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Molly Hancuh

Risk Perception and Vaccine Uptake:

An analysis of changes in vaccination coverage and new vaccinations before and after the US COVID-19 Delta-Surge

By Molly Hancuh

Master of Science in Public Health

Department of Global Epidemiology

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2018

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An abstract of

A thesis submitted to the Faculty of the

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Abstract

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Background: The COVID-19 Delta variant caused widely disseminated spikes in cases and hospitalizations. Risk perception of case severity has been documented as a facilitator to vaccine intent. We examined changes in COVID-19 vaccination coverage and vaccination rates associated with the COVID-19 Delta variant caused case surge in the summer of 2021.

Methods: Using the US county as our unit of study, we modeled weekly national COVID-19 vaccination coverage (% of the US population with one or more dose) and vaccination rates (per capita newly initiated vaccinations), separately, using linear regression. We compared outcomes before and after publicized indicators of the US case surge, used as proxies for risk perception, to study which event had the highest associated increase in vaccine uptake.

Results: County-level vaccination coverage increased from pre-surge to surge periods for all three definitions of the surge; the largest increase--3.8 pp (95% CI 3.58-4.01)--was using the July 27th surge date. Similarly, rate of new vaccinations increased for all three surge dates, and the rate increase was largest for the July 27th date (0.44 pp; 95% CI 0.37 – 0.52). Weekly vaccination coverage was statistically significantly lower in counties with the largest share of limited English speakers (-6.75 pp; 95% CI -8.37 – -5.31) and minorities (-5.43 pp; 95% CI -7.26 – -3.59). However, counties with the largest share of foreign born had 7.15 pp (95% CI 5.32 – 8.98) higher vaccine coverage. Change in vaccination rates for these comparison by county characteristics related to immigration were not significant.

Discussion: We observed significant increase in vaccine uptake across multiple definitions of the Delta case surge, suggesting that perceived risk played a role. These results highlight the importance of repeated messaging on disease severity and may help to improve risk communication strategies for future surges and outbreaks.

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Table of Contents

Introduction

Less than a year after identifying the first case, the United States of America began mass vaccination campaigns to mitigate spread of COVID-19. These FDA approved vaccines have efficacy ranging from 86% - 97% [1]. Still, barriers, both modifiable and not, have prevented specific populations from receiving the vaccine. These barriers include, but are not limited to, culture and language barriers, mistrust in medical professionals, inability to access online resources, cost, and scheduling conflicts. Some barriers have been overcome, such as having bilingual providers, federal grants covering costs COVID-19 vaccines, and mobile clinics to access all populations. However, risk perception and mistrust in government officials and medical professionals have been exacerbated by dis/misinformation. After a decrease in cases due to initial mass vaccination campaigns, the surge of cases associated with the Delta surge may have increased fear of infection and severity, leading to increased vaccination rates in previously unvaccinated populations.

In this thesis, we sought to investigate the relationship between perception of the Delta surge and change in vaccine uptake. We do so by examining the one dose vaccine coverage and weekly vaccination rates before and after the Delta surge. We hypothesized that, at the county level, the surge in cases due to the Delta variant would be associated with spikes in vaccination rates due to elevated risk perception of infection or disease severity. To define a date of the Delta surge, we identified three events that may have warned populations of increased infection rates, including a press conference by Dr. Fauci, the initial rise in case rates, and updated CDC recommendations. We also hypothesized one dose vaccine coverage and weekly vaccination rates would vary for countries which experience higher rates of social vulnerability, specifically those with high rates of foreign born, minorities, and limited English proficiency. These factors were chosen due to their documented barriers to healthcare access, including culture and language barriers, mistrust in medical professionals, and cost.

Background and Literature Review

Development of US COVID-19 vaccines

First identified in 2019, the novel severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) caused the coronavirus disease 2019 (COVID-19) global pandemic, declared by the World Health Organization (WHO) on March 11, 2020. The respiratory disease is spread via droplets from person-to-person and can cause cold or flu-like symptoms, with the most severe presentation being acute respiratory distress syndrome [2]. In response to an urgent need for pharmaceutical prevention, the Departments of Health and Human Services (HHS) and Defense (DOD) collaborated to accelerate the vaccine's development [3]. Operation Warp Speed (OWS) allowed vaccine manufacturers to overlap clinical trials to study the efficacy and safety of each vaccine candidate at a reduced timeline [4]. By February 2021, the Food and Drug Administration (FDA) had given emergency use authorization to three vaccines against COVID-19 , and the primary prevention method swung from non-pharmaceuticals to vaccines [5].

COVID-19 variants

While emerging variants have raised concerns about the effectiveness of vaccination to bring the virus below epidemic levels, these new variants have also appeared to raise risk perception of the virus. By summer of 2021, variants of concern (VOC) being monitored globally including B.1.1.7 (Alpha), B.1.351 (Beta), P.1 (Gamma), and B.1.617.2 (Delta) [6,7]. The Delta variant, first isolated in India in December 2020, has 23 mutations compared to the Alpha variant including a mutation in the spike protein [6]. It is believed the effective reproduction number of the Delta variant increased by an estimated 50-60% in comparison to alpha and has a range somewhere between 3.2 and 6, depending on the population dynamics [7–9].

Vaccination policy: Failures

Despite the availability of effective vaccines, the COVID-19 vaccine rollout plans fell short of both federal projections and public expectations – particularly in the earliest phase. Manufacturers struggled to meet demands and inadequate supply chains left vaccines unused while underlying risk factors continued to cause disproportionate morbidity and mortality rates among vulnerable populations [10–16]. Vaccination prioritization was given to those suffering from biological risk factors such as being immunocompromised, older than 65 years old, and obese as well as healthcare professionals and frontline workers [10,12]. Despite consistently having higher case rates than white, non-Hispanic populations, racial and ethnic minorities experienced greater barriers to vaccination [17–20]. Experts highlighted the logistic challenges of distributing millions of vaccines, concerns about ethnical rollout, and state variances from federal recommendations as reasons for the range of vaccine access across the country [12]. According to the Kaiser Family Foundation (KFF), only two states (Utah and Missouri) included specific racial/ethnic minority considerations in their rollout phase adaptations to the CDC’s Advisory Committee on Immunization Practices (ACIP) recommendations [21].

Ongoing barriers to vaccination uptake in the US population

There are several ongoing barriers to vaccination, commonly separated between structural and attitude. Structural barriers can include cost, physical inaccessibility due to proximity or transportation, lack of time for an appointment, supply chain issues, lack of internet for scheduling, and culture or language. Attitude barriers are an individual’s perception that reduces vaccination intention, such as low perceived risk of infection or disease severity, mis/disinformation, mistrust in medical professionals, and high perceived risk of adverse effects of vaccination [18,22,23].

