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Give Me Your Best Shot! Diffusion of Complete versus Booster Covid-19 Vaccines across US Counties

Abstract

This paper compares drivers of full COVID-19 vaccinations and booster doses across U.S. counties. Booster doses are contingent upon someone receiving the primary doses, and the risk attitudes and propensities to get vaccinated may be different across individuals, along with the supply chain differences across the primary and booster doses. Results show that new covid cases do not significantly impact vaccinations, while supply chain aspects via pharmacies had a positive impact. The effects of income, race, age, and education were largely consistent with intuition. Further, political ideologies mattered, while government decentralization did not. There were differences in the signs, magnitudes, and significance of the influence of some drivers across primary versus booster doses. Robustness checks include using alternative estimation techniques and examining differences across counties with low- and high vaccination rates. Policy implications are discussed.

JEL-Codes: I180, I110, H750, H110, D720.

Keywords: Covid-19, vaccination, pandemic, booster, government, supply chain, pharmacies, political ideology, risk attitudes, county, United States.

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1. Introduction

The persistence of the current pandemic and the mutations of the underlying COVID-19 virus has necessitated a continued effort on the part of policymakers to not only increase vaccination rates for the complete initial doses, but also to enhance outreach to provide booster shots that increase immunity and help guard against evolving virus streams.

Various government and other organizations continue to recommend vaccinations, including booster doses.[1] However, the desirability and efficacy of booster vaccines is not universally accepted,[2] and this might disproportionately impact populations that are already vaccine-hesitant (see Hu et al. (2022), Karpman et al. (2021)).

Early on in the pandemic, the U.S. government partnered with various retail pharmacies under the Federal Retail Pharmacy Program to facilitate the distribution of COVID-19 vaccines. While the original intent was to use the locational and community involvement of pharmacies located in various parts of the country to help get the vaccines quickly and securely to the public, over time this strategy also helped address emerging supply chain issues in vaccines (Alam (2021)). According to the Centers for Disease Control and Prevention, “As of February 9, 2023, more than 300 million doses of COVID-19 vaccine have been administered and reported by Federal Retail Pharmacy Program participants in the US. This includes 8 million doses administered onsite to long-term care facilities in the early days of the COVID-19 vaccination program.”[3]

The success of complete versus booster vaccination rates differs, both in the United States and elsewhere. However, it is not clear whether similar factors drive the propensities to obtain complete and booster shots. If it turns out that some of the drivers of complete versus booster shots are different, then public outreach policies can be modified accordingly.

For the purposes of this analysis, a person has completed the COVID-19 “primary” vaccination series if they have had the second dose of the two-dose vaccine, or one dose of the single-dose vaccine. “Booster” refers to an additional dose after the completion of the primary series and is not meant to refer to the more recent updated (bivalent) booster designed to protect against both the original virus and the Omicron variants BA.4 and BA.5. The first booster vaccination was recommended by the U.S. Centers for Disease Control and Prevention in November 2021 to all Americans who are age 18 and over that had completed the primary series at least six months earlier.[4]

As of April 1, 2022, a little over two-thirds of the U.S. population had received the primary vaccination series.[5] In contrast, the percentage of the population that had received a booster vaccine dose by that date stood at 43 percent. Vaccination rates vary considerably across

[1] https://www.cdc.gov/coronavirus/2019-ncov/vaccines/stay-up-to-date.html; https://www.uchicagomedicine.org/forefront/coronavirus-disease-covid-19/third-doses-and-covid-booster-shots; https://dhs.wisconsin.gov/covid-19/vaccine-booster.htm
[2] https://time.com/6246525/bivalent-booster-not-very-effective-paul-offit/; https://www.nytimes.com/2023/02/02/well/live/covid-bivalent-booster-omicron.html
[3] https://www.cdc.gov/vaccines/covid-19/retail-pharmacy-program/index.html
[4] https://www.cdc.gov/media/releases/2021/s1129-booster-recommendations.html
[5] Vaccination status as of April 1, 2022, is used in the analysis presented below.

counties. For example, primary vaccination rates as of that April date varied from a low of 11% (Slope County, North Dakota) to a high of 95% (seven counties) according to the CDC.[6]

Whereas the data at county level allow us to focus on a finer level of detail in the analysis, it seems important to motivate why one would expect complete and booster vaccine doses to be different. This distinction should be viewed both from the demand and supply sides.

On the supply side, booster doses would again pose supply chain/dissemination challenges with a new vaccine rollout. However, one would expect that there would be some lesson learned and logistics strengthened from learning from the rollout of the initial full dose of vaccines (https://theconversation.com/us/topics/vaccine-supply-chains-99237). Obviously, counties/states differ in location and in infrastructure, which would impact the access to vaccines, and our analysis at the county level enables a better accounting of the underlying differences than more aggregate analyses.

