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IF YOU BUILD IT, WILL THEY VACCINATE? THE IMPACT OF COVID-19 VACCINE SITES ON VACCINATION RATES AND OUTCOMES

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ABSTRACT

Safe and effective vaccines have vastly reduced the lethality of the COVID-19 pandemic worldwide, but disparities exist in vaccine take-up. Although the out-of-pocket price is set to zero in the U.S., time (information gathering, signing up, transportation and waiting) and misinformation costs still apply. To understand the extent to which geographic access impacts COVID-19 vaccination take-up rates and COVID-19 health outcomes, we leverage exogenous, pre-existing variation in locations of retail pharmacies participating the U.S. federal government's vaccine distribution program through which over 40% of US vaccine doses were administered. We use unique data on nearly all COVID-19 vaccine administrations in 2021. We find that the presence of a participating retail pharmacy vaccination site in a county leads to an approximately 26% increase in the per-capita number of doses administered, possibly indicating that proximity and familiarity play a substantial role in vaccine take-up decisions. Increases in county-level per capita participating retail pharmacies lead to an increase in COVID-19 vaccination rates and a decline in the number of new COVID-19 cases, hospitalizations, and deaths, with substantial heterogeneity based on county rurality, political leanings, income, and race composition. The relationship we estimate suggests that averting one COVID-19 case, hospitalization, and death requires approximately 25, 200, and 1,500 county-level vaccine total doses, respectively. These results imply a 9,500% to 22,500% economic return on the full costs of COVID-19 vaccination. Overall, our findings add to understanding vaccine take-up decisions for the design of COVID era and other public health interventions.

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1. INTRODUCTION

Many goods and services outside of private markets are allocated through rule-based mechanisms (Hurwicz 1973). How these allocation mechanisms impact economic outcomes is critical to assessing their efficacy, in particular relative to alternative mechanisms or market-based allocation. Particularly relevant to the COVID-19 pandemic, the role of misinformation makes understanding the consumer demand for certain medical products challenging, absent exogenous variation in the cost of procuring the product. The availability of more vaccine administration sites within one's own county may increase familiarity, reduce take-up hassle, and improve the likelihood of accepting the service. Research from randomized experiments for other vaccines show that increasing outreach can improve vaccination rates (Nowalk et al. 2010). A meta-analysis on vaccination strategies found that increasing salience (reminders and recall systems) have been shown as effective in improving immunization rates (Vann et al. 2018). The COVID-19 pandemic offers an important and relevant context in which to assess these issues.

While COVID-19 vaccines have saved over one hundred thousand lives in the United States alone (Gupta et al. 2021; Steele et al. 2022), understanding factors that drive take-up of the vaccine is important to answering whether the protective effects of the vaccine were distributed equitably and efficiently. Unlike many other types of medical care, COVID-19 vaccines are allocated outside of private markets, at zero out of pocket costs, and through rule-based administration. As described in more detail in Section 2, the number of COVID-19 vaccine doses were allocated to jurisdictions[1] based on the number of people 18 years of age or older that lived in the jurisdiction in proportion to the entire U.S. population (Centers for Disease Control and Prevention 2021). To administer vaccines, the U.S. government primarily relied on retail pharmacies, hospitals, long-term care facilities, public health clinics, and skilled nursing facilities. Because pharmacy and hospital locations are limited in their geographic scope and driven by consumer demand and policy factors prior to the pandemic, relying on existing pharmacies and hospitals creates gaps in access to COVID-19 vaccines (Chevalier et al. 2021). This allocation design has led to discussion on optimal strategies going forward for COVID-19 vaccine and other vaccine distribution for the U.S., and the optimal design of vaccine allocation mechanisms in general (Press, Huisingh-Scheetz, and Arora 2021; Agarwal et al. 2021; Cole 2021; Guo et al. 2021; Więcek et al. 2022).

Despite zero out-of-pocket costs to patients, vaccine take-up has been slow and lower than complete, pointing to the importance of familiarity and proximity costs. Much anecdotal evidence also points to importance of misinformation. In a typical economic setting, misinformation is viewed as increasing demand beyond the realized benefits of a product (Glaeser and Ujhelyi 2010). However, COVID-19 misinformation has the opposite effect of decreasing demand of a beneficial product. Prior to this study, there was no way to empirically disentangle misinformation and access, and to know if familiarity or proximity explain a substantial amount of vaccination rates.

[1] A jurisdiction is defined as one of 50 states and the District of Columbia, 3 major cities (Chicago, New York City, and Philadelphia) or 8 territories (American Samoa, the Federated States of Micronesia, Guam, the Marshall Islands, the Northern Mariana Islands, Palau, Puerto Rico, and the U.S. Virgin Islands) (https://www.gao.gov/assets/gao-22-104457.pdf, p.13)

In this paper, we examine the effect of physical access to COVID-19 vaccination locations on both vaccination administration and COVID-19-related outcomes, including confirmed cases, deaths, and hospitalizations. We focus on variation in access to a common distribution channel for COVID-19 vaccines, retail pharmacies, and examine both the extensive-margin effect of having any participating retail pharmacy in a county and the intensive-margin effects of the per-capita number of pharmacies. Conceptually, we view individuals as making vaccination decisions based on perceived benefits vs. costs. Perceived costs are affected by familiarity and proximity. Exogenous increases to familiarity and proximity allow us to estimate the impact on vaccination, holding all else fixed.

In addition, while substantial clinical trial evidence demonstrates the efficacy of COVID-19 vaccines (Polack et al. 2020; Thomas et al. 2021; Falsey et al. 2021), their impacts outside of a clinical trial setting could be different for at least three reasons. First, some patients may not fully adhere to the multi-dose regimen examined in clinical trials, or patients may not receive their booster dose, which would reduce their immunity to infection (Forni and Mantovani 2021; Pal et al. 2021). Second, COVID-19 vaccines may have important externalities (Brito, Sheshinski, and Intriligator 1991; Philipson 2000; Boulier, Datta, and Goldfarb 2007; Carpenter and Lawler 2019). Vaccinated individuals are less likely than unvaccinated individuals to transmit disease to individuals in their community (Salo et al. 2021), thus externalizing the protective benefits of vaccination. Finally, because many patients experience side effects, blinding treatment randomization is challenging for COVID-19 clinical trials. Patients who effectively observe treatment assignment through the presence of side effects may change behaviors that reduce COVID transmission (Agrawal, Sood, and Whaley 2022).

An important empirical concern with attempting to examine the causal effect of site location on population vaccination rates is the potential that vaccine locations are determined endogenously based on both demand for vaccinations and the trajectory of the pandemic (Markowitz, Nesson, and Robinson 2019). Conceptually, having a vaccination site nearby reduces costs associated with familiarity and proximity to the COVID-19 vaccine. However, vaccine sites are generally not exogenous, as state and county health departments locate them where they are most likely to be attended or have the largest impact on vaccination rates. For example, workplaces are the most common locations for influenza vaccines (Singleton et al. 2005).

To address this concern, we leverage the types of facilities that were chosen to administer COVID-19 vaccines and the size of their allocations, using plausibly exogenous variation in pre-pandemic location of pharmacies of certain national chains that opted into the vaccine allocation program. Initial vaccines were targeted towards hospitals and long-term care facilities. Later, select retail pharmacies were eligible to receive and administer vaccines through the Federal Retail Pharmacy Program (FRRP) (The White House 2021). Important for our identification strategy, the decision was made at the national level, and then all existing locations of that pharmacy become outlets, allowing us to use study designs common in economics where national decisions have local variation because of existing locations.

The FRRP, which launched February 11, 2021, provides both distribution channels to vaccine locations and allows for consumers to view vaccine availability at each participating location through the Vaccines.gov website (initially vaccinefinder.org). Since its launch in February of 2021, this website received over 100 million unique page views. Importantly for our identification strategy, the majority of location choices of specific retail chain pharmacies within each state precede the COVID-19 pandemic. Initial COVID-19 vaccine pharmacy allocations began by distributing doses among the selected pharmacy partners based on each partner's number of stores and their reach, which was defined as the percent of the total U.S. population living within 5 miles of a store location (Government Accountability Office 2021). Prior to the COVID-19 pandemic, pharmacies and hospitals chose to locate where they perceive demand to be high, which creates substantial variation in access (Chevalier et al. 2021). In 2021, 45% of vaccines were administered in retail pharmacies participating in the program. Between April and July 2021, the proportion of vaccine doses distributed through the program increased from 29 percent to 92 percent (Government Accountability Office 2022). Beginning in June 2021, weekly allocations were based on vaccine availability and the demand for doses (Government Accountability Office 2021). Our identification strategy uses the location of the vaccine sites and follows similar approaches used to in pre-pandemic literature examine how access to health care providers impacts health outcomes (Swensen 2015; Deza, Maclean, and Solomon 2020; Horn, Joshi, and Maclean 2021).

A second empirical concern in estimating the impact of site location on COVID-19 outcomes is the lack of complete data on vaccination sites and allocations. Despite the importance of

COVID-19 vaccines, data on vaccine administrations, both locations and numbers, are not commonly available. We use restricted-use Centers for Disease Control and Prevention (CDC) inventory data on almost all COVID-19 vaccine administration sites in the United States.[2] This resource contains detailed inventory data from the CDC's Vaccine Tracking System (VTrckS) for entities ordering COVID-19 vaccines. For each vaccine location, we observe the location's full address, the type of provider (i.e., pharmacy, federally qualified health center [FQHC], hospital, etc.), the daily number of doses on hand for each vaccine (e.g., Pfizer, Moderna, and J&J). This data underlies the public facing vaccines.gov website used by vaccine locations to display their location and vaccine availability to the public. These data have been used previously to calculate geographic accessibility to COVID-19 vaccination locations (Rader et al. 2021).