In the context of social distancing measures, health information technology (HIT) expanded and improved healthcare access for multiple populations, including rural and those unable to leave their homes. However, those lacking reliable internet, a strong understanding of healthcare system, or English proficiency were at a disadvantage to access care [17,19,24,25]. Barriers further included the utilization of online systems and portals for vaccine appointments [25,26]. Individuals with higher annual household incomes and greater educational attainment are more likely to utilize online medical portals [25]. KFF reported four in ten of those who were vaccinated needed help scheduling an appointment while three in ten of those who looked for vaccination information said it was difficult to find [27].

Trust in both scientistic and politicians has become a major component of vaccine uptake during the pandemic. Though similar trends have been seen during the COVID-19 pandemic, the rationale of trust and its importance is not as well understood in recent literature. The popularized idea of citizens being vigilant and doing their own research instead of trusting medical professionals can cause a rift between professionals and the public when the information doesn't align [28]. Past crises have outlined four major groups expected to have low trust in pandemic scientists: racial and ethnic minorities, religious groups with historical conflicts with scientists, individuals with lower education and income, and those who identify as Republican [11,15,29]. Search engines such as Google prioritize results based on previous search history, resulting in bias information and a majority of the population endorsing at least one mistrust belief [30,31]. Vaccine concerns are then linked to unpublished or un-peer reviewed studies with inadequate data or analysis, opinion pieces, and report of adverse medical effects that may or may not be linked to vaccination [30].

Potential for health outcome inequities due to social determinants of health

The CDC defines social determinants of health (SDOH) as the conditions of one's environment that affect health risks and outcomes. The social determinants framework, according to Healthy People 2030, states there is an underlying, societal condition to every individual decision and behavior [32]. As stated previously, barriers to healthcare include social risk factors which can also affect risk perception of both the disease and associated medical interventions [29,33]. We aimed to incorporate relevant SDOH into the analysis to account for counties with large proportions of the population experiencing disproportionate case and hospitalization rates due to socioeconomic risk factors.

The role of risk perception in vaccination intent

Risk perception, defined as one's instinctual evaluation of the danger they may be exposed to due to a specific action, are influenced by different cultural, social, and contextual factors [3,24,34,35]. Previous studies reported vaccinated populations reported greater risk of disease and lesser risk of adverse events associated with vaccines than unvaccinated populations, and that longer exposure to risk was associated with increased engagement in preventative measures [35,36]. More recent studies also found that knowledge about vaccines does not directly increase vaccination intention which has contradicted past studies, but does have indirect effects [24,36,37]. Therefore, vaccine-related risk perception may have been exacerbated by OWS as mis/disinformation on safety protocols has affected trust in public health and medical professionals [3].

We identified three specific times over a two-month period when risk perception of COVID-19 may have increased. First, during a June 22nd White House Press Briefing, Dr. Anthony Fauci, the Chief Medical Advisor to the President, spoke about the increase transmissibility and severity of the Delta variant [38]. Next, in the first week of July, case rates began rising again according to the CDC's COVID-19 Tracker and John's Hopkin's COVID-19 Dashboard [39,40]. Lastly, on July 27th, the CDC's updated masking guidance recommended everyone wear a mask in public indoor settings, regardless of vaccination status [41]. The CDC also issued a health advisory to increase vaccination coverage.

Methods

Data sources

The unit of analysis for this study was the county-week. We developed a county-level database by week for analysis from multiple national databases and aggregated based on FIPS code.

Data on COVID-19 cases and vaccination rates between January 1 and December 31, 2021, were taken from the CDC's COVID Data Tracker. The CDC collects COVID-19 test results from state, local, and territorial health departments.

Percent uninsured, who completed high school, with some college education, with access to broadband internet, female, and rural were taken from 2021 County Health Rankings. Produced by the University of Wisconsin Population Health Institute and the Robert Wood Johnson Foundation since 2010, the County Health Rankings are based on both health outcomes and health factors, each divided between multiple components.

From the CDC's 2018 Social Vulnerability Index (SVI), we took percent living below the poverty line, unemployed, minority, and who speak English "less than well". Percent born outside the United States was taken from the 2020 US Census and includes naturalized citizens, lawful permanent residents, temporary migrants, humanitarian migrants, and unauthorized migrants. For the CDC's SVI, the Agency for Toxic Substances and Disease Registry (ATSDR) uses 15 census variables to assess populations especially at risk during public health emergencies. Linked variables are grouped into four factors: socioeconomic status, household composition and disability, minority status and language, and housing type and transport.

Outcome definitions

The primary outcomes were cumulative vaccination and weekly rate of vaccination among adults. Cumulative vaccination coverage was defined as the total percent of county population older than 18 years old vaccinated with at least one dose of a COVID-19 vaccine at the midpoint of each week (Thursday). Weekly vaccination rate, a measure of newly initiated vaccinations, was defined as the change in the percentage of adults with at least one dose of a COVID-19 vaccine compared to the previous week. This was computed by subtracting the cumulative percentage of adults with at least one dose of a COVID-19 vaccine of the previous week from the present week.

Vaccination periods

Time periods were defined based on their relation to national vaccination guidelines and US COVID-19 Delta surge. We considered three different indicators of the Delta surge: June 22, 2021 (based on Dr. Fauci's press conference warning of the Delta variant's potential surge); July 1, 2021 (based on the increase in observed cases); and July 27, 2021 (the CDC's updated mask and vaccine recommendations). The yearlong analysis is split into three time periods: initial vaccine rollout from January 1, 2021 to April 17, 2021; pre-surge rollout from April 18, 2021 to the defined indicator date; and post-surge rollout from the defined indicator date to December 31, 2021. The two-month analysis is split between one month before (pre-surge) and one month after (surge) the defined indicator date.

Key Immigration-related county covariates

The three main covariates of interest were percent minority, percent who speak English "less than well", and percent born outside the United States. We chose these three variables due to their documented barriers to vaccine accessibility in the United States, including but not limited to mistrust in medical professionals, lack of resources, and inaccessibility [17,18,22–25]. Counties were split into "high" versus "low" levels of each immigration-related characteristic at the 95th percentile. Using this criterion, counties where ≥65.3% of the population identified as minority, ≥ 6.9% of the population spoke English "less than well", and ≥16.5% of the population was foreign born were classified as being in the high group of each respective characteristic. Vaccination outcomes in counties classified in the high group were compared to those in the low group.

Statistical Analysis

For each county characteristic, we reported the mean, standard deviation, minimum, maximum, and median. To study the relationship between county demographics, we used a correlation matrix. We described temporal trends in vaccination coverage of one dose and vaccination rates.

Utilizing the county as our unit of analysis, we modeled weekly national COVID-19 vaccination coverage and vaccination rates, separately, using linear regression for the entire 2021 time period and a time period restricted to one month before and after the defined indicator dates. We estimated a separate linear model for each outcome, surge date, and time period combination (a total of 12 models). For the yearlong analysis, the linear regression models were fit to estimate association between ordinal indicators of the vaccine rollout and surge (0=initial vaccine rollout; 1=pre-surge rollout; 2=post-surge rollout). The linear regression models for the two-month analysis were fit to estimate the association between a binary indicator of the defined surge date (0=before the surge; 1=during the surge) and each vaccination outcome accounting for calendar week and for county demographic factors.