One could envision several potential differences on the demand side of full doses versus booster doses. Broadly speaking, the demand for booster shots is a sequential demand, contingent upon a person having received the full vaccine course (one or two doses, depending upon the vaccine type chosen). This could be seen as the demand for a refill cup of coffee, where the refills are viewed as having a more elastic demand. The analogy does not extend completely, with the price of vaccine being zero, given government subsidy in the United States, and the booster doses are aimed at tackling a different variant of the virus (so the "good" demand is not identical, but differentiated).

One could also theoretically draw upon the theory of risk attitudes and risk bearing, where other things being the same, more risk averse individuals would be more willing to seek vaccinations. The underlying risk attitudes, however, might be different for full dose versus booster vaccines (although tempered by how someone views the additional variants of the virus). This dimension is somewhat accounted for in our analysis by considering the influence of different demographic groups (e.g., the elderly, race).[7]

Further, some individuals may perceive they are adequately protected from the virus after receiving the first shot or believe that the pandemic is over. Others may have suffered from severe personal reactions from the first dose. On top of all this, media influence on potential vaccine-takers, both legitimate and fake information, might potentially work differently on full- versus booster doses, again, with differences across counties/regions.

Figure 1 shows the relative diffusion paths of complete and booster vaccine doses, with, for obvious reasons, the booster doses being available at a later date. Whereas casual observation of the figure reveals relatively similar diffusion patterns, it is less clear whether the different factors

[6] Centers for Disease Control and Prevention (https://data.cdc.gov/Vaccinations/COVID-19-Vaccinations-in-the-United-States-County/8xkx-amqh/data).
[7] An alternate determination of individual risk attitudes would warrant surveys, which is beyond the scope of the present study.

noted above were equally effective in driving primary and booster vaccination rates. The present research will uniquely shed light on this aspect.

Ensuring equitable vaccine access across jurisdictions is one of the goals of policymakers (also see Shen et al. (2020)). It is likely that the government health care structure at state level in the United States would partly address that as well as supply-chain issues that have emerged with the vaccine delivery.[8] Finally, the location of counties, e.g., metropolitan counties versus others, encounter different supply chain challenges related to the infrastructure and that would impact their abilities to vaccinate their residents, ceteris paribus.[9]

This paper studies the determinants of complete versus booster COVID-19 vaccinations, using data across a sample of counties in the United States. The analysis at the county level also enables us to address aspects of government public health decentralization and its effectiveness in serving the health needs of the population.

Some of the key questions addressed in this research are:

- Are the drivers of complete vaccination doses the same as those for booster doses?
- What is the influence of government health care decentralization on COVID-19 vaccinations in the United States?
- How significant were supply chain initiatives in enabling COVID-19 vaccinations?
- Is the influence of political ideology significant in dictating vaccination propensities?
- Do metro counties perform better in vaccinating their populations than non-metro counties?

Our results show a number of quantitative and qualitative differences in the propensities to obtain primary versus booster vaccinations. Besides adding to the literature, our findings have implications for health policies to more effectively tackle the ongoing pandemic and others that inevitably will occur in the future.

The structure of the rest of this paper includes the background and the model in the next section, followed by data and estimation, results, and conclusions.

2. Background and the model

2.1 Background

In the nearly three years since the onset of the current COVID-19 pandemic, a rather substantial body of research has emerged surrounding vaccination efforts to combat the disease, both by medical researchers and non-medical researchers. Initial efforts, using data across different jurisdictions, were aimed at determining the success in vaccine invention, dissemination of initial

[8] https://poole.ncsu.edu/thought-leadership/article/the-covid-19-vaccine-supply-chain-potential-problems-and-bottlenecks/#:~:text=There%20are%20a%20lot%20of,waste%20being%20generated%20by%20vaccinations%3F; Alam et al. (2021).

[9] Logistics performance would be another measure of supply-chain performance. However, we are not aware of corresponding data at the county-level for the United States.

doses, non-pharmaceutical interventions (Motie and Biolsi (2021)), etc. Over time, the research evolved into determinants of complete doses, with more recent works beginning to consider booster doses (Hagger and Hamilton (2022)). A number of studies have recognized the influence of social factors in driving propensities to seek vaccinations (Karpman et al. (2021), Ku (2022), Pal et al. (2021)). Relatedly, an index of community vulnerability has also been employed in the context of the United States (Brown et al. (2021)).

A related strand of this literature considers the determinants of vaccine hesitancy (Goel et al. (2023), Hu et al. (2022), Karpman et al. (2021), Pal et al. (2021)). While the focus of the present study is on the United States, global vaccine hesitancy has been considered elsewhere (see, for example, (Leigh et al. (2022), Recio-Román et al. (2021)).

