconomic statuses						
Education (ref = less than high school)						
High school graduate					1.282	***
Some college or associate degree					1.087	
Bachelor's degree or higher					0.588	***
Household income (ref = less than $25,000)						
$25,000–49,999					0.945	***
$50,000–74,999					0.874	***
$75,000–99,999					0.810	***
$100,000–$149,999					0.693	***
$150,000 and above					0.487	***
Housing tenure (ref = rental)						
Owner-occupied housing					1.052	***
Pandemic-induced hardships						
COVID-19 infection (ref = no)						
Yes					1.287	***
Employment income loss (ref = no)						
Yes					1.094	***
Food insufficiency (ref = no)						
Yes					1.154	***
Housing instability (ref = no)						
Yes					1.260	***
Mental health problem (ref = no)						
Yes					0.679	***
Temporal fixed-effects						
HPS week (Ref = week 22, 1.6–18, 2021)						
Week 23 (1.20–2.1)			0.841	***	0.828	***
Week 24 (2.3–15)			0.860	***	0.825	***
Week 25 (2.17–3.1)			0.943	+	0.879	***
Week 26 (3.3–15)			0.994		0.884	**
Week 27 (3.17–29)			1.245	***	1.083	
Week 28 (4.14–26)			2.967	***	2.425	***
Week 29 (4.28–5.10)			5.925	***	4.765	***
Week 30 (5.12–24)			8.257	***	6.560	***
Week 31 (5.26–6.7)			9.943	***	7.921	***

(continued)

Table 2. (continued)

	Model (1)		Model (2)		Model (3)	
	OR	Sig.	OR	Sig.	OR	Sig.
Week 32 (6.9–21)			14.397	***	11.588	***
Week 33 (6.23–7.5)			15.219	***	12.194	***
Week 34 (7.21–8.2)			14.490	***	11.498	***
Week 35 (8.4–16)			15.960	***	12.361	***
Intercept	3.824	***	2.228	***	2.491	***
Number of observations	204,933		204,933		204,933	
Log pseudolikelihood	−116,613		−130,078		−116,547	
Wald chi-squared	104,866	***	497	***	104,866	***
Akaike's information criterion (AIC)	233,317		260,184		233,194	
Bayesian information criterion (BIC)	233,788		260,327		233,705	

Notes: Standard errors were clustered at the state level. OR = odds ratio; HPS = Household Pulse Survey; A&PI = Asian and Pacific Islander. The odds ratio (OR) is the measure of association which can be either i) 1.0 (or close to 1.0), ii) greater than 1.0, or iii) less than 1.0. An odds ratio of 1.0 (or close to 1.0) means that the independent variable is not associated with the vaccine hesitancy. An odds ratio of greater than 1.0 means that the independent variable has a positive association with vaccine hesitancy. An odds ratio of less than 1.0 means that the independent variable has a negative association with vaccine hesitancy. See Supplemental Table 4 for the summary of collinearity diagnostics which shows 2.040 as the average of VIFs. + = $p < .10$, * $p < .05$, ** $p < .01$, *** $p < .001$.

mask mandate and restaurant closure again lower vaccine hesitancy but people of color still hold a relatively higher level of hesitancy compared to non-Hispanic whites. Especially, vaccine hesitancy remains strong among non-Hispanic black when statewide social distancing becomes more stringent, followed by non-Hispanic Asian and Pacific Islanders and Hispanics. This finding implies that people of color, particularly non-Hispanic blacks, are vaccine-hesitant even if statewide regional circumstances alarm a widespread COVID-19 infection. In the same context, this paper finds that the relationship between vaccine rollout challenges and vaccine hesitancy is weakened among people of color. This result can be interpreted that people of color are less affected by the overall challenges related to vaccine supply and demand.

Focusing on the moderating role of COVID-19 infection, this study finds that statewide social distancing, particularly mask mandate, again reduces individuals' COVID-19 vaccine hesitancy but the relationship is weakened among people who were infected by the virus. Also, vaccine supply- and demand-related difficulties still increase vaccine hesitancy; however, infected people are less sensitive to the state-level conditions of vaccine rollout.