Finally, we analyzed county-level weekly vaccination coverage and vaccination rates by county immigration characteristics, grouped as high versus low levels of each characteristic. We described vaccination trends stratified by county immigration characteristics. We also estimated differences in overall weekly vaccination coverage and vaccination rates by immigration characteristics using linear regression. The visualization of trends and linear regression were conducted for the entire year and to the time period of June 24th to August 26th.

Results

Characteristics of US counties

Data were taken from 3144 counties and county equivalents. The distribution of county characteristics can be found in Table 1. At the county-level, the average minority (not white, non-Hispanic) percentage of populations was 23.49%, average percent of population born outside the US was 4.72%, and average percent of population who speak English "less than well" was 1.70%. On average, 86.95% of the population graduated from high school, 15.27% lived before the poverty line, and 11.5% did not have healthcare.

The Pearson correlation coefficients for all county characteristics studied here are reported in Table 2. There was a strong positive correlation between living below the poverty line and unemployment $r(3142) = 0.964$, $p < 0.0001$ as well as being born outside of the US and limited English proficiency $r(3142) = 0.865$ $p < 0.0001$. Not having health insurance had a weak, positive correlation with limited English proficiency $r(3142) = 0.39$ $p<0.0001$, being a minority $r(3141) = 0.46$ $p<0.0001$, and being born outside the US $r(3142) = 0.23$ $p<0.0001$. Access to broadband internet inversely correlated with not having healthcare $r(3142) = -0.38$ $p<0.0001$ and being a minority $r(3142) = -0.25$ $p<0.0001$.

Trends in county vaccination

Figure 1 shows the 2021 county average one dose vaccine coverage and national county average change in weekly vaccination rates. County-level cumulative vaccination coverage increased from 0.22% in the first week of January to 61.27% at the end of December 2021. Weekly county-level cumulative vaccination rates ranged from near 0% to 6% throughout 2021. Figure 2 shows the same data for May through August 2021. County-level cumulative vaccination coverage in mid-May was 35.15% and increased to 44.05% by the end of August. During the same time period, the weekly county-level cumulative vaccination rates were lowest in late June, with a low of 0.16%, and highest in the beginning of August, with a high of 1.28%.

Differences in weekly vaccination coverage and rates associated with the Delta surge across the 2021 calendar year

Table 3 shows the results of linear regression models estimating the association of time periods marked by three different definitions of the Delta surge with cumulative vaccination coverage and vaccination rates for the entirety of 2021.

When using June 22nd as the indicator of the Delta surge, the cumulative vaccination coverage was 20.4 percentage points (pp) lower (95% CI -19.9 – -20.9) in the initial rollout period (Jan 1st – Apr 17th) and 14.2 pp higher (95% CI 13.9 – 14.4) in the post-surge rollout period (Jun 24th – Dec 31st) compared to during the pre-surge rollout period (Apr 18th – Jun 22nd; reference). The vaccination rate was 1.41 pp higher (95% CI 1.36 – 1.45) in the initial rollout period and 0.17 pp higher (95% CI 0.12 – 0.22) in the post-surge compared to during the pre-surge period.

When using July 1st as the defined Delta surge date, the cumulative vaccination coverage was 20.61 pp lower (95% CI -21.1 – -20.11) in the initial rollout period (Jan 1st – Apr 17th) and 14.39 pp higher (95% CI 14.09 - 14.69) in the post-surge period (Jul 1st – Dec 31st) compared to pre-surge period (Apr 18th – July 1st; reference). The vaccination rate was 1.46 pp higher (95% CI 1.41 – 1.50) in the initial rollout period and 0.25 pp higher (95% CI 0.19 – 0.30) in the post-surge compared to the pre-surge period.

When using July 27th as the defined Delta surge date, the cumulative vaccination coverage was 21.49 percentage points (pp) lower (95% CI -22.01 – -20.97) in the initial rollout period (Jan 1st – Apr 17th) and 15.47 pp higher (95% CI 15.47 – 15.82) in the post-surge period (Jul 27th – Dec 31st) compared to the pre-surge period (Apr 18th – July 27th; reference). The vaccination rate was 1.49 pp higher (95% CI 1.45 – 1.53) in the initial rollout period and 0.35 pp higher (95% CI 0.30 – 0.40) in the post-surge compared to the pre-surge period.

County-level changes in weekly vaccination coverage and rates associated with the Delta surge in the month before and after the surge

Table 4 shows the results of linear regression models estimating the association of the Delta surge with vaccination coverage and vaccination rates for the time period restricted to one month before and after each Delta surge indicator date.

Applying the June 22nd Delta surge date, we found the cumulative vaccination coverage was 1.59 pp higher (95% CI 1.43 – 1.75) in the surge period (Jun 23rd – Jul 22nd) compared to the pre-surge period (May 27th – Jun 22nd; reference). The vaccination rate was 0.03 pp higher (95% CI -0.03 – 0.10) in the surge period compared to pre-surge.

Applying the July 1st Delta surge date, we found the cumulative vaccination coverage was 1.87 pp higher (95% CI 1.71 – 2.03) in the surge period (Jul 1st – Jul 28th) compared to pre-surge (Jun 3rd– Jul 1st; reference). The vaccination rate was 0.28 pp higher (95% CI -0.21 – 0.35) in the surge period compared to pre-surge.

Applying the July 27th Delta surge date, we found the cumulative vaccination coverage was 3.80 pp higher (95% CI 1.71 – 2.03) in the surge period (Jul 1st – Jul 28th) compared to pre-surge (Jun 3rd– Jul 1st; reference). The vaccination rate was 0.28 pp higher (95% CI -0.21 – 0.35) in the surge period compared to pre-surge.

County-level changes in weekly vaccination coverage and rates associated with the Delta surge by county immigration characteristics

Table 5 shows the results of linear regression analysis of the association between the key immigrant-related county covariates and vaccination outcomes from June 24th to August 26th. As shown in Figure 3, the cumulative vaccination coverage in counties with high populations with limited English had 6.75 pp lower (95% CI 5.13 – 8.37) cumulative vaccination coverage compared to those with low populations with limited English proficiency. In the same time period, counties with high populations of minorities were 5.43 pp lower (95% CI 3.59-7.26) compared to counties with low populations of minorities, as shown in Figure 4. The cumulative vaccination coverage for counties with high populations of foreign born was 7.15 pp higher (95% CI 5.32-8.98) than counties with low populations of foreign born, as shown in Figure 5. Weekly vaccination rates were not statistically significantly different across counties defined by high versus low population percentages of minority, foreign-born, or limited English proficiency in the two-month analysis centered on July 27th.