This work adds to this body of work by examining and comparing the relative determinants of full and booster vaccinations. Another contribution lies in considering data at the county level in the United States in contrast to the many studies addressing vaccine-related questions that make use of data at the state level (Goel and Nelson (2021a,b)). This allows the researcher to explore a data set that should be characterized by greater diversity of the public response to vaccination initiatives and the circumstances that drive individuals' decision making on whether or not to become vaccinated.

<u>2.2 Model</u>

Our empirical model takes the following general form, and we estimate variations of this base model using data from U.S. counties (details about the data are in Table 1, and the estimation strategies are discussed in Section 3.2):[10]

Vaccine dose (*PrimaryDose*; *BoosterDose*) = f (*CovidCASES*, Z, Supply chain {(Pharmacies$_j$), Location (*Non-Metro*)}, Political ideology (*Trump*), Public health care decentralization (*health_decent*), Physician interaction/information (*doctor_visits*)) …(1)

where

j = *nPharm, nPharm_land*

Z = *INCOME, ELDERLY, RACE, lowEDUCATION*

The dependent variables are, alternately, the share of the population with the primary dose(s) of the COVID-19 vaccine or the booster dose. While a number of studies have considered the determinants of primary doses across different jurisdictions (Goel and Nelson (2021b)) and some have considered boosted doses (Hagger and Hamilton (2022), Mahase (2021)), the comparison of primary and booster doses considered in the present work seems unique. The correlation between *PrimaryDose* and *BoosterDose* in our sample is 0.28.[11]

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[10] The unit of analysis in the related data is a county in the United States (see Table 1 for details).
[11] We are taking one date (April 1, 2022) to compare the diffusion of complete and booster vaccine doses. Obviously, over time the vaccination rates, both for the complete vaccine series and booster doses could have evolved differently. Yet, this work uniquely is able to address the comparison of the booster and complete doses using data at a fine level of detail.

An obvious explanatory variable to include in the empirical set up is the severity of the covid outbreak (*CovidCASES*), see Puranik et al. (2021). To mitigate endogeneity concerns, we measure new covid cases as the average daily value for the month prior to the April 2021, vaccination data used in this analysis. As of March 2022, there was an average of 97.52 new covid cases per 100,000 population in our dataset. One would expect higher covid cases to increase vaccination rates, although the greater prevalence of the virus could be associated with supply chain issues and with congestion. However, it is less clear whether potential vaccine seekers are more impacted by historic cases (a stock variable - see Barrett et al. (2022)) or by current cases (a flow variable). This difference likely also draws a different response from the media and from decision-makers.

The role pharmacies in disseminating vaccinations and ensuring the smooth running of vaccine supply chains has been crucial, both as providers of information, access, and in many instances, being the only disseminator of vaccine doses.[12] Recognizing the role of pharmacies and to address supply chain issues, the United States government had partnered with pharmacies early on in the pandemic to facilitate the distribution of vaccines;[13] see Pammal et al. (2022). We account for the role of pharmacies by including their sheer number at the county level (*nPharm*), and weighting *nPharm* by county area (*nPharm_land*).[14] One useful insight from this research would be whether the pharmacies were equally effective in disseminating complete- and booster doses.

In the vector of Z variables that appear in all the different models, *INCOME* captures economic prosperity that is tied to local capacity, affordability (Roghani and Panahi (2021)), (even though the vaccines were free in the United States (see Kliff (2021)), and access to information.[15] The share of the elderly population (*ELDERLY*) is relevant, given the potentially greater negative health consequences that this demographic group faces if they contract the disease and public policy initiatives directed at this group encouraging them to get vaccinated.[16] *RACE* (denoted by the share of Black or African-American population - see Karpman et al. (2021), Ku (2022)), and education (*lowEDUCATION*) capture demographic aspects that might be crucial in dictating vaccination propensities (Ku (2022)).[17] It is not clear, however, whether these propensities for primary doses and booster doses are alike.

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[12] https://www.cdc.gov/vaccines/covid-19/retail-pharmacy-program/index.html#:~:text=As%20of%20January%2026%2C%202023,the%20COVID%2D19%20vaccination%20program

[13] https://www.cdc.gov/vaccines/covid-19/retail-pharmacy-program/index.html.

[14] Obviously, pharmacies are only one dimension of the supply chain, which can encompass labor shortages, communications and transportation bottlenecks, etc. (see Goel et al. (2021) for an international study using of supply chain bottlenecks). These issues are to some extent mitigated by the focus on a single country considered here.