Leveraging this data and the variation in vaccination site location and type of provider, we find that the extensive margin of simply having a vaccination site versus not within a county leads to an approximately 26% increase in the number of administered doses. For the intensive margin, an increase of one participating pharmacy per 10,000 residents leads to a 4.3% increase in weekly dose administrations. For COVID-19 outcomes, we find that the presence of a participating retail pharmacy leads to a 2.3 per 10,000-person reduction in the number of cases (11.7% relative decline) and a 0.4 per 10,000-person reduction in COVID-related hospitalizations (36.7% relative decline). An increase of one participating pharmacy per 10,000

[2] Not included vaccines are those not administered through the Vaccine Tracking System (VTrckS), which includes Indian Health Service and Bureau of Prisons providers.

residents leads to reductions of 0.6 per 10,000 persons in the number of confirmed COVID-19 cases (3.3% relative reduction), 0.06 in the number of COVID-related hospitalizations (5.8% relative reduction), and 0.01in the number of COVID-19 deaths (2.7% relative reduction).

When combining these first stage and reduced form results, we find that a 1,000 increase per 10,000 population (e.g., 10 percentage points) in the number of vaccination doses administered leads to an approximately 50, 5, and 0.5 per 10,000 person reductions in COVID-19 cases, hospitalizations, and deaths, respectively. Put differently, our results imply that to reduce COVID-19 cases by one per 10,000, 25 doses need to be administered; 192 doses for a one per 10,000 reduction in hospitalizations, and 1,429 doses for a one per 10,000 reduction in deaths. It is important to note that these estimates are not quantifying the effect of the first, second, or third dose of the vaccine. Using previous estimates of the statistical value of life years lost due to COVID-19 deaths (Robinson, Sullivan, and Shogren 2021; Ash et al. 2021), our mortality results imply a 9,500% to 22,500% economic return on the costs of COVID-19 vaccination.

To assess the robustness of our results, we examine differences based on county-level rurality (metropolitan vs. rural markets), political affiliation, and internet access, which could impact information channels to access the vaccines.gov site. We find both larger vaccine administration rates and impacts of access to participating retail pharmacies in metropolitan counties, counties in which President Biden won the majority of votes in the 2020 election, and in which the median megabits per second (Mbps) download and/or upload speed do not meet the Federal Communication Commission's (FCC) definition of high speed (Federal Communication

Commission 2021). We also find larger impacts in counties with higher visits to retail pharmacies in 2019, using cellphone mobility data to measure foot traffic to pharmacies.

This paper contributes to an important literature on COVID-19 vaccination strategies. Prior research finds that the distribution of vaccines disadvantages rural and medically vulnerable populations (Rader et al. 2021; Jean-Jacques and Bauchner 2021; Gertz et al. 2022). Most closely related to our study, Barro (2022) instruments for vaccination rates using Trump voter share and estimates a $55,000 cost to avert one COVID-19 death, which is comparable to our estimates. Our results add to this literature by quantifying the number of lives saved due to a common COVID-19 vaccine allocation policy. Our study also contributes to the broader economics literature on how to allocate goods outside of market-based mechanisms. Health care services are commonly allocated through public mechanisms (Besley and Coate 1991), although market forces often influence firm performance and outcomes (Chandra et al. 2016). Our study focuses on how market mechanisms that precede the pandemic, namely being located near customers, influences public provision of COVID-19 vaccines.

Section two provides an overview of COVID-19 allocation programs, Section three describes our data, and Section four explains our empirical approach. Section five presents our main results, Section six presents heterogeneity analyses, and Section seven concludes.

2. BACKGROUND ON COVID-19 VACCINE ALLOCATION

There were three key programs that the federal government used to allocate COVID-19 vaccines (U.S. Department of Health & Human Services 2020) once population-based quotas were determined at the jurisdiction level. First, the Federal Retail Pharmacy Program sent doses to 21 retail pharmacy partners that had approximately 40,000 active stores. Under this program, pharmacy partners vaccinate eligible individuals at no cost, and the pharmacy bills private and public insurance for the vaccine administration fee. Uninsured patients are reimbursed through the Health Resources and Services Administration (HRSA) Provider Relief Fund. According to a fact sheet circulated by the CDC in December 2020, pharmacy partners directly order and receive COVID-19 vaccines from the federal government. The pharmacy partners must report daily to CDC the number of doses of COVID-19 vaccine (a) ordered by store location in VTrckS, and (b) on hand in each store reported through VaccineFinder (Centers for Disease Control and Prevention 2020). As of February 9, 2022 an estimated 229.2 million COVID-19 doses have been administered by retail pharmacies through this program (Centers for Disease Control and Prevention 2022).

The second federal program, the Health Center COVID-19 Vaccine Program, is a partnership between HRSA and the CDC to provide vaccines to HRSA-funded health centers that specialize in caring for hard-to-reach and disproportionately affected populations (i.e., individuals experiencing homelessness, public housing residents, migrant/seasonal agricultural workers, patients with limited English proficiency, etc.). In the initial phase of the program, 250 health centers were invited to participate. As of April 7, 2021, there were around 1,470 health centers that were invited to participate. It is also important to note that this supply is separate from jurisdictions weekly allocations (Health Resources & Services Administration 2021a).

The third channel is the Rural Health Clinic COVID-19 Vaccine Distribution Program which sent COVID-19 vaccines directly to Rural Health Clinics in order to increase the availability of COVID-19 vaccines in rural communities. The purpose of the program was to increase both vaccine access and vaccination rates in underserved rural communities. The CDC and HRSA invited all Medicare-certified rural health centers to receive federal vaccine allocations separate from jurisdictions' weekly allocations (Health Resources & Services Administration 2021b). Several studies have examined if these allocation mechanisms lead to disparities in COVID-19 vaccine coverage. Previous studies find higher vaccination coverage in socially-vulnerable counties, but lower in rural counties (Hughes et al. 2021; Murthy et al. 2021; Saelee 2022). Other work uses data from Publix grocery stores, which were the first retail pharmacies to provide COVID-19 vaccinations in the state of Florida and finds vaccine locations were disproportionately placed in ZIP codes that were older, richer, and had a higher share of white residents (Attonito et al. 2021). Related to our study, Chevalier et al. (2021) evaluate the FRPP to understand disparities in vaccination access and find that the majority of Americans are located within five miles of a vaccination site, but lower-income households have lower proximity to partnering retail pharmacies. However, while this study looks at vaccine locations, it does not examine vaccine administrations or COVID-19 outcomes.

3. DATA

3.1. Vaccine Administration and Location Data

We acquired data on all COVID-19 vaccine sites that operated in the U.S during 2021 from Vaccines.gov. The data are a comprehensive, national vaccine system maintained by Boston Children's Hospital in collaboration with the CDC and Castlight Health. We assign each COVID-19 vaccine location to its county based on United States Department of Housing and Urban Development data (U.S. Department of Housing and Urban Development 2020). We then create a balanced panel at the county level, showing the presence of COVID-19 vaccine locations in each week during our study period. We create measures for the number of vaccine locations in each county, as well as a dichotomous measure for the presence or absence of a COVID-19 vaccine location in the county, in each week. In addition, we created the same measures for up to five weeks of lags.

The VaccineFinder database contains the number of doses on hand for each site reported per day. Doses administered are imputed as the difference between doses on hand each day and the day prior. Days with negative values (e.g., more doses on Tuesday than Monday) were considered "supply days" and excluded from analysis. This method allowed for the systematic exclusion of centralized warehouses reporting large dose quantities, but not administering doses to individuals. This approach may lead to underestimating total dose quantity administered in exchange for better capturing precise locations where doses are being administered.

We are unable to link vaccine administrations to individual patients or the home location of the vaccine recipient. Thus, we are unable to account for patients who travel from counties with low vaccine availability to counties with higher availability. As a result, our estimates of the health impact of vaccine administrations will not account for spillovers from individuals who are vaccinated in other counties. Thus, we would be underestimating the effect of having a COVID-19 vaccine location within a county by not completely capturing all individuals within the county who received a COVID-19 vaccine. These spillovers will conservatively bias our results.

We identify all vaccine locations in our dataset and categorize them by type of location (e.g., retail pharmacy, hospital, clinician office, etc.). As shown in Figure 1, both in absolute and relative shares, the main settings for vaccine administration are hospitals and retail pharmacies. The majority of vaccines are delivered in a retail pharmacy (45%) or a hospital (18%). Hospitals were the primary source of administration in the first months of the pandemic, but retail pharmacies soon surpassed them to become the primary administration location.

In Figure 2, we map the geographic distribution of counties without any participating COVID-19 vaccine locations during the pandemic, in both March 2021 (Panel A) and December 2021 (Panel B). While most counties have a location in both time periods, many counties, primarily in the Midwest, do not have a participating vaccine location throughout 2021. Figure 3 presents similar maps, but for participating retail pharmacies. When compare Figure 2 and Figure 3 we see that fewer counties have access to a participating pharmacy than any participating vaccination location. In addition, there is limited growth in the rates of participating pharmacies.

While these maps show the extensive margin level of access to any participating location, they do not inform intensive-margin access to participating locations. Figure 4 plots the share of counties with access to any participating vaccine location throughout 2021. We assume that no counties had access to any participating location prior to the February 2021 launch of Vaccines.gov. Following the launch, there was an immediate increase in the number of counties with any participating provider, and then limited extensive-margin growth during the rest of 2021. In Panel B, we plot the number of participating locations in each county and week per 10,000 residents. Unlike the slow extensive-margin growth following launch, we find steady intensive-margin increases in the number of participating locations. The intensive-margin growth rate is larger for non-pharmacy locations than for pharmacy locations.