Discussion

Between the three timelines with different Delta surge periods, weekly vaccination rates were higher during the initial and post-surge rollout periods than during the pre-surge rollout period throughout the yearlong analysis. When narrowed down to two-months centered on the indicator date, the weekly vaccination rates for the surge period were higher than during the pre-surge for all three defined timelines. Together, the findings suggest a potential role for the Delta variant shaping risk perception in a manner that prompted modest increases in uptake of vaccination. In the two-month analysis, differences in vaccine coverage and weekly vaccination rates from pre-surge to surge periods were largest when the surge was defined by July 27th as compared to June 22nd and July 1st. We also found the vaccine coverage significantly differed in populations experiencing higher rates of social vulnerability compared to those with lower rates of social vulnerability. For the three demographics analyzed, the weekly vaccination rates were not significantly different between the counties with high and low proportions of these key immigrant-related covariables. To our knowledge, this was the first study to consider these specific sources as causes for increased risk perception of COVID-19 infection and severity in the United States.

The initial rollout period showed the greatest difference in both vaccine coverage and weekly vaccination rate in comparison to the pre-surge period, however, this trend is more likely caused by mass vaccination clinics and emphasis on vaccinating frontline workers and those with biological risk factors in first few months of 2021 than true risk perception of COVID-19 [10–13]. Similarly, the post-surge period saw a large spike in vaccinations in population over 18 near the end of October. We believed these are due to a combination of workplace mandates and families getting vaccinated together once vaccines were approved for children. The post-surge period also includes the case surge associated with the Omicron variant. Only the pre-surge rollout period is not partially during the winter where cold weather has caused most of the personal interactions to occur indoors, resulting in greater risk of infection as seen with the seasonal flu [42].

The findings are consistent with an cumulative risk hypothesis, which argues multiple factors are needed to increase risk perception to a threshold when behavior is changed [43]. It suggests that no singular press release or weekly COVID-19 report had a stronger association with the increase in vaccination rates in relation to the Delta surge. Instead, the accumulation of multiple events such as press conferences and spikes in infection and hospitalization rates may have contributed to increased vaccine uptake [44]. The CDC's updated recommendations for the Delta variant on July 27th saw slightly greater differences in both outcomes for the post-surge rollout period in comparison to the pre-surge rollout period, potentially due to the amassing of information in late June and early July. In contrast, the White House Press Conference in late June had the lowest difference in vaccine coverage and weekly vaccination rate between surge and post-surge periods, suggesting either mistrust in political figures and scientists or continued hesitation, especially that vaccines may not be as effective against variants. Taking a "wait and see" approach to vaccination was common both during initial rollouts and later surges [15]. Further, the notion of citizens being vigilant and making their own health choices may have played a role in the increased vaccinations once cases began to rise [28].

Our analysis was consistent with other studies which saw lower vaccine coverage in populations with large proportions of minorities and those with limited English proficiency [14,45–47]. We did not find significant differences in weekly vaccination rates in populations with higher rates of social vulnerability. These results align with other studies that concluded the same vaccine inequities or barriers affecting minorities and populations with limited English in the beginning of rollout may no longer be present, but little to nothing has been done to right lingering inequities from initial stages of vaccination campaign [45–47]. While we expected to see the same trend for vaccination coverage in counties with high percentages of foreign born, the opposite was found. The two spikes in weekly vaccination rates also differed as they were delayed to the beginning and middle of August, as shown in Figure 5. This association may be attributed to increased outreach or immigrants making up a disproportionately large percentage of the essential workforce which was prioritized in phase 1b of vaccine rollout [48–50]. Community partnerships with health facilities who primarily serve immigrant and minority populations may also have facilitated strong trust in healthcare workers, shown to increase vaccination intention [24,51]. We also found being foreign born has a weak positive correlation with living in urban areas, which tend to have greater access to healthcare facilities and resources than rural areas.

Strengths and limitations:

This yearlong, ecological study allowed us to analyze vaccine uptake and weekly vaccination rates per capita efficiently as collecting individual level data on these variables would have been extremely time and resource exhaustive. The study design also allows for reduced confounder effect by including all counties in the US and nationwide generalizability [52,53]. Due to the use of regularly obtained data on the economy, environment, and health and wellbeing of populations, our study only included data revised within the last four years, making it extremely applicable to current county demographics.

We had multiple limitations to this studying. Because this was an ecological study, we were unable to directly estimate changes in individual-level vaccination uptake that were independently associated with the Delta variant surge and related announcements. Our analysis is also limited because we used first dose vaccinations as a proxy for vaccine intention when we are aware there are both barriers and facilitators between the two which may have affected results. For the yearlong analysis, there were secular changes in access to the vaccine. The initial rollout period was one in which there was lower eligibility for the vaccine, and lower vaccination uptake in this period is a faulty measure of risk perception prior to the actual Delta variant cases surge in the US. It is also difficult to define a surge using specific dates as case rates differed across counties. We were also limited by the lack of standard baseline for vaccinations due to its recent approval which made interpreting vaccine uptake differences difficult. Our analysis also did not include heterogeneity for variables of minorities, lack of English proficiency, or foreign born.

Conclusion

The Delta variant caused COVID-19 case surge in the summer of 2021 was associated with an increase in weekly vaccination rates according to three different definitions of the surge period. This is consistent with the hypothesis that accumulation of risk perception due to multiple reports and rising case rates may be associated with greater vaccine uptake. The greatest difference between pre-surge and surge vaccination rates occurred for July 27th, when the CDC updated masking and vaccine recommendations, suggesting that a fraction of the public was influenced by this federal guidance. Greater emphasis is needed for understanding how risk perception can be utilized in the future to encourage vaccinations or other preventative strategies, especially across different demographic profiles. While vaccine coverage was lower in counties with high proportions of the population who are minorities and who speak English “less than well”, coverage was higher in counties with high proportions of the population who were foreign born. This suggests that counties with high proportions of minorities, individuals with limited English abilities, and the foreign-born may not be one in the same, and that these characteristics are differentially associated with vaccine uptake. All the same, the large and consistent gaps in vaccination coverage over the 2021 year by immigration characteristics suggests that more is needed to achieve optimal vaccination coverage across the US counties.