Discussion and Implications

Regional Policy Implications to Expedite COVID-19 Vaccination and Reduce Vaccine Hesitancy

Public hesitancy around COVID-19 vaccines, as commonly noted by previous studies, is a significant challenge for public health and regional management in the COVID-19 era and future pandemics (Forsyth 2020; Office of the Assistant Secretary for Planning and Evaluation 2021; Ziafati Bafarasat 2021). Adjusting for individual-level and state-level variables in addition to temporal effect, this study found that not all measures of social distancing affect individuals' vaccination. Findings showed that it was a more stringent mask mandate that is related to an increase of vaccine acceptance. Statewide difficulties of vaccine rollout, as measured by Vaccine Rollout Index, are related to stronger vaccine hesitancy. These statewide effects were significant even after controlling for a wide range of individual characteristics. In addition, the state effects were unequal among different racial and ethnic groups and COVID-19-infected people. These findings on the role of regional contexts are valuable to help inform evidence-based regional health policies that may better prioritize certain population subgroups and regions in most urgent need of public assistance (Bailey et al. 2021; McCann et al. 2021a, 2021b). From the perspective of public health policy, findings of this study largely support the maintenance of social distancing measures, particularly mask mandate, because the measure itself may contribute to lowering vaccine hesitancy and expedite herd-immunity before COVID-19 variants evolve which is often described as a race between vaccine and variants. More specific policy implications for regions across the world may be three-fold as discussed below.

First, the population subgroups who are younger age, female, non-Hispanic Black, children in the household, greater household size, lower education, lower household income, and renter are on average found to be more vaccine-hesitant than their counterparts. Results also showed that the pandemic-induced hardships – COVID-19 infection, income loss, food insufficiency, housing instability – raised vaccine hesitancy. These findings show that people who have been often identified to be historically and socioeconomically disadvantaged before the pandemic are most hesitant about COVID-19 vaccines (Kang et al. 2020). They also have higher coronavirus transmission rates than others, implying the pandemic may widen existing public health disparities and individual-level interventions can be effective and efficient when aimed at specific groups instead of the public as a whole (Chervenak et al. 2021; Finney Rutten et al. 2021; Grünebaum et al. 2021). Individual-level interventions, in this context, have to target the most vaccine-hesitant people as identified in this paper. When offer in combination with interventions at the organization and interpersonal level, individual-level educational interventions can empower health care teams to promote vaccination and optimize efforts to address hesitancy among patients. Furthermore, policymakers should prioritize those who have long suffered from socioeconomic disadvantages. Given that statewide vaccinations and vaccine hesitancy have

critical multiplier effects on the local business consumption and economy, state and local leaders also need to consider difficulties among small business owners due to delayed vaccinations (Callen 2021a).

Second, this paper found that statewide social distancing measures and vaccine rollout have a relation with individuals' vaccine hesitancy even after controlling for individual factors. The consistent association suggests the importance of state-level aggregated contexts in expediting vaccinations and reducing vaccine hesitancy among state residents. From the vaccine supply side, federal policymakers need to continue to extend and timely distribute vaccine rollout across regions though this paper found a weak association between vaccine supply and hesitancy. More importantly, from the vaccine demand side, this paper found that political ideology strongly affects vaccine hesitancy. This implies a need to prioritize conservative states to boost vaccinations in the nation as a whole. Given that densely populated states show less hesitancy, vaccine education and campaigns might have to be targeted to less dense and rural areas (Kim et al. 2014). Also, the result from the COVID-19 Vaccine Coverage Index emphasizes the urgency of addressing both vaccine supply- and demand-related challenges.

Third, this paper revealed that the state-level effects of social distancing and vaccine rollout are unequal across population subgroups, especially among people of color, mentally ill people, and people who were infected by COVID-19. Non-Hispanic blacks and Hispanics living in states where vaccine supply relative to population is greater and the COVID-19 Vaccine Coverage Index is higher, as well as COVID-19 spread is more prevalent, were less likely to be hesitant about vaccinations. These findings suggest that racial and ethnic minorities are more hesitant about vaccinations but their hesitancy reduces when statewide pandemic conditions are worse and more threatening. At the same time, the findings support the importance of a supply-driven strategy to encourage minorities to get vaccinated. An additional important finding is the moderating role of statewide political ideology which was found to have interactions with race/ethnicity and means that even in the liberal states, minorities are more likely to hesitate to receive COVID-19 vaccines. To partly address the political hesitancy, the state government can help leverage emerging grassroots and local-level programs and initiatives and scale those efforts up in envisioning state-led vaccinations. In the long run, it is critical to invest more in designing and improving local programs for vaccinations.

Limitations and Future Research

Future research can expand knowledge about COVID-19 vaccinations and vaccine hesitancy in the U.S. and other countries in the world. First, as HPS evolves with new questionnaires, more nuanced research can be conducted to help understand and address vaccine hesitancy. For example, phase 3.1 and later phases of HPS ask how COVID-19 vaccines affect recipients' behaviors, which may be utilized to examine changing travel behaviors and urban activities before and after receiving vaccines (Callen 2021b). Additional research on public behaviors of the vaccinated (or

Table 3. Summarized Results With Interactions of Key Individual Variables With Statewide Social Distancing and Vaccine Rollout.