[15] Greater income is also related to the ability to secure insurance, and that might be significant in spite of the fact that the vaccines are subsidized by the U.S. government (Goel and Nelson (2022)).

[16] https://www.hhs.gov/immunization/who-and-when/adults/seniors/index.htm

[17] About a third of the US population only had a high school diploma in 2018 and in 2019 about a tenth of the population was classified as belonging to the African American race (Table 1). Further, a fifth of the population was classified as elderly.

Besides demographic factors, the political ideology of the public feeds into vaccine hesitancy (see Goel et al. (2023), Pal et al. (2021) on vaccine hesitancy), and we proxy political ideology by the share of votes Donald Trump received in the 2016 election (*Trump*).[18] Trump received more than a 50% share of all votes cast in over 75% of all counties in 2016.

Locational considerations are accounted for by identifying non-metropolitan counties (*Non_Metro*). On average, 63 percent of sample counties were classified as non-metro. Metropolitan areas have greater media and political focus and better public health infrastructure. Further, the transaction/transportation costs, impacting the supply chain, might be lower in such areas, although such areas might have greater congestion (also see Murthy et al. (2021)). This might impact vaccination rates.

The structure of public health care might be related to the provision of information and public outreach (see Goff et al. (2022)), and this is captured by a variable *health_decent*.[19] This variable is coded as one if local health units in a state are primarily led by employees of local governments. States with centralized or largely centralized structures (local health units are primarily led by state employees), mixed structures, and shared or largely shared structures are coded as zero. A majority of US counties had either decentralized or largely decentralized health care governance structure in the year prior to the start of the pandemic (Table 1). The inclusion of health care governance would also somewhat capture government's involvement/ability to address vaccine supply chain issues. Among other things, there might be different degrees of public outreach about vaccination necessity and availability across decentralized and centralized counties, and these differences might be dissimilar for primary and booster doses.

Finally, visits to the physician (*doctor_visits*) are related to information and persuasion that the physicians can provide, even for individuals not affected by the virus. The behavior and outreach of physicians might be different towards booster doses after they have received primary doses themselves.

3. Data and estimation

3.1 Data

As noted above, a county in the United States comprises the unit of analysis in this research. As of the time of this writing, there were 3,142 counties in the US. Of this total, 17 counties were excluded in the analysis below due to a lack of data for one or more of the variables in the model, leaving a total of 3,125 counties in our data set.

Data on vaccination rates for the US population are drawn for the Center for Disease Control and Prevention and are available on a daily basis since the start of the pandemic. Vaccination rates

[18] At the time of this writing, we had access to Trump votes for only about two-thirds of all counties in the US for the 2020 election. Because the voting data was nearly complete for all US counties in 2016, we elected to use that voting data instead. Not surprisingly, for counties where we had data for both election years, the correlation between the two election data exceeded 0.98.

[19] See Karsten (1995) for broader arguments about the role of government in health care.

as of April 1, 2022, are used in our data set. The remainder of the data sources used in this paper are all widely used in the literature and available in the public domain. Complete details about the variables used, including summary statistics, definitions, and data sources are in Table 1.

3.2 Estimation

We employ different estimation strategies to estimate the baseline models, address additional aspects, and to check for the robustness of our findings. First, the primary estimation in the baseline models (Tables 2-4), is carried out using Ordinary Least Squares for ease of interpretation of the results. Hypothesis testing is conducted using state-level clustered standard errors to account for possible correlation of the model residuals within the counties of a given state. Further, we employ quantile regression to examine whether the factors driving complete versus booster doses are sensitive to the prevailing vaccination rates (Section 4.3). Finally, fractional regression results are reported in Section 4.4 to account for the measurement of the dependent variables. The results section follows.

4. Results

4.1 Baseline models: Complete versus booster shots

The baseline results in Table 2 show that wealthier counties and counties with a greater share of the elderly were more successful in vaccinating their populations (both primary and booster shots). This is consistent with the notion that wealthier counties have better infrastructure, ceteris paribus, and that wealthier residents are more empowered (e.g., own transportation) to seek vaccines.

The influence of race (captured by the share of the Black population), showed a negative effect on vaccination rates, with relatively greater statistical support in the case of booster shots. These results suggest that initiatives to promote vaccine equity among racial and ethnic minority groups have fallen short, at least for as of the April 2022 timeline used in this analysis.[20]

Interesting contrasts between primary and booster shots emerge with regard to the effects of low education *[lowEDUCATION*]. The low educated were less likely to obtain primary doses, but more likely to obtain booster doses (both sets of coefficients being significant in half the instances considered). It could be the case, that the scale and type of information outreach to the relatively less educated was different in the initial stages of the pandemic, relative to the latter stages - see Goel and Nelson (2021a) for the role of the internet in this regard during the initial stages. Pal et al. (2021) found lower education to be associated with greater vaccine hesitancy among health care workers.