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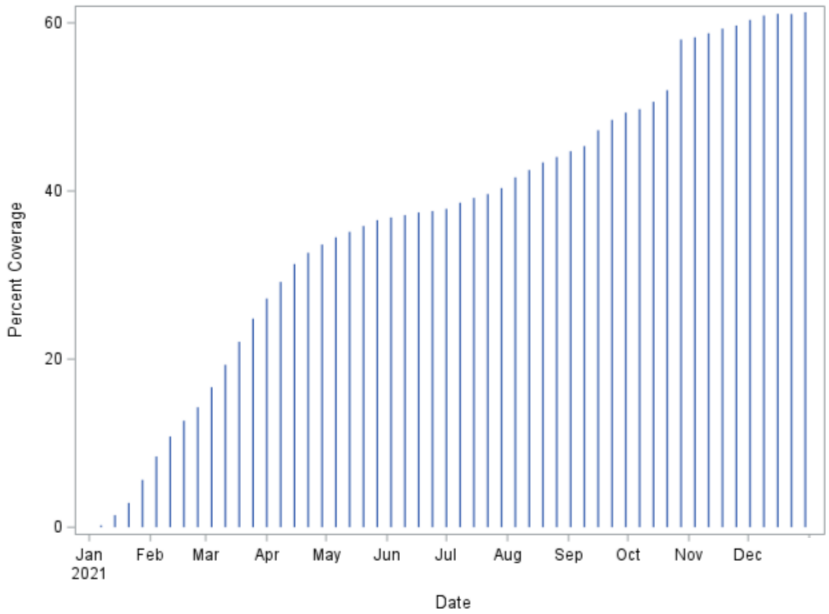
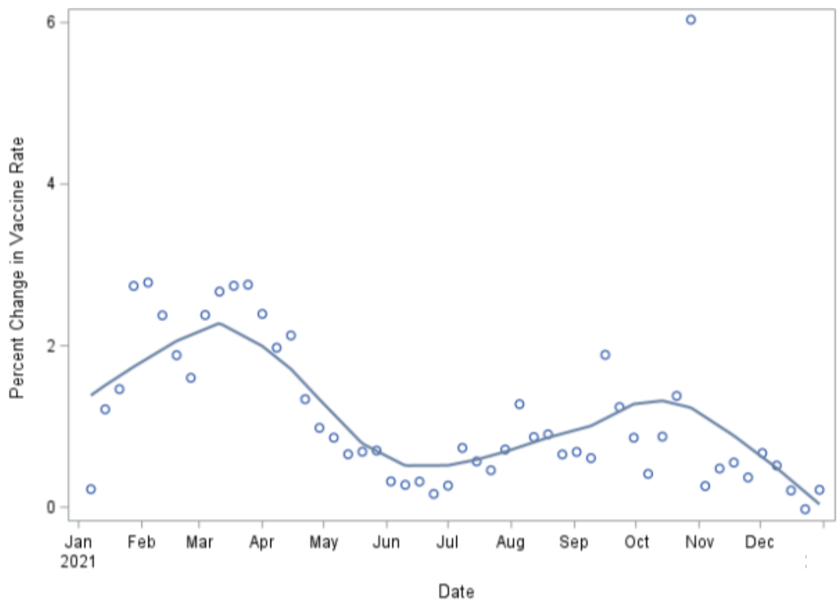
Tables and Figures

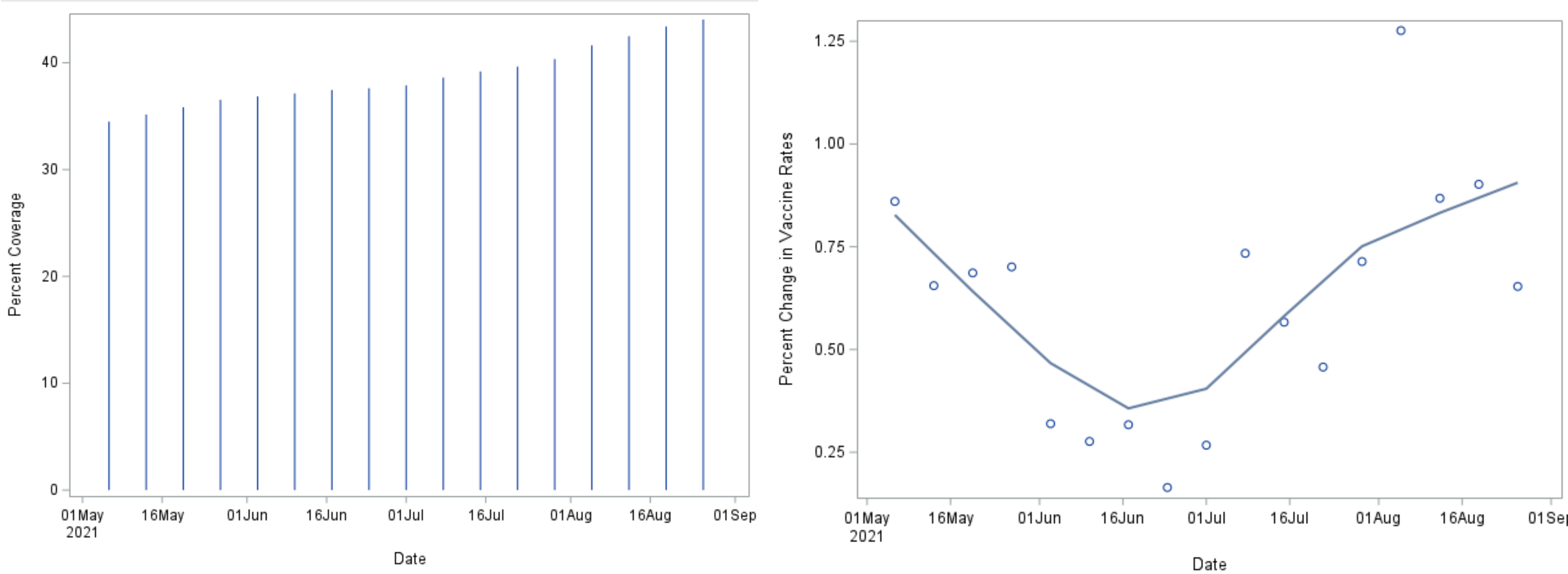
Figure 1. County average coverage for one dose COVID-19 vaccine in people 18+, 2021 and county average weekly rate of vaccination in people 18+, 2021