3.2. CDC Vaccination Data

As an additional measure of vaccination, we use the per-capita cumulative number of individuals who have been fully vaccinated (e.g., received both Pfizer or Moderna doses, or a single dose of the Johnson & Johnson vaccine). To construct the fully vaccinated measure, we use restricted-use data from the CDC on county-level vaccination rates. This data also includes the number of people who have received one dose, as well as vaccination rates by age category. We also measure the share of 12-plus, 18-plus, and 65-plus individuals who have received both at least one dose and who have been fully vaccinated.

Compared to our measures of weekly vaccine doses administered, which represent the “flow” of vaccinations in each county, these vaccination measures represent the “stock” of vaccinated individuals. Because these vaccination measures are tied to the county of residence, they suffer from the opposite limitation as the vaccine administration data. Individuals who travel from their home county to a county with potentially more access to get vaccinated will not count in the receiving county's vaccination rate.

3.3. County-Level COVID Data

We also pulled data on the number of cumulative cases and deaths within each county originated from USAFacts. We then calculated the number of new COVID-19 cases and deaths in each week and county. These COVID-19 data have been commonly used in the literature to evaluate the effect of COVID-19 pandemic or pandemic-related policies (Cantor et al. 2022). We used the weekly number of COVID-19 hospitalizations in each county using data from the Department of Health and Human Services (U.S. Department of Health and Human Services 2021).

3.4. County-Level Characteristics Data

We downloaded data on the county's urbanicity from the National Center of Health Statistics (Centers for Disease Control and Prevention 2017), and 2020 presidential election results from the MIT Election Data and Science Lab (MIT Election Data and Science Lab 2021). From USAFacts we also acquired the county's population (USAFacts 2020). We quantify internet broadband coverage, by downloading data from the FCC. Their definition of high-speed, or broadband, internet is having a minimum download speed of 25 Mbps and minimum upload speed of 3 Mbps (Federal Communication Commission 2021). If the county did not meet the median Mbps download and/or upload speed, they were classified as having insufficient broadband access.

3.5. SafeGraph Mobility Data

To measure pre-COVID consumer demand and preferences for pharmacies, we also use cellphone-based mobility data provided by SafeGraph to measure pre-COVID foot traffic to retail pharmacies. This data has been used to measure changes in mobility during the COVID-19 pandemic in several studies (Allcott et al. 2020; Goolsbee and Syverson 2021; Cantor et al. 2022; Bravata et al. 2021; Cantor et al. 2021). We identified the total number of visits to pharmacies in each week for 2019. We identified pharmacies in the SafeGraph data based on their North American Industry Classification System code (four-digit code 4461). Across counties, we construct a measure of standardized visits per 10,000 residents to retail pharmacies in week of 2019, which we calculate using the *z-score* of county-level pharmacy visits.

4. ESTIMATION APPROACH

4.1. Difference-in-Differences Effect of Access to Vaccination Facilities

To estimate the effect of access to vaccination locations on COVID-19 outcomes, we leverage the variation in geographic access to vaccination sites. We first estimate the two-way fixed effect model described in equation (1), which reveals the relationship between each county's COVID-19 number of vaccines administered, number of new cases, number of COVID-19-related hospitalizations, and the number of new deaths predicted by the number of COVID-19 vaccination sites. To adjust for differences in county population, all outcomes are per-10,000 population. We estimate the following regression specification:

$$y_{ct} = \alpha + \alpha_c + \alpha_t + \partial Facility_{ct} + \varepsilon_{ct} \quad (1)$$

In this model, y_{ct} represents the outcomes of interest in county c and week t—weekly doses administered, the share of the population that is fully vaccinated, new COVID-19 cases, and new COVID-19 deaths. To control for time-invariant differences between counties and general time trends in vaccination rates during the pandemic, we include county and week fixed effects, α_c and α_t. The county fixed effects control for time-invariant county characteristics that may be correlated with each of our outcome measures. For example, there are differences in vaccination rates based on the urbanicity of the county and on the political leaning of the county (Sun and Monnat 2021; Ye 2021; Barro 2022). The week fixed effects are to control for time-varying shocks and changes in the national COVID-19 policy. We cluster all standard errors at the county-level.

Our key treatment variable, $Facility_{ct}$, captures actively-participating vaccination sites in county *c* and week *t* that have vaccine inventory in that week. We likewise adjust this measure to per 10,000 population. In a sensitivity test, we also estimate models with a binary outcome of the presence of a vaccine administration site. We also used the vaccine distribution data to estimate a sensitivity test that uses the number of vaccines per 10,000 allocated to each site. However, we note that this measure is potentially endogenous to unobserved vaccine demand. When estimating the relationship between vaccine access and vaccines administered, we use the contemporaneous number of facilities in the county and week. To account for the incubation period of the SARS-CoV-2 virus, we use a two-week lag period between the number of facilities and COVID-19 cases (McAloon et al. 2020), a three-week lag period for COVID-related hospitalizations, and a four-week lag period for COVID-19 deaths (Irons and Raftery 2021). The main coefficient of interest, ∂, quantifies how a county's COVID-19 vaccination rate, number of COVID-19 cases, number of hospitalizations, and number of COVID-19 deaths differs from the national weekly average, due to the per-capita number of COVID-19 vaccination sites within that county.

To have a causal interpretation, our model requires several assumptions. Most importantly, we assume that the *ex-ante* location of vaccination sites is not related to the future trajectory of the pandemic. For example, if vaccination sites were selected based on where cases or COVID-19 incidence was highest, then any increase in vaccination rates could reflect greater demand for vaccines, and reductions in cases or deaths could represent reversion in the trajectory of the pandemic. As described above, this concern is limited by the rules that governed vaccine facility choice.

A related concern is that places with higher COVID-19 incidence or differential exposure to the pandemic differ along socioeconomic or other grounds (Almagro and Orane-Hutchinson 2022; Benitez, Courtemanche, and Yelowitz 2020; Alsan, Chandra, and Simon 2021). These same differences (e.g., income) also likely influence location choices for retail pharmacies. However, these forms of time-invariant differences between markets are controlled for in the county fixed effects. As long as the COVID-19 pandemic does not change the composition of counties (e.g., lead to time-varying changes between counties) *and* these changes do not influence location choices of retail pharmacies, our identification assumptions should not be threatened.

As a robustness test to alleviate concerns that there are other causes for the relationship, we also include regression models that include state-by-week fixed effects. The state-by-week fixed effects are used to control for state-specific shocks. For example, differences in the trajectory of the COVID-19 pandemic across states, changes in economic conditions that may influence the opening or closing of retail pharmacies, and week-to-week changes in state-level COVID-19 vaccination rules. As an additional robustness test, we leverage the SafeGraph mobility data described above to examine differential impacts based on pre-COVID-19 retail pharmacy mobility patterns.

4.2. Effect of Vaccination Rates on COVID-19 Outcomes

The above models estimate the impact of vaccination locations on COVID-19 vaccinations and outcomes. As an additional test, we use the variation in vaccination locations to estimate the effect of county-level vaccination rates on COVID-19 cases and deaths. Using the presence of a vaccination location in a county, equation (1) above represents both a first stage regression when using vaccination rates as the outcome and a reduced form regression when using COVID-19 cases and deaths as an outcome. We pair these to estimate the effect of vaccination rates ($vaccine_{ct}$) on COVID-19 outcomes (cases, hospitalizations, and deaths), using the presence of a vaccination site in a county as an instrument for vaccination rates:

$$vaccine_{ct} = \alpha + \alpha_c + \alpha_t + \partial Facility_{ct} + \varepsilon_{ct} \quad (2)$$

$$y_{ct} = \alpha + \widehat{vaccine}_{ct} + \alpha_c + \alpha_t + \varepsilon_{ct} \quad (3)$$

This approach isolates the portion of vaccination distributions that are due to exogenous locations and requires the standard instrumental variable assumptions. First, variation in vaccine locations must drive differences in vaccination rates. As described below, the presence of a vaccination site is associated with large differences in vaccination rates. The *F-statistic* on our first stage regressions are above conventional thresholds (Stock and Yogo 2005). More challenging are the exclusion restriction assumptions discussed above. If vaccine locations are allocated on either unobserved demand for vaccinations or the underlying trajectory of the pandemic, then our instrumented results will yield biased estimates of the effect of vaccines on COVID-19 cases and deaths. Our identification relies on the same assumption that retail pharmacy location choices are not made based on consumer demand for COVID-19 vaccines.

Our two-way fixed effects approach does not capture the optimal time period between vaccination rates and COVID-19 outcomes. As an additional sensitivity test, we include lags of vaccination rates in the four weeks prior. Because our vaccination rates are cumulative, lagged vaccination rates are highly correlated with current vaccination rates. We estimate the IV model using Two-Stage Least Squares (2SLS). As in our two-way fixed effects approach, we include county and time fixed effects and cluster standard errors at the county level.

5. RESULTS

5.1. Effect of Access to Participating Retail Pharmacies on COVID-19 Vaccinations

We first present results from our first-stage regressions that measure the effect of access to vaccination sites on the number of vaccine doses administered per-10,000 persons in a county and the per-capita number of people who have received at least one dose. As shown in Panel A of Table 1, we find that the extensive margin treatment having a participating pharmacy location in a county leads to a 55 per 10,000 person increase in the number of vaccinations doses administered each week (e.g., a 0.55 percentage point increase). In columns 3 and 4, the intensive margin treatment of an additional vaccine location per 10,000 persons leads to an approximately 10 per 10,000 person increase in the weekly number of administered doses. Relative to mean per-capita 2021 vaccine dose rates (201 doses per 10,000), these increases translate to approximately 27% and 5% increase in vaccination administrations.