The non-metropolitan [*Non-Metro*] areas also fared better with regard to booster shots compared to the metropolitan areas. Most state capitals and most media houses are located in metropolitan

[20] https://www.cdc.gov/coronavirus/2019-ncov/community/health-equity/vaccine-equity.html

areas and the resulting greater scrutiny/attention to metropolitan areas might have been one cause of greater primary vaccinations in metropolitan areas.

Interestingly, new covid cases [*CovidCASES*] failed to exert a significant influence on vaccination rates. It could be the case that individuals were basing their decisions to seek vaccinations based on older or more aggregated information on cases (and this lag also makes sense considering the delays in scheduling vaccinations, especially in the initial periods of the pandemic). Puranik et al. (2021), examining vaccination rates across 580 counties, found decreased county-level COVID-19 incidence in the United States related to higher COVID-19 vaccination rates.

To account for the sequential nature of the booster dose demand, Models 1.2 and 1.4 also include *PrimaryDose* as a regressor. The coefficient on *PrimaryDose* is positive in both cases, but statistically significant in Model 1.2.[21]

Finally, we check for the influence of political ideology, proxying for it by the county vote share for Trump in the 2016 election. The results show that counties with a greater share of Trump voters were less likely to seek vaccinations, and this was true for both primary doses and booster doses. The results for the negative effect of Trump votes are consistent with an earlier study at the state-level by Ku (2022). That study, however, did not consider booster doses. Quantitatively, however, the coefficient on *Trump* was almost double in magnitude in the case of *PrimaryDose* (comparing Models 1.3 and 1.4).

4.1.1 Relative elasticities of effects

To obtain additional insights into the relative magnitudes of effects it seems useful to consider the elasticities of some of the key factors impacting primary and booster doses. For the sake of consistency in comparisons, we focus on Models 1.3 and 1.4 from Table 2, for primary and booster doses, respectively.

Whereas the elasticity *INCOME* was relatively similar across primary and booster vaccines (both elasticities equal to 0.2), there were more pronounced differences with respect to the effects of age and race, with both elasticities, in absolute values being greater in the case of booster shots. In particular, the elasticity of *ELDERLY* was 0.1 in Model 1.3, and 0.3 in Model 1.4; and the elasticity of *BLACK* with respect to *PrimaryDose* was -0.04 versus -0.07 for *BoosterDose*.[22] The relatively greater responsiveness of the elderly and African Americans to booster doses may be attributed to differences in risk attitudes.

Finally, Trump voters had a greater negative reaction to complete vaccination, compared to booster vaccinations. Specifically, the elasticity of Trump with respect *PrimaryDose* was -0.7, while that with respect to *BoosterDose* was -0.3, signifying a relatively greater initial reluctance towards primary doses.

[21] It could be the case that, when Trump vote share is included in Model 1.4, the incentives of some of those with primary vaccine doses to obtain booster doses are blunted.
[22] All elasticities are evaluated at the respective sample means (see Table 1).

All this points to underlying differences in the strength of various influences on primary versus booster doses, influences that are readily evident from an examination of Figure 1. Thus, while the pattern of diffusion of primary and booster shots looks somewhat similar from the figure, the relative strength of the underlying factors driving the diffusion is different in many instances and this is potentially informative for policymakers trying to increase the reach of different booster doses to the population.

4.2 Additional considerations: Influence of pharmacies, and government decentralization

Tables 3 and 4 extend the baseline models by examining the influence of additional factors, especially the role of government health care decentralization, doctor visits, and the prevalence/access to pharmacies. All the models in Table 4 also include *PrimaryDose* as a regressor.

Of the two measures of the prevalence of pharmacies, the sheer number of pharmacies facilitated vaccinations (with relatively stronger statistical support in the case of *PrimaryDose* in Table 3); however, when the number of pharmacies was weighted by a county's land area (*nPharm_land*), the resulting coefficient failed to achieve statistical significance in both Tables 3 and 4.

The decentralization of public health services *[health_decent]* did not have a significant impact, and this was true for both primary doses and booster doses.[23] The related policy implication is that public health policies towards coronavirus policies could be uniformly made for decentralized and centralized health systems.

In Table 4, the coefficient on *PrimaryDose* is positive and significant throughout, supporting the sequential nature of booster shots.

Finally, visits to the doctor's office [*doctor_visits*] had a positive impact on primary doses, but did not significantly impact booster doses. This might have to do with information and persuasion in the case of primary doses, with no additional significant information/persuasion gains impacting the latter. The results for the other determinants are quite similar to what was reported in Table 2.