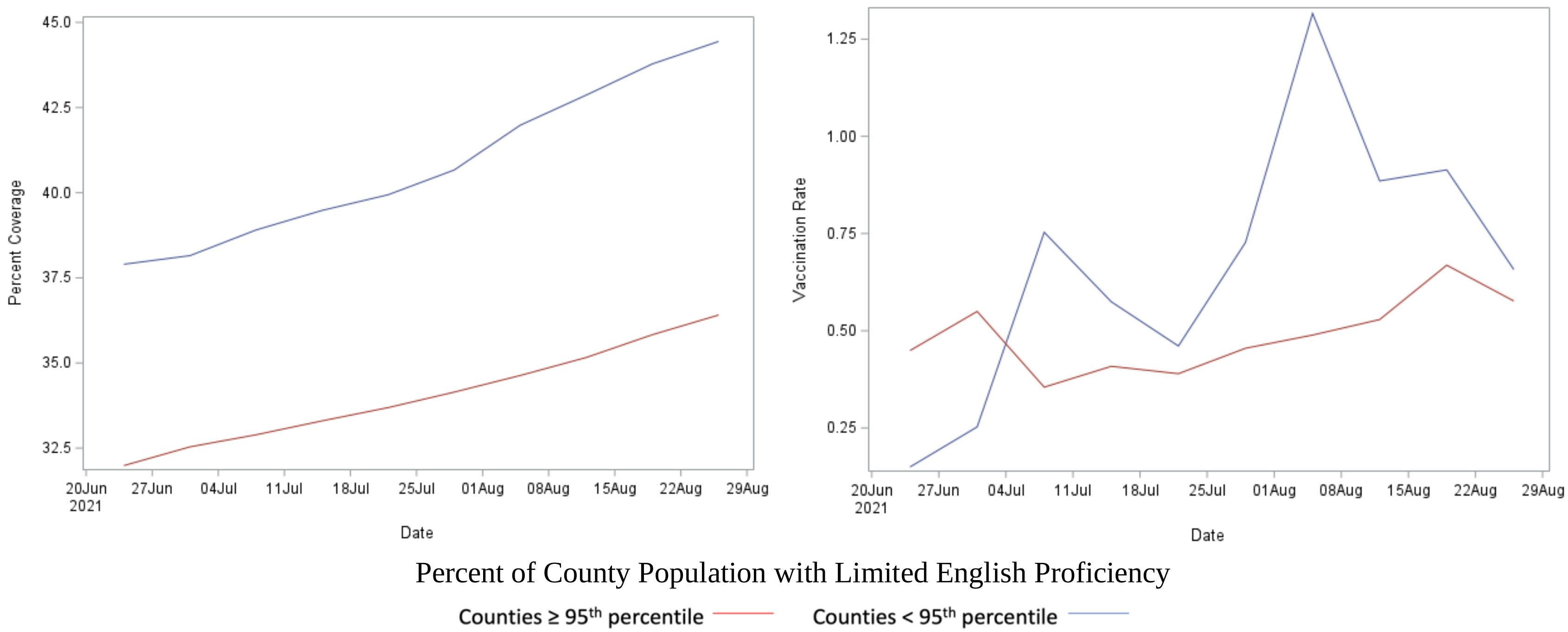
The bar graph shows the average percent coverage of one dose of a COVID-19 vaccine for 1344 counties within the US. The line graph shows the average weekly vaccine rate for one dose of a COVID-19 vaccine for 1344 counties within the US. For both graphs, only those over the age of 18 were counted.

Figure 2. County average coverage for one dose COVID-19 vaccine and county average weekly rate of vaccination in people 18+ , May – August 2021



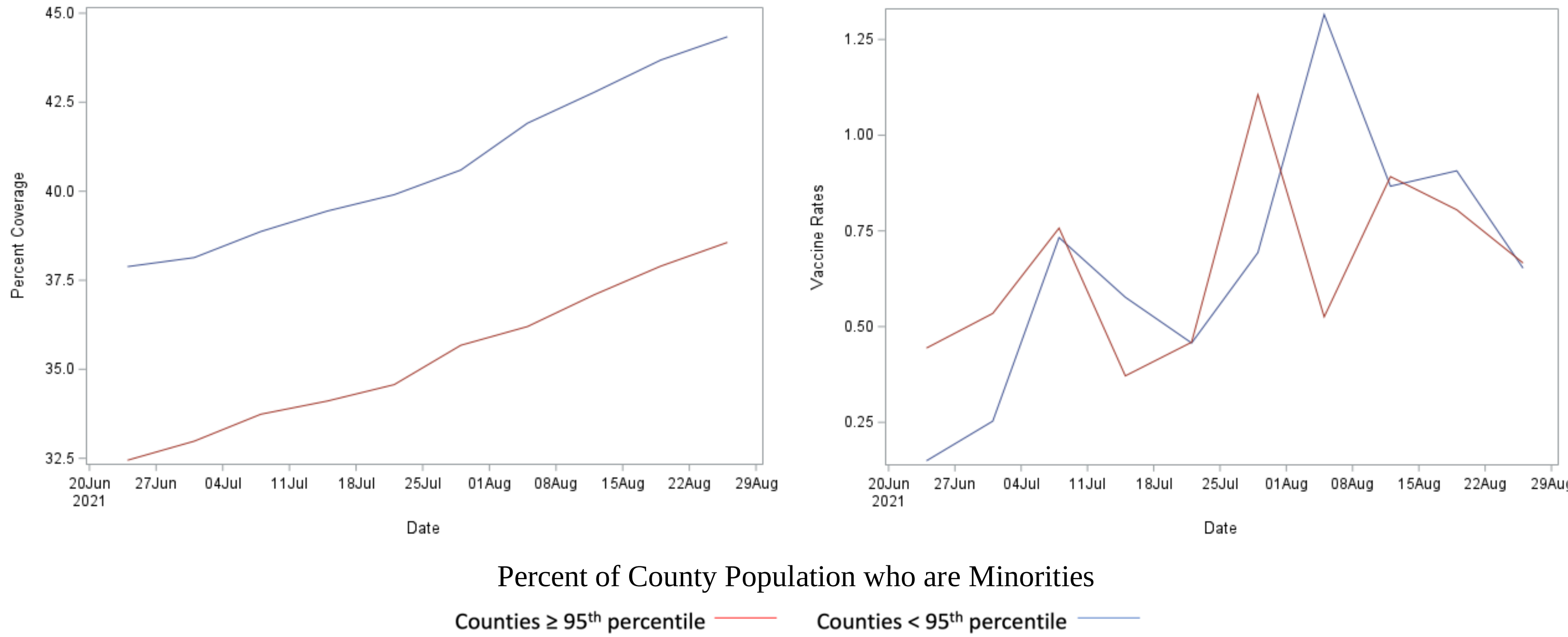
The bar graph shows the average percent coverage of one dose of a COVID-19 vaccine for 1344 counties within the US. The line graph shows the average weekly vaccine rate for one dose of a COVID-19 vaccine for 1344 counties within the US. For both graphs, only those over the age of 18 were counted and the timeframe was restricted to beginning of May through end of August.

Figure 3. County-level trends in population coverage of 1+ dose COVID-19 vaccine and weekly rate of vaccination in people 18+ , June – August 2021, stratified by percent of county population with limited English proficiency