Panel B presents the similar effect of access to participating retail pharmacies on the total number of individuals who have been vaccinated in a county. Unlike the number of doses administered, which could include individuals who have traveled across counties, vaccination rates are specific to individuals in a given county. Similar to doses administered, we find that the extensive margin treatment of having a participating retail pharmacy located in a county leads to a 265 per 10,000 person increase in the number of people who have received at least one dose. The magnitude of this extensive-margin effect decreases to 160 per 10,000 persons when including the state-by-week fixed effects, which corresponds to a 6% weekly increase in the number of county residents with at least one vaccine dose. When looking at the intensive margin treatment and including the state-by-week fixed effects (column 4), we find an increase of one participating retail pharmacy per 10,000 residents leads to a 68-per 10,000 person increase in the number of residents with at least one dose.

In Table 2, we test for non-linear responses in the number of per-capita participating retail pharmacies and vaccine administrations. Among counties with any participating pharmacy, we categorize the per-capita number of pharmacies into quartiles, with the first quartile of 2.2 per 10,000, the second quartile of 3.3 per 10,000, the third quartile as 4.5 per 10,000, and all greater than as the fourth quartile. Consistent with a dose response mechanism, we find that, relative to counties with no participating retail pharmacies, counties with more per-capita participating retail pharmacies have higher weekly per-capita vaccine administrations and individuals who have received at least one dose. When including the state-by-week fixed effects, we find a 89-per 10,000 increase in weekly vaccination doses among counties in the highest quartile of participating retail pharmacies, and a 452 per 10,000 increase in the number of individuals who have received at least one dose.

Combined, these results show an extensive-margin effect of having any participating retail pharmacies in a county and a larger intensive-margin effect of having more per-capita pharmacies on COVID-19 vaccinations. In Table 3, we find similar intensive and extensive margin effects when using the share of individuals who have received a single dose and who have been fully vaccinated. We find larger effects among individuals above age 65, suggesting that access to retail pharmacies leads to increased vaccination rates among high-risk populations.

5.2. Effect of Access to Participating Retail Pharmacies on COVID-19 Outcomes

In Table 4, we report our reduced form results that assess the effect of access to participating pharmacies on COVID-related outcomes. In columns 1 and 2, we find that having a participating pharmacy location in a county leads to a 2.3 per 10,000 person reduction in confirmed cases (with a two-week lag). A one-pharmacy increase per 10,000 persons leads to a 0.6 per 10,000 decrease in cases. Relative to 2021 mean infection rates of 19.6 per 10,000 these coefficients translate to 11.7% and 3.3% relative reductions in cases, respectively.

Columns 3 and 4 present similar results, but for COVID-related hospitalizations. For hospitalizations, participating pharmacies are estimated with a three-week lag. Having a participating pharmacy in a county reduces hospitalizations by 0.4 per 10,000, while a one-per 10,000 population increase in the number of participating pharmacies leads to a 0.07 per 10,000 reduction. Relative to mean 2021 hospitalization rates of 1 per 10,000, these results translate to 36.7% and 5.8% relative reductions. We find similar results for confirmed COVID-19 deaths in 6, but the “any pharmacy” result in column 5 is not statistically significant. For deaths, we use a four-week lag period. A one pharmacy per 10,000 population increase leads to a 0.01 per 10,000 reduction in weekly COVID-19 deaths in that county, which translates to a 2.7% relative decrease.

In Table 5, we find similar evidence of a dose response relationship, with counties in the top quartiles of per-capita participating pharmacy locations having larger reductions in COVID-19 cases, hospitalizations, and deaths. However, the dose response relationship is weaker than in the first stage, suggesting that a primary mode of expanded access to vaccine locations is an increased use of COVID-19 vaccines.

5.3. Effect of COVID-19 Vaccinations on COVID-19 Outcomes

The results in Table 6 combine the first stage and reduced form results to estimate the effect of COVID-19 vaccine administrations on COVID-19-related outcomes. Panel A use the endogenous COVID-19 treatment of the weekly number of vaccines administered, while Panel B uses the cumulative number of fully vaccinated individuals, per-10,000. In columns 1 through 3, we estimate the effect of vaccines delivered in the past two weeks on COVID cases. Column 1 presents Ordinary Least Squares (OLS) results, while column 2 instruments for each vaccination measure using the lagged binary presence of a participating pharmacy, and column 3 uses the lagged number of participating pharmacies as an instrument. As in the reduced form results, vaccination lagged.

In the OLS results (column 1), we find no association between lagged vaccine administrations and COVID cases, and a 0.2 percentage point association between the per 10,000 number of people vaccinated and per-10,000 confirmed cases. When instrumenting, we find that a one per 10,000 increase in vaccines administered leads to a 0.4 to 0.6 per 10,000 reduction in confirmed cases. In Panel B, we estimate that a 100 per 10,000 increase (e.g., one percentage point) in the number of fully vaccinated individuals leads to a 0.8 per 10,000 reduction in the per-10,000 number of cases. These results imply that the number of vaccine administrations needed to reduce one confirmed case ranges from 18 to 25, while the number of fully vaccinated individuals needed to reduce one case ranges from 126 to 131.

Columns 4 through 6 present similar results for COVID-related hospitalizations. We again find no association in the OLS results in Panel A, and a small relationship in Panel B. When instrumenting, we find a 0.006 to 0.005 per 10,000 reduction in weekly hospitalizations for the doses administered measure. When looking at fully vaccinated individuals (Panel B), we find a 0.5 to 0.6 per-10,000 reductions following a 1 percentage point increase in vaccinations. These results imply 156 to 192 vaccine administrations are needed to achieve a one-unit reduction in hospitalizations and 758 to 1,282 fully vaccinated individuals are needed to reduce one COVID-19 case.

For COVID-19 deaths (columns 7 through 9), we find a small reduction in both OLS results. When instrumenting for the per-capita number of participating pharmacy locations, we find that a one-unit increase in vaccine administrations leads to a 0.0007 reduction in deaths. We likewise find that a one percentage point increase in the number of fully vaccinated individuals leads to a 0.01 reduction in COVID-19 deaths. These reductions translate to one COVID-19 death averted per 1,429 vaccine administrations and 9,091 fully vaccinated individuals.

In Table 7, we find similar results when using the share of individuals who have either received a single dose or who have been fully vaccinated. Importantly, these measures also allow us to examine differences in population-level vaccination effects by the age composition of vaccinated individuals. When looking at effects on confirmed COVID-19 cases (Panel A), we find that a one percentage point increase in the share of individuals who have received a single dose leads to a 50 per 10,000 reduction in cases, while a one-percentage point increase in the share fully vaccinated leads to a 76-per 10,000 reduction in cases. We interpret this as a single dose leads to roughly two-thirds the reduction in cases as full vaccination. Also importantly, the share of vaccinated, either partial or full, individuals ages 65 or older accounts for approximately 80% of the estimated reduction in cases.[3]

We find similar effects when examining COVID-19 hospitalizations (Panel B) and deaths (Panel D). A one percentage point increase in the share of partially vaccinated individuals leads to a 5 per 10,000 reduction in hospitalizations and a 0.7 per 10,000 reduction in COVID-19 deaths. For the share of fully vaccinated individuals, the respective reductions are 8 and 1. As with cases, approximately 80% of the reductions are driven by vaccination among the 65+ population.

6. HETEROGENEITY BASED ON COUNTY CHARACTERISTICS

Our main results are across counties, but important differences in both access to retail pharmacies, other vaccination sources, and COVID-19 care exist. To examine potential sources of heterogeneity, we examine differences in both our first stage and reduced form results, based on county-level characteristics. We include county rurality (metropolitan vs. rural), political leanings (Biden vs. Trump won 2020 vote), high-speed internet access (county has high speed vs. county does not have high speed), race composition (above vs. below median white/non-white race), income (above vs. below median income), and 2019 foot traffic visits to retail pharmacies.

[3] We are unfortunately unable to measure age-specific COVID-19 outcomes.

Table 8 presents heterogeneity in our first-stage estimates. In Panel A, we do not find consistent differences in the first stage effect of access to participating retail pharmacies on the weekly number of COVID-19 vaccine doses administered. The primary exception is for counties above median income, where we find an additional 7.7 per 10,000 weekly vaccinations. However, in Panel B, we find meaningful differences for the per-capita fully vaccinated population. We find 135.7 and 19.6-per 10,000 reductions in the number of fully vaccinated individuals in rural counties and counties won by Trump. We also find lower vaccination rates in higher-income counties. On the other hand, among counties with high-speed internet access and above the median share of white residents, the effect of per-10,000 participating pharmacy locations on the per-10,000 fully vaccinated population is 101.9 and 82.1 higher, respectively. We do not find a strong relationship between 2019 foot traffic visits to retail pharmacies and weekly doses, but do find a one standard deviation increase in foot traffic leads to an additional 25.7 per 10,000 reduction in the number of fully vaccinated individuals (per 10,000) for every participating retail pharmacy.

Table 9 presents similar differences for the reduced form outcomes—COVID-19 cases, hospitalizations, and deaths. In Panels A, and C, we find corresponding differences for confirmed COVID-19 cases and deaths. However, as shown in Panel B, we find less consistent evidence of heterogeneity in the effect of access to participating retail pharmacies on COVID-19 hospitalizations. Relative to metropolitan areas, a one per 10,000 population increase in participating retail pharmacies leads to a 0.4 per 10,000 increase in cases and a 0.02 per 10,000 increase in deaths. In other words, the health effects of access to participating retail pharmacies are lower in rural counties than in metropolitan counties. We find larger differences based on political leanings, with counties won by Trump showing 0.7 and 0.03 per 10,000 increases (e.g., reduced effectiveness) in COVID-19 cases and deaths relative to counties won by Biden, respectively. We also find 1.4 and 0.02 per 10,000 increases in COVID-19 cases and deaths among counties with an above-median share of white residents. On the other end, we find reductions of 0.3 and 0.02 per 10,000 among counties with high-speed internet. Finally, we also find additional 0.1 and 0.02per 10,000 reductions in COVID-19 cases and deaths for every standard deviation increase in 2019 foot traffic to retail pharmacies.