4.3 Robustness check1: Determinants of complete and booster shots across counties with different vaccination rates

With wide disparities in the vaccination rates across counties, it seems useful to study and compare the drivers of both complete and booster vaccination rates across low- and high vaccination rate counties. For this purpose, we employ the quantile regression and report the corresponding results in Table 5 (with Panels A and B, respectively, reporting the results for the two dependent variables). The advantage of the quantile regression is that it considers the effects

[23] Admittedly, our measure of public health care decentralization is binary (see Table 1), and might not capture some nuances (qualitative aspects) of the government's involvement in the health care sector. In particular, the decentralization measure used in this analysis only represents a general characterization of the public health care infrastructure in a state. Some individual counties within a state may stand out from the state norm with respect to how public health responsibilities are shared between these two levels of government. We were not able to find public health care decentralization data at the county level.

of the chosen control variables on different quantiles of the dependent variable, while still using the whole distribution (see Koenker and Hallock (2001) for details on quantile regression). This treatment also helps us control for the effects of outliers. Furthermore, the related policy implications deal with whether vaccination efforts for counties with low vaccination rates should be different from others.

For *PrimaryDose* in Panel A, a comparison of the results reported at q25 (least vaccinated), q50 (median), and q75 (most vaccinated) shows that the magnitudes of the effects varies across the distribution of the primary doses. Furthermore, interestingly, covid cases do not impact primary dose vaccinations in counties with low vaccination rates. Furthermore, while race is insignificant in the OLS regression, the quantile regression estimates are significant (and positive) across the distribution.

The story is somewhat different in Panel B with *BoosterDose*, the sign of the *lowEDUCATION* varies across the distribution. Specifically, booster doses were greater in counties with low booster vaccination rates, insignificant in the median regression, and negative in counties with high booster rates. A possible explanation for this difference might be a greater sense of vulnerability with the less educated, prompting them to seek booster vaccinations, while a relatively greater sense of empowerment (or feeling of herd immunity) when vaccination rates are high.

Counties with low vaccination rates were also unaffected by changes in covid cases or being in non-metro areas. While the insignificance of *CovidCASES* was also, true for primary doses in Panel A, the results for non-metro counties were negative and significant throughout in Panel A. In contrast, the reverse is true for non-metro counties with regard to booster doses, especially for counties with median to high prevalence of booster shots.[24] In other words, while non-metropolitan areas lagged behind metro areas in primary vaccinations, they were ahead in getting booster doses (except counties with a low prevalence of booster shots (q25)).

In Panel B, the coefficient on *PrimaryDose* remains positive and significant throughout the distribution of the dependent variable.

Overall, we see that the use of the quantile regression, besides addressing outlier issues and tackling underlying nonlinearities, reveals some additional insights about the magnitudes, signs, and statistical significance of the estimated related over what was reported in Table 2.

4.4 Robustness check2: Using alternative estimation methodology

Given the properties of the dependent variables, where they are denoted as a fraction, a useful robustness check might to estimate a fractional regression (Papke and Wooldridge (1996)). Accordingly, we re-estimated the baseline models from Table 2 using fractional regressions (instead of OLS). The results largely supported the baseline findings. These results are not reported here but are available upon request. The concluding section follows.

[24] The resulting coefficient on *Non-Metro* in baseline models with OLS estimation was statistically insignificant (Table 2).

5. Conclusions

The ongoing pandemic and the emergence of different strains of the related virus over time has necessitated a focus on possible differences in the drivers of booster vaccine doses, compared to primary doses. The demand for booster doses is sequential, being dependent on the demand for primary doses. There are a number of qualitative, behavioral, and logistical differences on both the demand and supply sides that would possibly impact the dissemination of primary and booster vaccine doses differently. Furthermore, the examination of these differences at a finer level of detail in the data might reveal differences potentially useful for policy formulation that more aggregate analyses might not be able to discern.

This paper adds to the research on the determinants of COVID-19 vaccinations by comparing the relative drivers of full vaccination doses versus booster doses. For this purpose, data from counties in the United States is employed. The continuing pandemic and its evolution into different streams necessitates that policymakers keep focusing on addressing vaccine hesitancy and in focusing on booster vaccines.

Results show that the number of new covid cases is not significantly impacting vaccination rates, while the number of pharmacies had a positive impact. The effects of pharmacies can be seen in the context of accessibility/transaction costs and information provision related to vaccines. Therefore, policies facilitating/subsidizing pharmacies would aid in faster/wider vaccine rollouts. Furthermore, we find evidence to support the sequential nature of the demand for booster doses of the vaccines. A ten percent increase in primary doses would increase booster doses by about three percent (based off the corresponding elasticity evaluated at respective sample means in Model 3.1 from Table 4). This implies that counties lagging in primary doses would need to redouble their efforts in vaccinating booster doses.