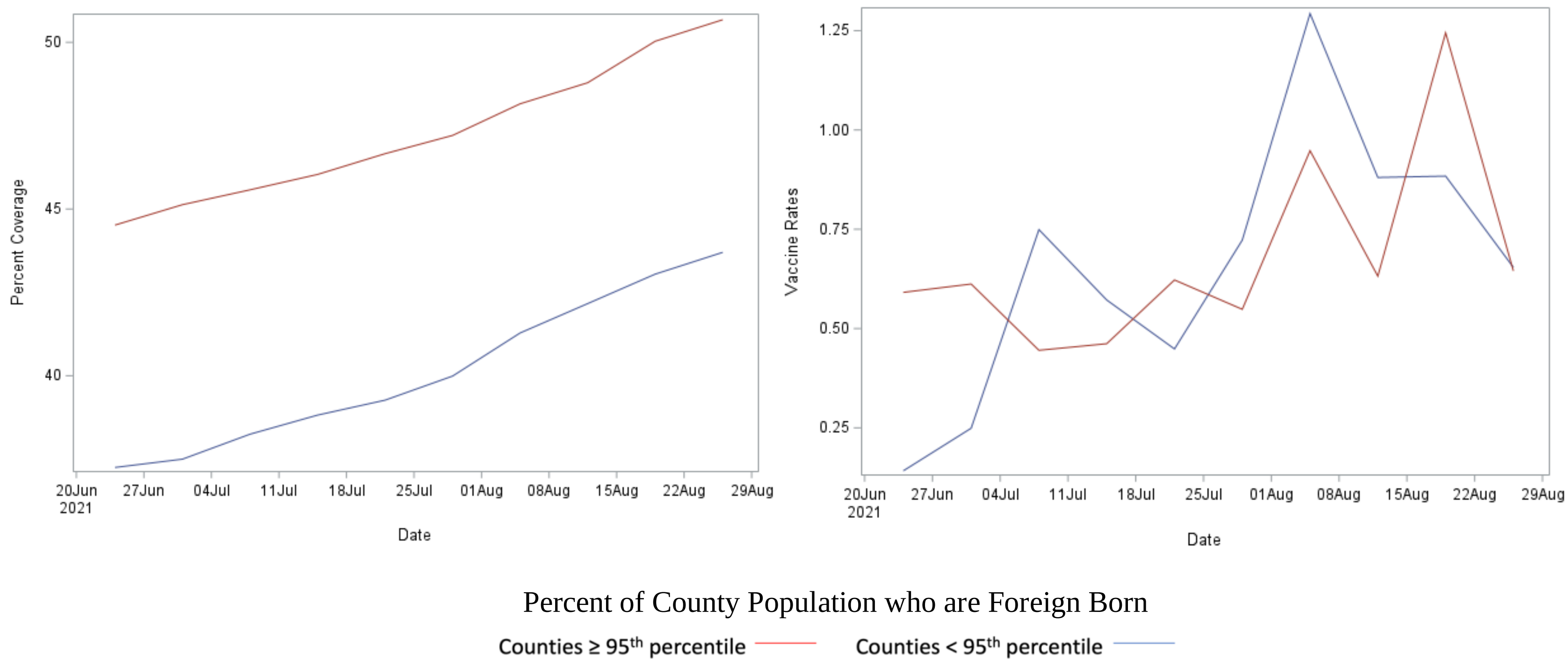
At the county level, the percent coverage of one dose of the COVID-19 vaccine and weekly vaccines rates for those 18+ are stratified by English proficiency. Counties at or above the 95th percentile (≤ 6.9% with limited English) for percentage of population who spoke English “less than well” were compared to those below the 95th percentile.

Figure 4. County-level trends in population coverage of 1+ dose COVID-19 vaccine and weekly rate of vaccination in people 18+ , June – August 2021, stratified by percent of county population who are minorities.



At the county level, the percent coverage of one dose of the COVID-19 vaccine and weekly vaccines rates for those 18+ are stratified by percent of population who identified as minority. Counties at or above the 95th percentile (≤ 65.3% minority) for minority percentage of the population were compared to those below the 95th percentile.

Figure 5. County-level trends in population coverage of 1+ dose COVID-19 vaccine and weekly rate of vaccination in people 18+ , June – August 2021, stratified by percent of county population who are foreign born



At the county level, the percent coverage of one dose of the COVID-19 vaccine and weekly vaccines rates for those 18+ are stratified by percent of population born outside the US. Counties at or above the 95th percentile (≤ 16.5% foreign born) for percentage of population born outside of the US were compared to those below the 95th percentile.

Table 1: Distribution of Sociodemographic Features across 3142 Counties, United States

County Characteristics	Mean (SD)	Minimum	Maximum	Median
Demographic composition				
Population, thousands 2021	102.8 (329.9)	0.075	10098.1	257.3
% Rural, 2021	58.5 (31.48)	0.00	100.0	59.5
% Female, 2021	49.8 (2.3)	26.5	57.0	50.3
% over 65 years old, 2021	18.3 (4.6)	3.8	55.6	18.0
Immigration related factors				
% Minority (not white, non-Hispanic), 2021	23.5 (20.2)	0.0	99.3	16.1
% Foreign-born, 2021	4.7 (5.7)	0.0	53.3	2.7
% who speak English "less than well", 2018	1.70 (2.79)	0.0	30.4	0.7
Economic and social characteristics				
Median income, thousands, 2021	27 (6.5)	10.1	72.8	26.2
Population below the poverty line, %	15.3 (19.2)	0.0	55.0	14.7
Civilian population unemployed, %	5.8 (2.9)	0.0	28.9	5.4
Population with some college, %	58.1 (12.0)	1.0	100.0	58.0
Population with access to broadband, %,	75.4 (8.8)	35.0	96.0	76.0
Population with high school diploma equivalency, %	87.0 (6.3)	26.0	99.0	88.0
Healthcare characteristics				
Population without health insurance, %	11.5 (5.1)	2.0	32.0	11.0

Table 2. Correlation matrix of included county level demographics

		1	2	3	4	5	6	7	8	9	10
	Demographic composition										
1	% Rural, 2021	1.00	-0.31	-0.49	-0.32	0.10	-0.03	-0.32	-0.49	-0.15	0.17
2	% Minority, 2021	-0.31	1.00	0.52	0.55	0.44	0.46	-0.26	-0.25	-0.49	0.46
3	% Foreign-born, 2021	-0.49	0.52	1.00	0.87	-0.09	-0.02	0.08	0.29	-0.21	0.23
4	% who speak English "less than well", 2018	-0.32	0.55	0.87	1.00	0.07	0.04	-0.16	0.05	-0.46	0.39
	Economic and social characteristics										
5	Population below the poverty line, %	0.10	0.44	-0.09	0.07	1.00	0.64	-0.53	-0.64	-0.61	0.33
6	Civilian population unemployed, %	-0.03	0.46	-0.02	0.04	0.64	1.00	-0.40	-0.35	-0.43	0.17
7	Population with some college %	-0.32	-0.26	0.08	-0.16	-0.53	-0.40	1.00	0.63	0.78	-0.46
8	Population with access to broadband, %,	-0.49	-0.25	0.29	0.05	-0.64	-0.35	0.63	1.00	0.60	-0.38
9	Population with high school diploma equivalency, %	-0.15	0.05	-0.21	-0.46	-0.61	-0.43	0.76	0.60	1.00	-0.55
	Healthcare characteristics										
10	Population without healthcare insurance , %	0.17	0.46	0.23	0.39	0.33	0.17	-0.46	-0.38	-0.55	1.00

Table 3. County-level change in weekly cumulative vaccination coverage (% of the population with one dose) and vaccination rates (per capita newly initiated vaccinations) associated with the Delta surge, January 1, 2021 to December 31, 2021