7. DISCUSSION

Considerable attention has focused on ensuring the equitable distribution of COVID-19 vaccinations throughout the United States (Jean-Jacques and Bauchner 2021), and prior work has indicated unequal distributions (Rader et al. 2021). Transaction costs and familiarity also matter for demand for otherwise free vaccines. Understanding drivers of the demand for vaccines is especially important for future policy aims in vaccination campaigns, and in preventive health more broadly, especially in the face of misinformation affecting patient demand for vaccinations. It is also important to understand the demand for COVID-19 vaccines given the Biden administration will soon cease paying for COVID-19 vaccines and consumers will have to rely on their healthcare provider to receive one at cost (Goodman 2022).

Because retail pharmacy locations were determined both before and independent of the COVID-19 pandemic, (and therefore, likely exogenous to COVID-19 outcomes and demand for vaccines). We use the location of retail pharmacies that participated in one of the largest COVID-19 vaccine distribution programs to estimate the causal impacts of COVID-19 vaccination on “real world” COVID-19 outcomes. We quantify the impact of a COVID-19 vaccine location placed in a county on the local vaccination rate, and the number of new COVID-19 cases, hospitalizations, and deaths. We find that having a COVID-19 vaccine location in the county has a large effect on each of these outcomes. In addition, we find that reducing one COVID-19 case, hospitalization, and death, requires approximately 25, 200, and 1,500 vaccines, respectively.

To place these results in additional context, over the course of 2021, the Medicare system has paid $2.32 billion for 70.7 million COVID-19 vaccine doses, a reimbursement rate of $32.85 per dose (CMS 2022). Our results imply an economic cost of $46,929 ($32.85 multiplied by 1,429 required doses to avert one COVID-19 death). Other studies have estimated a statistical-value of life of each COVID-19 death ranging from $4.5 million to $10.6 million (Robinson, Sullivan, and Shogren 2021; Ash et al. 2021). Thus, our results imply a 9,500% to 22,500% economic return on the costs of COVID-19 vaccination. Importantly, this estimate only includes the mortality reduction effects. While larger in importance, COVID-19 mortality is less frequent than COVID-19 infection and hospitalizations, which are not accounted for in this calculation. Other work also finds that COVID-19 vaccination leads to sizable secondary health benefits and reductions in depression and anxiety (Agrawal et al. 2021; Nguyen et al. 2021; Perez-Arce et al. 2021).

This study has limitations. First, while the COVID-19 pandemic has had a disproportionate impact on communities of color and vulnerable populations, we are unable to examine the effect of presence or absence of a COVID-19 vaccination site broken down by individual sociodemographic characteristics. However, recent work finds that completion of the COVID-19 vaccination regimen differs by the individual's income, occupation, race, age and insurance (Gertz et al. 2022; Baker et al. 2022). Second, there were notable logistic issues in the distribution of COVID-19 vaccines (Pambudi et al. 2022). For example, some of the vaccines required cold storage temperature. Unfortunately, we are not able to control for these logistical issues. Future studies should incorporate this information in their estimation strategies. Third, our study used county-level measures for COVID-19 vaccination locations and vaccination rates. However, there is no requirement that an individual who resides in a particular county receives a vaccination within the same county. Fourth, treatments for COVID-19, such as monoclonal antibodies, are distributed by the federal government based on the number of individuals hospitalized with COVID-19 (Assistant Secretary for Preparedness and Response 2021). Sites that can administer these treatments are unevenly unallocated throughout the U.S. (Rader et al. 2022). We do not adjust for the presence or absence of these locations in our regression models. Finally, while the use of openings and closings is common in the economics literature, there are persistent concerns of endogeneity given that openings and closings are not random (Swensen 2015; Currie et al. 2015; Alexander, Currie, and Schnell 2019; Corredor-Waldron and Currie 2021).

Despite these limitations, our study offers important results on the effect of COVID-19 vaccine distribution program on COVID-19 outcomes. We find that the location of a COVID-19 vaccine distribution site and the intensive-margin number of distribution sites have important effects on county-level COVID-19 vaccination rates, as well as the number of COVID-19 cases, hospitalizations, and deaths. Policymakers can use these results to inform vaccination distribution and plans for future COVID-19 variants as well as future public health emergencies.

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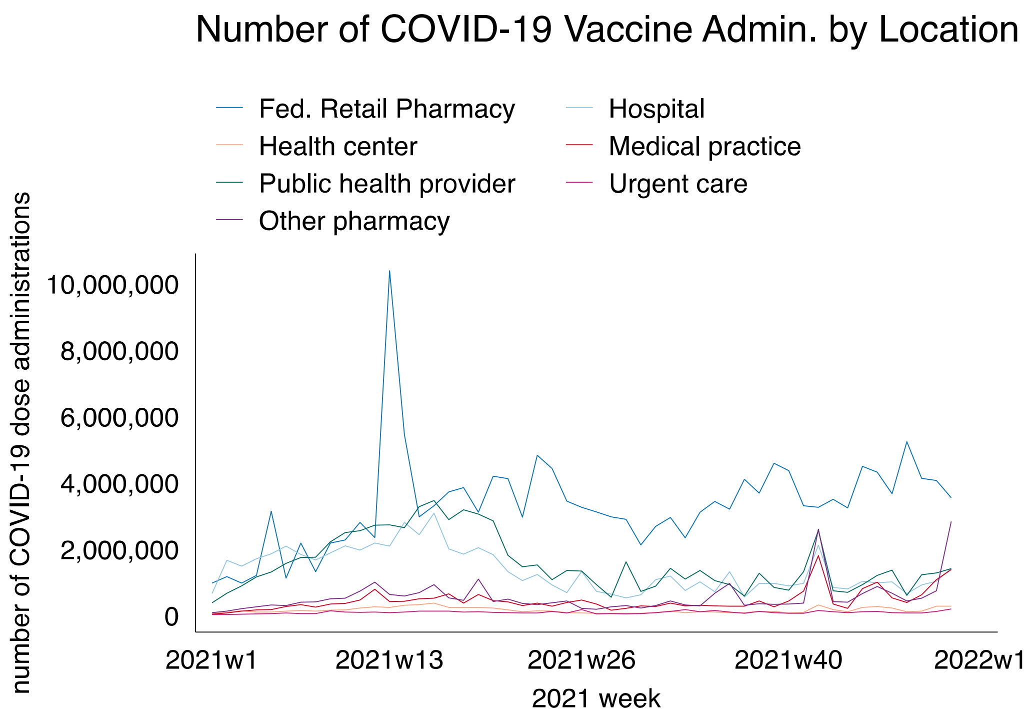
TABLES AND FIGURES

Figure 1: Vaccine Administrations by Participating Location Sites

(B) Number of Vaccines



(B) Share of Vaccines

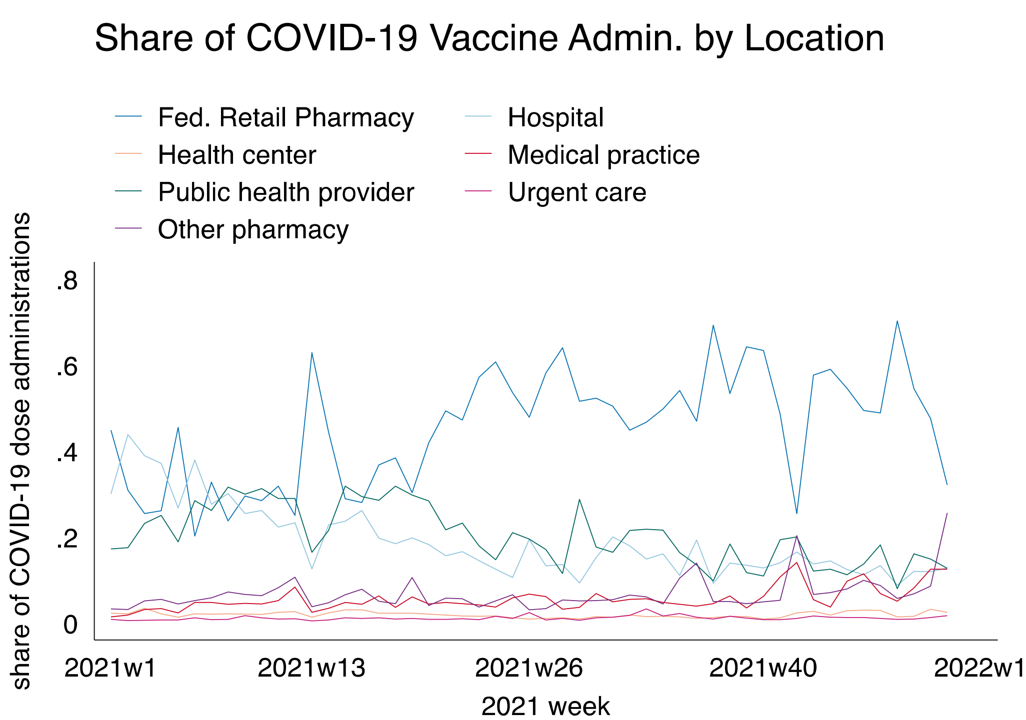
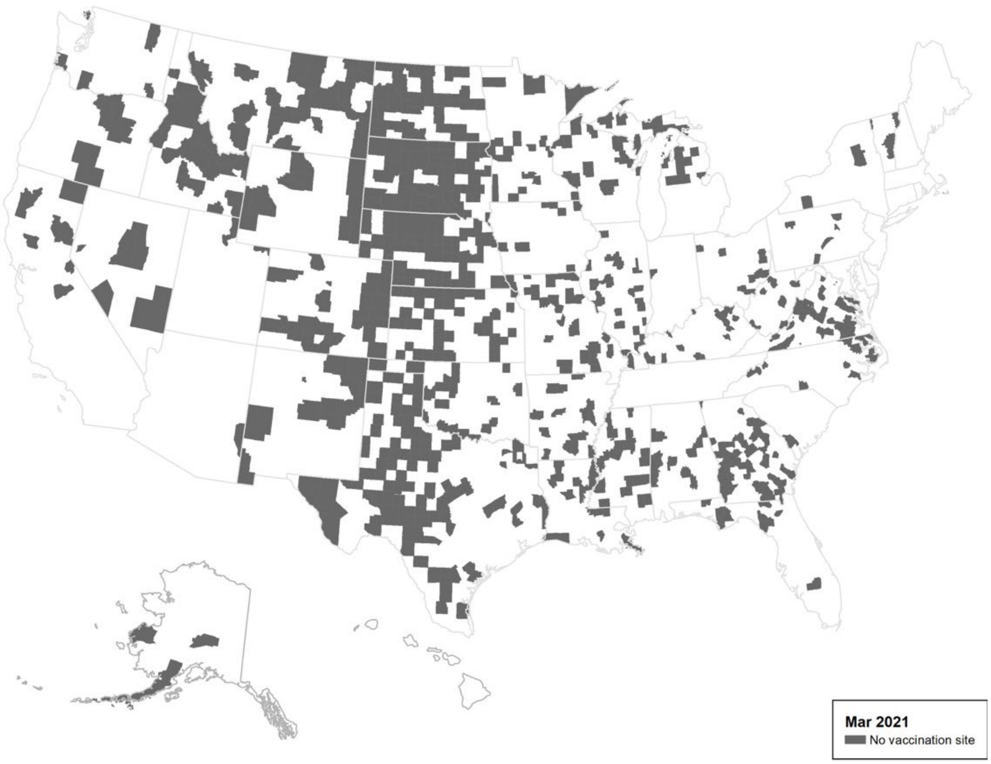