The socio-economic effects of income, race, age, and education were largely consistent with intuition, but showed some differences across complete and booster vaccine doses. While race, and age composition of different counties change slowly over time and are not readily amenable to policy manipulation, a case could be made to redoubled policy interventions for relatively poor and less educated jurisdictions to facilitate vaccinations.

Further, political ideologies mattered in driving vaccination propensities, while government decentralization in health care governance did not matter.

There were, however, important differences in the signs, magnitudes, and significance of the influence of some drivers across primary versus booster doses. For instance, with respect to the effect of low education, booster doses were greater in counties with low booster and median vaccination rates, and insignificant in counties with high booster rates. Furthermore, counties with low vaccination rates were also unaffected by changes in covid cases or being in non-metro areas. On the other hand, the effects of income, elderly, race, metro location, and primary doses on booster doses prevailed throughout the distribution of booster shot, however, with differences in relative magnitudes (Table 5, Panel B). Thus, besides the comparison across complete and booster doses, the analysis of differences in the influence of the various determinants across the distribution of vaccines is another contribution of this work.

Various robustness checks, including alternative estimation techniques, and examining the differences in vaccination drivers across counties with low- and high vaccination rates (both for primary and booster vaccination doses), are considered.

We are able to provide the following answers to the questions posed in the Introduction:

- Are the drivers of complete vaccination doses the same as those for booster doses?
  No, we found some significant differences in the influence of some drivers of primary versus booster dose. These differences were with respect to both the signs and the magnitudes of the parameter estimates.

- What is the influence of government health care decentralization on COVID-19 vaccinations in the United States?
  Government health care decentralization did not significantly impact vaccination rates, (Tables 3 and 4).

- How significant were supply chain initiatives in enabling COVID-19 vaccinations?
  Supply chain vaccination efforts via pharmacies positively impacted COVID-19 vaccinations (however, not when pharmacies were weighted by land area). Interestingly, the elasticity of *nPharm* with respect to *PrimaryDose* in Model 2.1 (at 0.01) is the same as the corresponding elasticity with respect to *BoosterDose* (Model 3.1), (although the latter is significant at the 10% level).
  On the other hand, the structure of government health care governance across different states did not appreciably matter in the context of supply chains.

- Is the influence of political ideology significant in dictating vaccination propensities?
  Political ideology (as denoted by votes for Trump in the 2016 election), negatively and significantly impacted both full and booster dose vaccination rates.

- Do metropolitan counties perform better in vaccinating their populations than non-metro counties?
  Metropolitan counties performed better with primary vaccinations, but not with booster doses. This finding is consistent with relatively better supply chain infrastructure in metropolitan areas. Given that boosters came later, when some of the supply chain issues were likely ironed out, the disadvantages of non-metro counties seemed to disappear (Table 4). These differences were further impacted by prevailing vaccination rates across counties (Table 5).

A key policy implication of this work is that strategies to increase booster vaccination rates cannot necessarily mimic those that were used for primary doses. Somewhat different policies to rollout booster doses might be needed. Another important revelation is that jurisdictions/counties with low vaccination rates might warrant additional policy considerations compared to other counties. This is significant even though the overall federalist structure of the central government is the same across the United States. Finally, given the differences we found in metro and non-metro counties, policymakers should either base policies on all available data or refrain from basing policies only on information from metropolitan areas. Going forward, as efforts to combat evolving variants of the virus continue, policymakers would be advised to continue looking for better ways to streamline the supply chains involved in delivery of vaccines.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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Table 1
Variable definitions, summary statistics, and data sources

Variable	Mean (std. dev.)	Source
Percentage of the population with completed primary vaccine series as of April 1, 2022. [*PrimaryDose*]	50.93 (12.03)	[1]
Percentage of the population with completed primary vaccine series and a booster (or additional) dose as of April 1, 2022. [*BoosterDose*]	43.01 (10.43)	[1]
Median household income (in thousands), 2019. [*INCOME*]	55.66 (14.47)	[2]
Percentage of the population 65 years of age and older, 2019. [*ELDERLY*]	19.73 (4.78)	[3]
Percentage of population (all ages) Black or African American, 2019. [*RACE*]	9.40 (14.49)	[3]
Percentage of adults (25 and over) with only a high school diploma, 2018. [*lowEDUCATION*]	34.32 (7.19)	[4]
County in question is not located in a metropolitan area (1= yes, 0 = no). [*Non-Metro*]	0.63 (0.48)	[1]
New COVID-19 cases per 100,000 population, average daily value for the month of March 2022. [*CovidCASES*]	97.52 (120.59)	[1]
Percentage of Trump votes in the county, 2016 elections. [*Trump*]	63.36 (15.63)	[5]
Number of pharmacies, pharmacy defined as a facility whose primary function is to store, prepare and legally dispense prescription drugs under the professional supervision of a licensed pharmacist, 2010. [*nPharm*]	19.73 (58.71)	[6]
Number of pharmacies per 1000 square miles of county land area, 2010. [*nPharm_land*]	50.44 (358.72)	[6], [7]
State-local public health care governance structure, 2019 (1 = decentralized or largely decentralized, 0 = otherwise). [*health_decent*]	0.59 (0.49)	[8]
Visits to doctor for a routine checkup within the past year among adults aged 18 and over (percent, age-adjusted prevalence), 2020. [*doctor_visits*]	72.79 (4.02)	[9]