	Vaccine coverage					Vaccination Rate				
	% (SD)	Change in vaccine coverage* percentage points	LB	UB	p value	Rate (std dev)	Change in vaccination rate**	LB	UB	p value
Surge defined by Dr. Fauci's press conference on emerging Delta variant (June 22)										
Initial rollout (Jan 1 -Apr 17)	15.13 (14.46)	-20.40	-20.89	-19.91	<0.0001	2.09 (2.76)	1.41	1.36	1.45	<0.0001
Pre-surge (Apr 18- Jun 22)	35.52 (21.45)	ref	-	-		0.68 (2.89)	ref	-	-	
Post-surge (Jun 23 - Dec 31)	49.68 (24.91)	14.15	13.86	14.45	<0.0001	0.85 (5.18)	0.17	0.12	0.22	<0.0001
Surge defined by increased case rates at beginning of July, attributed to Delta variant (July 01)										
Initial rollout (Jan 1 -Apr 17)	15.13 (14.46)	-20.61	-21.1	-20.11	<0.0001	2.09 (2.76)	1.46	1.41	1.5	<0.0001
Pre-surge (Apr 18- Jul 01)	35.73 (21.68)	ref	-	-		0.63 (2.92)	ref	-	-	
Post-surge (Jul 02 - Dec 31)	50.12 (24.85)	14.39	14.09	14.69	<0.0001	0.88 (5.24)	0.25	0.19	0.30	<0.0001
Surge defined by CDC's updated recommendations for Delta variant (July 27)										
Initial rollout (Jan 1 -Apr 17)	15.13 (14.46)	-21.49	-22.01	-20.97	<0.0001	2.09 (2.76)	1.49	1.45	1.53	<0.0001
Pre-surge (Apr 18- Jul 27)	36.62 (22.44)	ref	-	-		0.59 (3.04)	ref	-	-	
Post-surge (Jul 28 - Dec 31)	52.09 (24.45)	15.47	15.13	15.82	<0.0001	0.94 (5.51)	0.35	0.30	0.40	<0.0001

ref = reference category

*Linear regression analysis for change in national coverage of one COVID-19 vaccine in those over 18 using initial rollout, pre-surge, and post-surge timeframes as dependent variables for counties matched on percent rural, female, living below the poverty line, unemployed, with access to broadband internet, with high school diploma or equivalent, with some college education, minority, foreign born, having limited English proficiency, and uninsured.

** Linear regression analysis for change in one dose COVID-19 vaccination rate in those over 18 initial rollout, pre-surge, and post-surge timeframes as dependent variables for counties matched on percent rural, female, living below the poverty line, unemployed, with access to broadband internet, with high school diploma or equivalent, with some college education, and uninsured.

Table 4. County-level change in weekly cumulative vaccination coverage (% of the population with one dose) and vaccination rates (per capita newly initiated vaccinations) associated with the Delta surge, restricted to one month before and after the surge.

	One dose vaccine coverage					Vaccination Rate				
	% (std dev)	Change in vaccine coverage* %	LB	UB	p value	Rate (std dev)	Change in vaccination rate	LB	UB	p value
Surge defined by Dr. Fauci's press conference on emerging Delta variant (June 22)										
Pre-surge (May 27 - Jun 22)	36.99 (22.61)	ref	-	-		0.40 (2.76)	ref	-	-	-
Surge (Jun 23 - Jul 22)	38.32 (23.92)	1.59	1.43	1.75	<0.0001	0.43 (3.54)	0.03	-0.03	0.10	0.3
Surge defined by increased case rates at beginning of July, attributed to Delta variant (July 1)										
Pre-surge (Jun 3 - Jul 1)	37.26 (23.00)	ref	-	-		0.27 (3.02)	ref	-	-	
Surge (Jul 1 - Jul 28)	38.83 (24.10)	1.87	1.71	2.03	<0.0001	0.51 (3.33)	0.28	0.21	0.35	<0.0001
Surge defined by CDC's updated recommendations for Delta variant (July 27)										
Pre-surge (Jun 24 - Jul 27)	38.58 (23.99)	ref	-	-		0.44 (3.29)	ref	-	-	-
Surge (Jul 27 - Aug 26)	42.38 (24.99)	3.8	3.58	4.01	<0.0001	0.88 (3.59)	0.44	0.37	0.52	<0.0001

ref = reference category

*Linear regression analysis for change in national coverage of one COVID-19 vaccine in those over 18 using pre-surge and post-surge timeframes as dependent variables for counties matched on percent rural, female, living below the poverty line, unemployed, with access to broadband internet, with high school diploma or equivalent, with some college education, minority, foreign born, having limited English proficiency, and uninsured.

** Linear regression analysis for change in one dose COVID-19 vaccination rate in those over 18 using pre-surge and post-surge timeframes as dependent variables for counties matched on percent rural, female, living below the poverty line, unemployed, with access to broadband internet, with high school diploma or equivalent, with some college education, minority, foreign born, having limited English proficiency, and uninsured.

Table 5. County-level differences in weekly cumulative vaccination coverage (% of the population with one dose) and weekly vaccination rates (per capita newly initiated vaccinations) associated with county immigration characteristics, June 24 – August 26, 2021

	One dose vaccine coverage					Vaccination rate				
	% (std dev)	Differences in vaccine coverage* %	LB	UB	p value for interaction	Rate (std dev)	Differences in vaccine rate	LB	UB	p value for interaction
Percent of population with limited English										
High (≥ 95th percentile)	34.06 (33.67)	-6.75	-8.37	-5.13	<0.0001	0.49 (1.11)	-0.18	-0.39	0.02	0.08
Low (< 95th percentile)	40.81 (23.96)	ref				0.67 (3.53)	ref			
Percent of population minority										
High (≥ 95th percentile)	35.33 (32.46)	-5.43	-7.26	-3.59	<0.0001	0.66 (2.25)	-0.004	-0.24	0.24	0.97
Low (< 95th percentile)	40.75 (24.06)	ref				0.66 (3.50)	ref			
Percent of population foreign born										
High (≥ 95th percentile)	47.28 (33.88)	7.15	8.98	5.32	<0.0001	0.68 (2.24)	0.02	0.26	0.23	0.90
Low (< 95th percentile)	40.13 (23.93)	ref				0.66 (3.50)	ref			

ref = reference category

*Linear regression analysis for difference in vaccination coverage of one COVID-19 dose in those over 18 using county classification as having high or low percentages of population with limited English, who are minority, and who are foreign born as dependent variables for counties matched on percent rural, female, living below the poverty line, unemployed, with access to broadband internet, with high school diploma or equivalent, with some college education, and uninsured.

** Linear regression analysis for difference in one dose COVID-19 vaccination rate in those over 18 using county classification as having high or low percentages of population with limited English, who are minority, and who are foreign born as dependent variables for counties matched on percent rural, female, living below the poverty line, unemployed, with access to broadband internet, with high school diploma or equivalent, with some college education, and uninsured.