Figure 2: Geographic Distribution of Participating Vaccine Locations

(A) March 2021



(B) December 2021

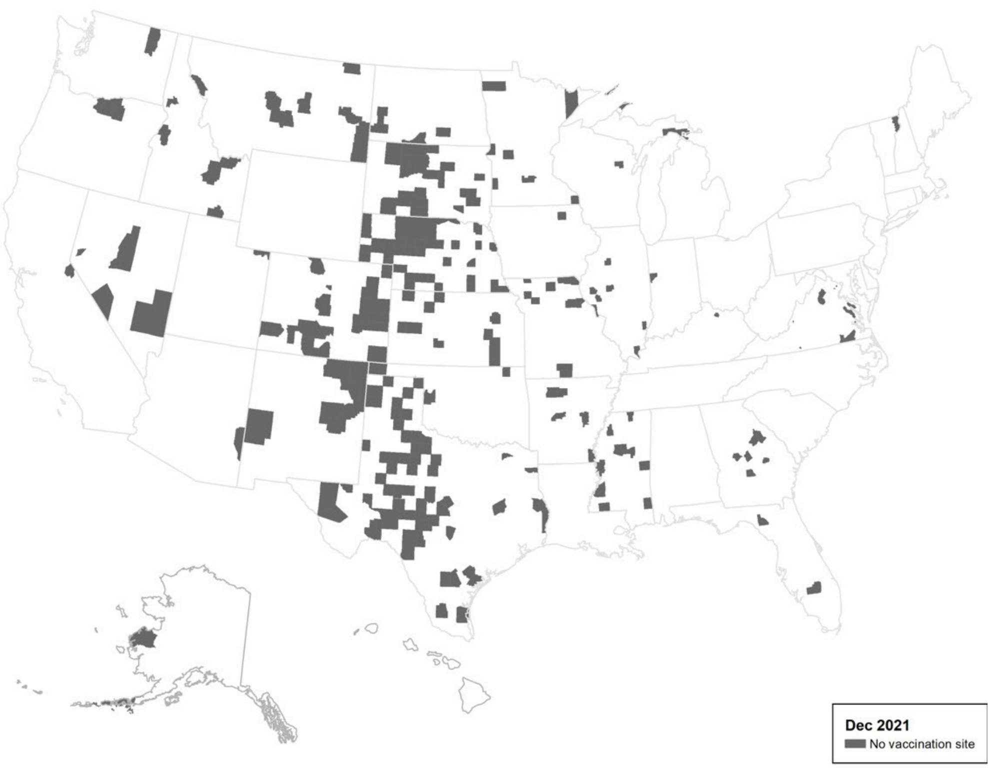
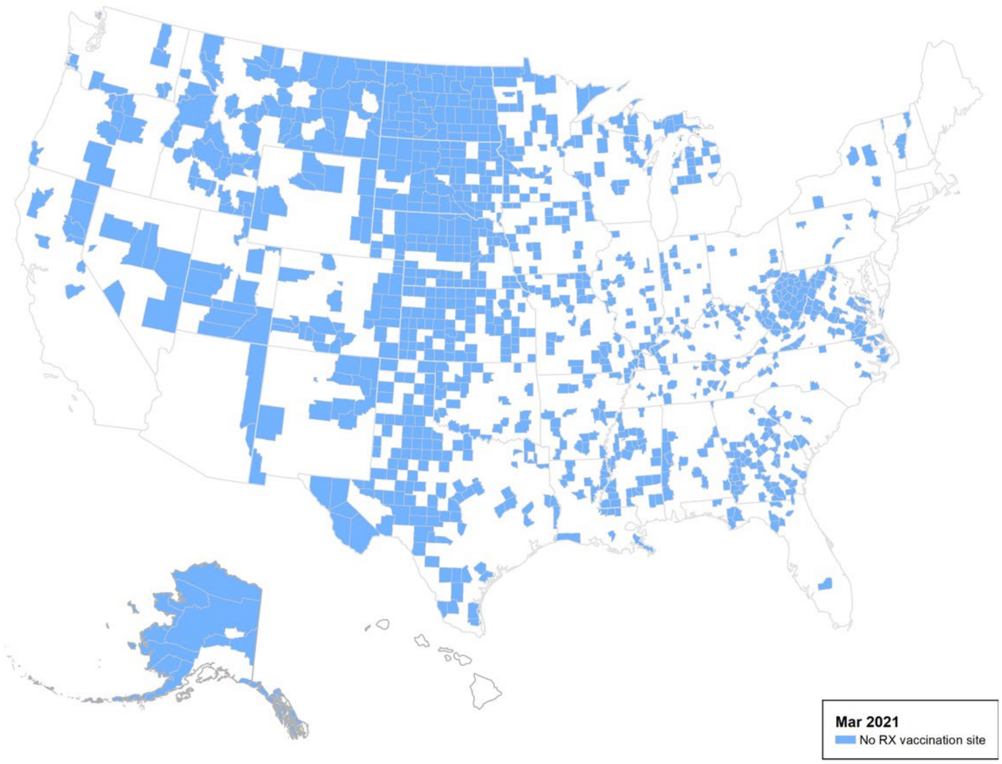


Figure 3: Geographic Distribution of Participating Retail Pharmacy Vaccine Locations

(A) March 2021



(B) December 2021

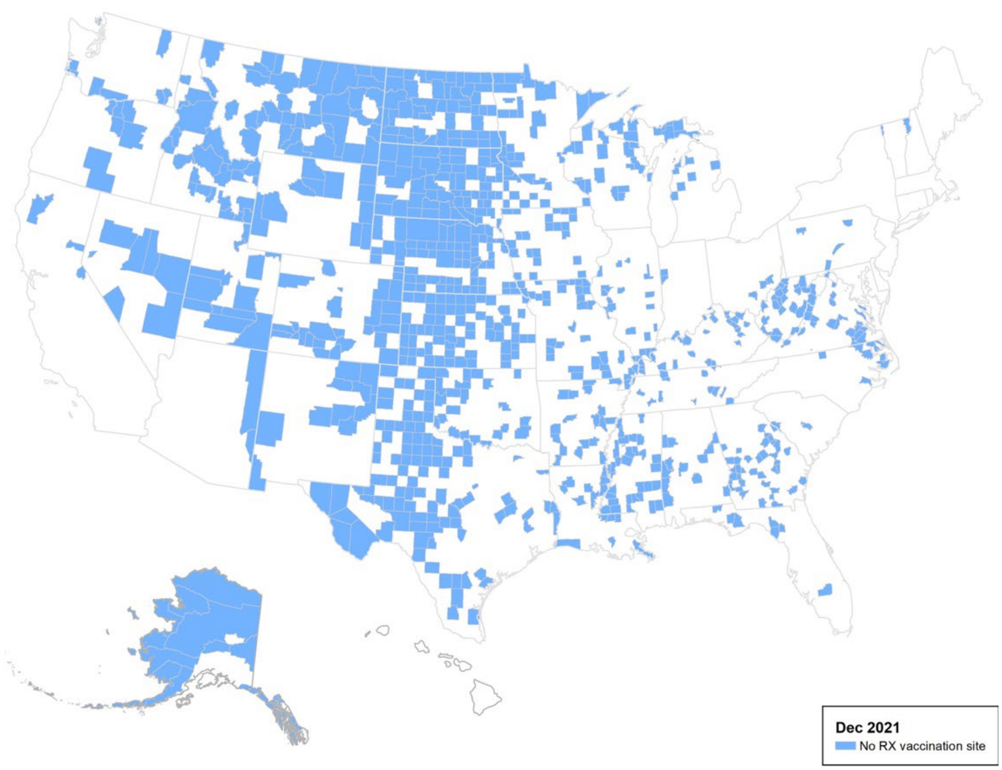
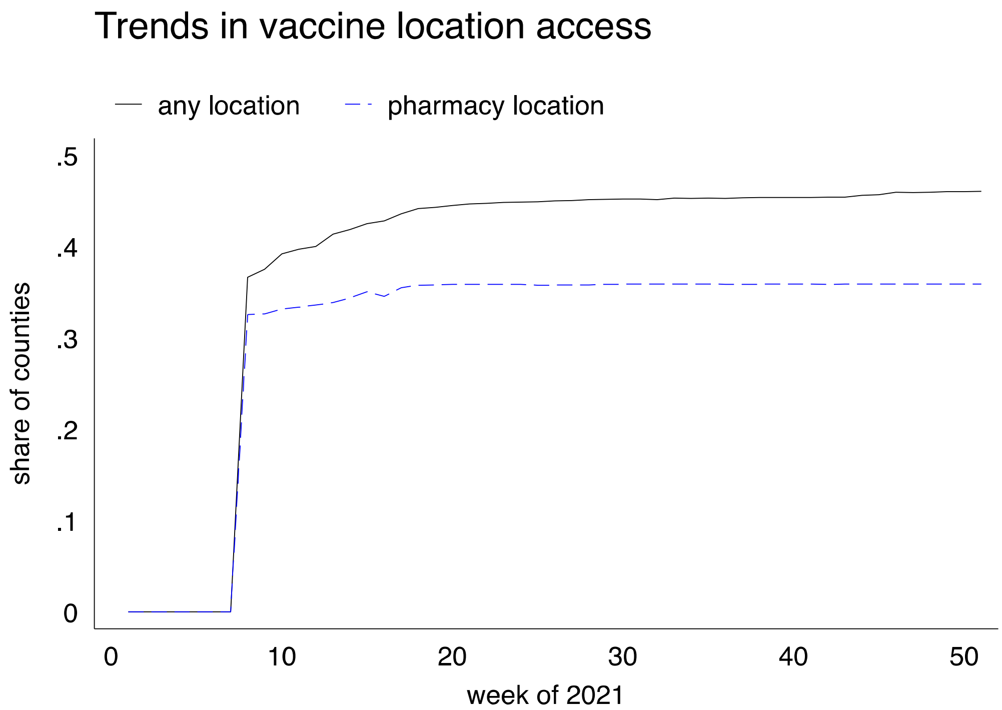