	Stay-At-Home Order		Restaurant Closure		Gathering Ban		Mask Mandate		Bar Closure		Vaccine Rollout Index	
Regional (Level-2) Variable:	OR	Sig.	OR	Sig.	OR	Sig.	OR	Sig.	OR	Sig.	OR	Sig.
Race/Ethnicity												
Regional (Level-2) variable	1.003		0.875	***	0.989		0.815	***	0.996		1.430	***
Race/ethnicity (ref = non-Hispanic white)												
Non-Hispanic black	1.450	***	0.897		1.214	+	1.042		1.283	*	2.258	***
Non-Hispanic A&PI	0.639	***	0.477	***	0.601	***	0.459	***	0.575	***	0.788	**
Non-Hispanic other	1.317	***	1.323	***	1.285	***	1.292	***	1.355	***	1.378	***
Hispanic	0.824	***	0.679	***	0.773	***	0.678	***	0.786	***	1.204	**
Interactions with regional variable												
Non-Hispanic black	1.169	*	1.912	***	1.099	***	1.763	***	1.240	**	0.524	***
Non-Hispanic A&PI	1.056		1.396	***	1.032		1.547	***	1.125	***	0.709	*
Non-Hispanic other	1.056		1.030		1.020		1.068		0.998		0.964	
Hispanic	1.087		1.301	***	1.041	*	1.380	***	1.095	**	0.560	***
Intercept	2.507	***	2.511	***	2.492	***	2.515	***	2.505	***	2.309	***
Number of observations	204,933		204,933		204,933		204,933		204,933		204,933	
COVID-19 infection												
Regional (Level-2) variable	1.028		0.950		0.998		0.854	***	1.020		1.312	**
COVID-19 infection (ref = no)												
Yes	1.254	***	1.133	**	1.212	***	1.143	***	1.243	***	1.437	***
Interactions with regional variable												
Yes	1.056	*	1.179	***	1.026	**	1.193	***	1.042	*	0.820	**
Intercept	2.500	***	2.535	***	2.508	***	2.535	***	2.502	***	2.444	***
Number of observations	204,933		204,933		204,933		204,933		204,933		204,933	

Notes: Full estimation results are available upon request. Standard errors were clustered at the state level. OR = odds ratio; HPS = Household Pulse Survey; A&PI = Asian and Pacific Islander. + = $p < .10$, * $p < .05$, ** $p < .01$, *** $p < .001$. The odds ratio (OR) is the measure of association which can be either i) 1.0 (or close to 1.0), ii) greater than 1.0, or iii) less than 1.0. An odds ratio of 1.0 (or close to 1.0) means that the independent variable is not associated with the vaccine hesitancy. An odds ratio of greater than 1.0 means that the independent variable has a positive association with vaccine hesitancy. An odds ratio of less than 1.0 means that the independent variable has a negative association with vaccine hesitancy.

unvaccinated) people may be plausible once individual vaccination records are joined with locational data (e.g., smartphone and credit card use) and other smart city technologies (Sonn et al. 2020). Second, additional regional variables can be considered to better capture the role of statewide characteristics in determining individuals' vaccine hesitancy. Given additional regional variables, COVID-19 vaccine estimations may be performed to predict the timing of herd immunity in the future and the spatial distribution of vaccine hesitancy at granular geographic areas (Centers for Disease Control and Prevention 2021; Gu 2021). Third, the HPS microdata was available only at the state level, which can be resolved as more COVID-19 research note geographically-granular effects of the pandemic on our society (Yilmazkuday 2021; Pak et al. 2020; Yao and Murray 2014). Furthermore, a panel survey-based research may allow researcher to control for individual-level fixed-effects which were not considered in this paper due to data limitation.

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Supplemental Material

Supplemental material for this article is available online.

Notes

1. United States Census Bureau's Household Pulse Survey COVID-19 Vaccination Tracker accessible at https://www.census.gov/library/visualizations/interactive/household-pulse-survey-covid-19-vaccination-tracker.html
2. The collaboration agencies are 1) Bureau of Labor Statistics (BLS), 2) Bureau of Transportation Statistics (BTS), 3) Centers for Disease Control and Prevention (CDC), 4)

Department of Defense (DOD), 5) Department of Housing and Urban Development (HUD), 6) Maternal and Child Health Bureau (MCHB), 7) National Center for Education Statistics (NCES), 8) National Center for Health Statistics (NCHS), 9) National Institute for Occupational Safety and Health (NIOSH), 10) Social Security Administration (SSA), and 11) USDA Economic Research Service (ERS).

3. A comparison test supports the representativeness of the main data. Please see Supplemental Table 2 for the comparison between HPS data and American Community Survey (ACS) data to see the representativeness of HPS in the nation as a whole and across states.
4. Phase 3 of the HPS has different answer options to the vaccine hesitancy question compared to those in phase 3.1 and later phases. The answer options in phase 3.1 and later surveys, unlike those in phase 3, include "Be unsure about getting a vaccine" between options 2 and 3, which is excluded from sample for consistency.

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