Figure 4: Trends in Vaccine Location Access

(A) Any Vaccine Location in County



(B) Per-Capita Number of Vaccine Location

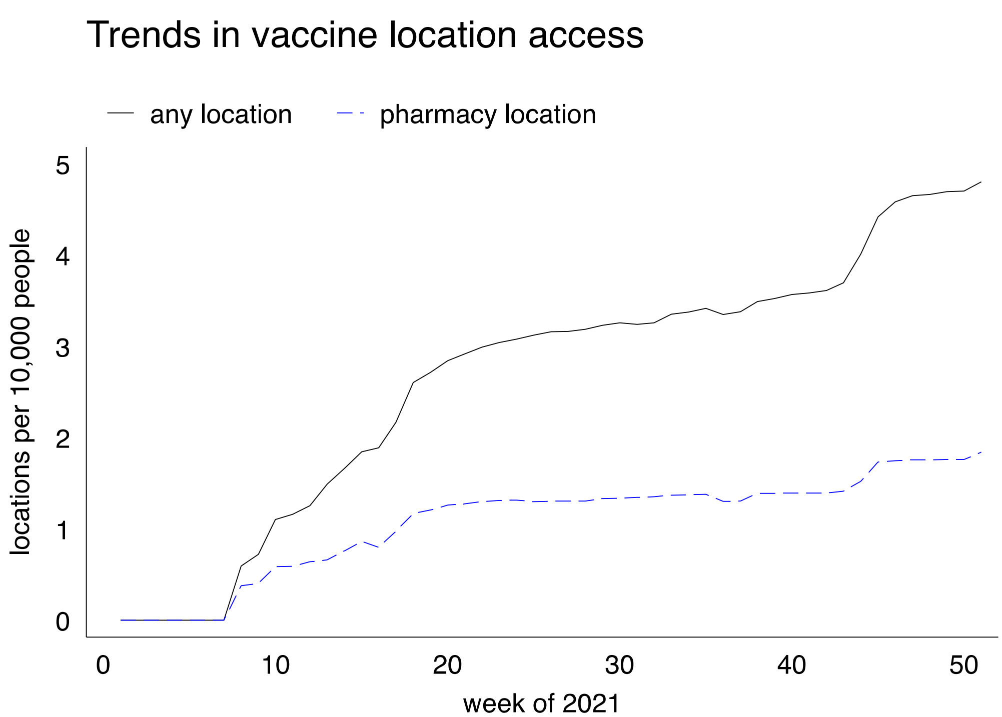


Table 1: First Stage Results: Effect of Pharmacy Vaccine Locations on COVID-19 Vaccination

	(1)	(2)	(3)	(4)
Panel A: Vaccines administered per 10,000 population				
Any pharmacy location	55.26***	52.64***		
	(15.06)	(16.46)		
Pharmacy locations per 10,000			10.21***	8.643**
			(3.374)	(3.729)
2021 mean	201.4	201.4	201.4	201.4
Relative change	27.4%	26.1%	5.1%	4.3%
Panel B: Number vaccinated per 10,000 population				
Any pharmacy location	264.8***	159.9***		
	(39.42)	(28.76)		
Pharmacy locations per 10,000			84.81***	68.21***
			(10.49)	(8.868)
2021 mean	2,684.28	2,684.28	2,684.28	2,684.28
Relative change	9.9%	6.0%	3.2%	2.5%
State x week FE		X		X

This table presents the first stage results that measure the effects of any participating retail pharmacy in a county and the per-10,000 number of pharmacies on per-capita COVID-19 vaccine doses administered and vaccination rates. Each regression includes county and week fixed effects. Columns 2 and 4 add state-by-week interaction fixed effects. Standard errors clustered at the county level. *** p<0.01, ** p<0.05, * p<0.1

Table 2: Effect of Quartiles of Pharmacy Vaccine Locations on COVID-19 Vaccination

	(1)	(2)	(3)	(4)
	Weekly doses per 10,000		**Number of people with at least one dose per 10,000**	
1st quartile of pharmacy locations per 10,000	26.64*	27.48**	23.02	-16.13
	(14.15)	(13.92)	(36.61)	(25.97)
2nd quartile of pharmacy locations per 10,000	48.24***	49.20***	235.6***	132.1***
	(17.23)	(18.62)	(43.71)	(30.38)
3rd quartile of pharmacy locations per 10,000	79.70***	77.84***	420.7***	309.6***
	(24.40)	(27.81)	(48.16)	(34.54)
4th quartile of pharmacy locations per 10,000	90.46***	88.76***	578.0***	452.2***
	(22.24)	(24.92)	(52.40)	(40.22)
Observations	160,242	160,191	160,242	160,191
R-squared	0.027	0.045	0.873	0.961
State x week FE		X		X

This table presents the non-linear first stage results that measure the effects of the per-10,000 number of pharmacies, which is categorized into quartiles, on per-capita COVID-19 vaccine doses administered and vaccination rates. Each regression includes county and week fixed effects. Columns 2 and 4 add state-by-week interaction fixed effects. Standard errors clustered at the county level. *** p<0.01, ** p<0.05, * p<0.1

Table 3: Effect of Pharmacy Vaccine Locations on COVID-19 Vaccination by Age Group

	(1)	(2)	(3)	(4)	(5)	(6)
	Share received first dose			**Share fully vaccinated**		
	All ages	18+	65+	All ages	18+	65+
Panel A: Extensive Margin						
Any pharmacy location	0.0206***	0.0239***	0.0372***	0.0160***	0.0209***	0.0419***
	(0.00324)	(0.00362)	(0.00416)	(0.00288)	(0.00333)	(0.00411)
Panel B: Intensive Margin						
Pharmacy locations per 10,000	0.00782***	0.00924***	0.00907***	0.00682***	0.00821***	0.00990***
	(0.000959)	(0.00107)	(0.00101)	(0.000887)	(0.00101)	(0.00108)

This table presents the first stage results that measure the effects of any participating retail pharmacy in a county and the per-10,000 number of pharmacies on per-capita COVID-19 age-specific vaccination rates. Each regression includes county and week fixed effects. Standard errors clustered at the county level. *** p<0.01, ** p<0.05, * p<0.1

Table 4: Reduced Form Results: Effect of Pharmacy Vaccine Locations on COVID-19 Outcomes

	(1)	(2)	(3)	(4)	(5)	(6)
	COVID cases per 10,000 population		COVID hosp. per 10,000 population		COVID deaths per 10,000 population	
Any pharmacy location (lagged)	-2.304***		-0.388***		0.0215	
	(0.705)		(0.0939)		(0.0200)	
Pharmacy locations per 10,000 (lagged)		-0.649***		-0.0666***		-0.00951**
		(0.128)		(0.0162)		(0.00385)
Observations	160,242	160,242	160,242	160,242	160,242	160,242
R-squared	0.240	0.240	0.303	0.303	0.105	0.106
2021 mean	19.6	19.6	1.0	1.0	0.4	0.4
Relative change	-11.7%	-3.3%	-36.7%	-5.8%	5.9%	-2.7%

This table presents the reduced form results that measure the effects of any participating retail pharmacy in a county and the per-10,000 number of pharmacies on per-capita COVID-19 cases, hospitalizations, and deaths. Each regression includes county and week fixed effects. Standard errors clustered at the county level. *** p<0.01, ** p<0.05, * p<0.1

Table 5: Effect of Quartiles of Pharmacy Vaccine Locations on COVID-19 Outcomes

	(1)	(2)	(3)	(4)	(5)	(6)
	COVID cases per 10,000 population		COVID hosp. per 10,000 population		COVID deaths per 10,000 population	
1st quartile of pharmacy locations per 10,000	-0.915	-0.0178	-0.362***	-0.306***	0.0477**	0.0626***
	(0.663)	(0.520)	(0.0934)	(0.0807)	(0.0204)	(0.0179)
2nd quartile of pharmacy locations per 10,000	-2.073***	-0.308	-0.371***	-0.251***	0.0332	0.0590***
	(0.734)	(0.553)	(0.0968)	(0.0863)	(0.0206)	(0.0185)
3rd quartile of pharmacy locations per 10,000	-3.530***	-1.075*	-0.414***	-0.241***	0.00640	0.0446**
	(0.784)	(0.587)	(0.100)	(0.0886)	(0.0214)	(0.0196)
4th quartile of pharmacy locations per 10,000	-3.743***	-0.998	-0.427***	-0.226**	-0.0253	0.0334
	(0.841)	(0.631)	(0.112)	(0.101)	(0.0229)	(0.0213)
Observations	160,242	160,191	160,242	160,191	160,242	160,191
R-squared	0.240	0.440	0.303	0.349	0.106	0.335
State x week FE		X		X		X

This table presents the non-linear reduced form results that measure the effects of the per-10,000 number of pharmacies, which is categorized into quartiles, on per-capita COVID-19 cases, hospitalizations, and deaths. Each regression includes county and week fixed effects. Columns 2 and 4 add state-by-week interaction fixed effects. Standard errors clustered at the county level. *** p<0.01, ** p<0.05, * p<0.1

Table 6: Effects of COVID-19 Vaccine Administrations on COVID-19 Outcomes

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	OLS	IV	IV	OLS	IV	IV	OLS	IV	IV
	COVID cases per 10,000 population			COVID hosp. per 10,000 population			COVID deaths per 10,000 population		
Panel A: Endogenous treatment = Weekly COVID-19 vaccinations administered									
Vaccines administered per	-2.05E-05	-0.0395**	-0.0565***	-2.80e-06	-0.00643***	-0.00520***	-1.15e-06**	0.000354	-0.000701**
10,000 population (lagged)	(1.41e-05)	-0.0154	-0.0191	(2.32e-06)	(0.00222)	(0.00190)	(5.87e-07)	(0.000343)	(0.000345)
Observations	160,242	160,242	160,242	160,242	160,242	160,242	160,242	160,242	160,242
Z=any pharmacy		X			X			X	
Z=Pharmacy locations per 10,000			X			X			X
2021 mean		19.6	19.6		1.0	1.0		0.4	0.4
Relative change		-0.2%	-0.3%		-0.6%	-0.5%		0.1%	-0.2%
F-statistic		15.89	11.47		16.79	13.56		16.75	14.37
Panel B: Endogenous treatment = Weekly per-capita number fully vaccinated									
Vaccines administered per	-0.00169***	-0.00803***	-0.00762***	-7.62e-05***	-0.00132***	-0.000788***	-2.47e-05***	7.18e-05	-0.000114**
10,000 population (lagged)	(0.000291)	(0.00273)	(0.00170)	(1.88e-05)	(0.000371)	(0.000225)	(4.26e-06)	(6.69e-05)	(5.21e-05)
Observations									
Z=any pharmacy		X			X			X	
Z=Pharmacy locations per 10,000			X			X			X
2021 mean		19.6	19.6		1.0	1.0		0.4	0.4
Relative change		-0.04%	-0.04%		-0.13%	-0.07%		2028.4%	-0.03%
F-statistic		49.22	60.95		50.06	55.63		50.58	50.27

This table presents the results that measure the effects of the per-10,000 number of COVID-19 vaccine doses administered (Panel A) and the share of fully vaccinated individuals (Panel B) on per-capita COVID-19 cases, hospitalizations, and deaths. Each regression includes county and week fixed effects. Columns 1, 4, and 7 are estimated using OLS. Columns 2, 5, and 8 use the presence of any participating pharmacy as an instrumental variable, while columns 3, 9, and 9 instrument using the per-10,000 number of participating retail pharmacies in a county. Standard errors clustered at the county level. *** p<0.01, ** p<0.05, * p<0.1

Table 7: Effects of Share of Population Vaccinated for COVID-19 on COVID-19 Outcomes

	(1)	(2)	(3)	(4)	(5)	(8)
	Share received first dose			**Share fully vaccinated**		
	All ages	18+	65+	All ages	18+	65+
Panel A: Cases						
Share vaccinated	-50.38***	-41.52***	-39.67***	-76.25***	-70.17***	-60.93***
	(10.25)	(8.530)	(8.440)	(16.99)	(16.15)	(14.84)
Panel B: Hospitalizations						
Share vaccinated	-5.110***	-4.189***	-3.897***	-7.881***	-7.249***	-6.193***
	(1.359)	(1.112)	(1.045)	(2.249)	(2.112)	(1.852)
Panel D: Deaths						
Share vaccinated	-0.723**	-0.590**	-0.538**	-1.139**	-1.049**	-0.885**
	(0.318)	(0.259)	(0.237)	(0.521)	(0.486)	(0.415)

This table presents the results that measure the effects of the age-specific share of both partially and fully vaccinated individuals on per-capita COVID-19 cases, hospitalizations, and deaths. Each regression includes county and week fixed effects. Vaccination rates are instrumented using the per-10,000 number of participating retail pharmacies in a county. Standard errors clustered at the county level. *** p<0.01, ** p<0.05, * p<0.1

Table 8: County-Level Heterogeneity in First Stage Estimates

	(1)	(2)	(3)	(4)	(5)
Panel A: Per-Capita Weekly Vaccine Doses Administered					
Pharmacy locations per 10,000	19.82***	24.59***	23.59***	22.98***	17.70***
	(3.096)	(3.086)	(3.891)	(2.988)	(2.990)
Pharmacy locations per 10,000 X rural	2.994				
	(2.948)				
Pharmacy locations per 10,000 X Trump won		-3.625			
		(2.660)			
Pharmacy locations per 10,000 X high-speed internet			-2.750		
			(3.411)		
Pharmacy locations per 10,000 X above median percent white				-2.567	
				(3.115)	
Pharmacy locations per 10,000 X above median poverty					1.078
					(1.059)
Panel B: Per-Capita Population Vaccinated					
Pharmacy locations per 10,000	162.6***	224.7***	7.973	36.72***	163.7***
	(15.21)	(24.80)	(13.48)	(13.78)	(14.01)
Pharmacy locations per 10,000 X rural	-135.7***				
	(14.60)				
Pharmacy locations per 10,000 X Trump won		-190.6***			
		(22.48)			
Pharmacy locations per 10,000 X high-speed internet			101.9***		
			(14.26)		
Pharmacy locations per 10,000 X above median percent white				82.12***	
				(14.03)	
Pharmacy locations per 10,000 X above median poverty					-25.73***
					(4.182)

This table presents the heterogeneous first stage results that measure the effects of the per-10,000 number of pharmacies on per-capita COVID-19 vaccine doses administered and vaccination rates. For outcome, differences are reported for rural counties, counties won by Trump, counties with high-speed internet, counties with above median percent white residents, and above median poverty levels. Each regression includes county and week fixed effects. Standard errors clustered at the county level. *** p<0.01, ** p<0.05, * p<0.1

Table 9: County-Level Heterogeneity in Reduced Form Estimates

	(1)	(2)	(3)	(4)	(5)
Panel A: Per-Capita COVID-19 Cases					
Pharmacy locations per 10,000	-0.115 (0.0714)	-0.350*** (0.0837)	0.342*** (0.0886)	-0.502*** (0.0709)	0.191*** (0.0739)
Pharmacy locations per 10,000 X rural	0.379*** (0.0683)				
Pharmacy locations per 10,000 X Trump won		0.652*** (0.0778)			
Pharmacy locations per 10,000 X high-speed internet			-0.315*** (0.0774)		
Pharmacy locations per 10,000 X above median percent white				1.381*** (0.0671)	
Pharmacy locations per 10,000 X above median poverty					-0.114* (0.0606)
Panel B: Per-Capita COVID-19 Hospitalizations					
Pharmacy locations per 10,000	-0.0343*** (0.0124)	-0.0299** (0.0149)	-0.0453** (0.0185)	-0.0522*** (0.0128)	-0.000696 (0.0123)
Pharmacy locations per 10,000 X rural	0.00954 (0.0129)				
Pharmacy locations per 10,000 X Trump won		0.00228 (0.0139)			
Pharmacy locations per 10,000 X high-speed internet			0.0262 (0.0166)		
Pharmacy locations per 10,000 X above median percent white				0.0517*** (0.0150)	
Pharmacy locations per 10,000 X above median poverty					-0.0233** (0.0101)
Panel C: Per-Capita COVID-19 Deaths					
Pharmacy locations per 10,000	-0.00731*** (0.00247)	-0.0175*** (0.00314)	0.0139*** (0.00311)	-0.00884*** (0.00269)	-0.00531** (0.00254)
Pharmacy locations per 10,000 X rural	0.0153*** (0.00236)				
Pharmacy locations per 10,000 X Trump won		0.0265*** (0.00268)			
Pharmacy locations per 10,000 X high-speed internet			-0.0174*** (0.00266)		
Pharmacy locations per 10,000 X above median percent white				0.0245*** (0.00239)	
Pharmacy locations per 10,000 X above median poverty					-0.00136 (0.00179)

This table presents the heterogenous reduced form results that measure the effects of the per-10,000 number of pharmacies on per-capita COVID-19 cases, hospitalizations, and deaths. For outcome, differences are reported for rural counties, counties won by Trump, counties with high-speed internet, counties with above median percent white residents, and above median poverty levels. Each regression includes county and week fixed effects. Standard errors clustered at the county level. *** p<0.01, ** p<0.05, * p<0.1