Notes: Statistics pertain to observations used in the first model that the variable appears.
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Table 2
Completion of primary COVID vaccination series and additional booster dose:
Baseline models

Model →	**[1.1]**	**[1.2]**	**[1.3]**	**[1.4]**
Dependent variable →	***PrimaryDose***	***BoosterDose***	***PrimaryDose***	***BoosterDose***
Median household income [*INCOME*]	0.205** (3.7)	0.121* (1.9)	0.145** (5.0)	0.136* (1.9)
Population ≥ 65 years old [*ELDERLY*]	0.222* (1.9)	0.538** (4.1)	0.308** (4.0)	0.601** (3.9)
Black population [*RACE*]	0.044 (1.1)	-0.200** (3.1)	-0.225** (6.8)	-0.295** (6.1)
High school diploma only *[lowEDUCATION*]	-0.505** (5.3)	0.163 (1.5)	-0.054 (0.8)	0.259** (2.5)
Non-Metropolitan area [*Non-Metro*]	-2.580** (2.5)	1.883** (2.1)	-1.128* (1.9)	2.091** (2.4)
New COVID cases [*CovidCASES*]	0.007 (1.5)	-0.001 (0.1)	-0.000 (0.1)	-0.002 (0.5)
Pct. completed primary vaccine series [*PrimaryDose*]		0.263** (2.7)		0.098 (0.5)
Trump vote in county [*Trump*]			-0.567** (15.8)	-0.218* (1.9)
F-Statistic	30.62**	37.35**	72.48**	48.66**
R-squared	0.26	0.30	0.58	0.33
Observations (counties)	3,125	3,125	3,097	3,097

Notes: Variable definitions are provided in Table 1.
Constant term included in all models but not reported to conserve space.
Models estimated via Ordinary Least Squares, with absolute t-statistics based on robust state-level clustered standard errors in parentheses.
** denotes statistical significance at the 10% level, and ** denotes significance at the 5% level (or better).*

Table 3
Completion of primary COVID vaccination:
Influence of pharmacies, and government decentralization

Dependent variable: *PrimaryDose*

Model →	**[2.1]**	**[2.2]**	**[2.3]**	**[2.4]**
Median household income [*INCOME*]	0.194** (3.6)	0.190** (3.4)	0.204** (3.7)	0.210** (3.6)
Population ≥ 65 years old [*ELDERLY*]	0.243** (2.1)	0.253** (2.1)	0.219* (1.9)	0.226* (2.0)
Black population [*RACE*]	0.031 (0.8)	0.038 (1.0)	0.055 (1.3)	-0.014 (0.3)
High school diploma only *[lowEDUCATION*]	-0.457** (4.7)	-0.516** (5.4)	-0.496** (5.0)	-0.575** (5.7)
Non-Metropolitan area [*Non-Metro*]	-1.852* (1.9)	-2.767** (2.8)	-2.650** (2.7)	-1.726** (2.1)
New COVID cases [*CovidCASES*]	0.007 (1.6)	0.004 (0.9)	0.008 (1.5)	0.009* (1.7)
Number of pharmacies [*nPharm*]	0.032** (3.2)			
Number of pharmacies, county land area adjusted.[1] [*nPharm_land*]		0.002 (1.7)		
Decentralized public health care governance [*health_decent*]			0.855 (0.4)	1.495 (0.8)
Routine doctor visits [*doctor_visits*]				0.543** (2.1)
F-Statistic	40.74**	27.81**	28.89**	23.92**
R-squared	0.28	0.26	0.26	0.28
Observations (counties)	3,125	3,096	3,125	3,125

Notes: See Table 2.

1. *Counties in the state of Alaska excluded.*

Table 4
Completion of additional booster dose:
Influence of pharmacies, and government decentralization

Dependent variable: *BoosterDose*

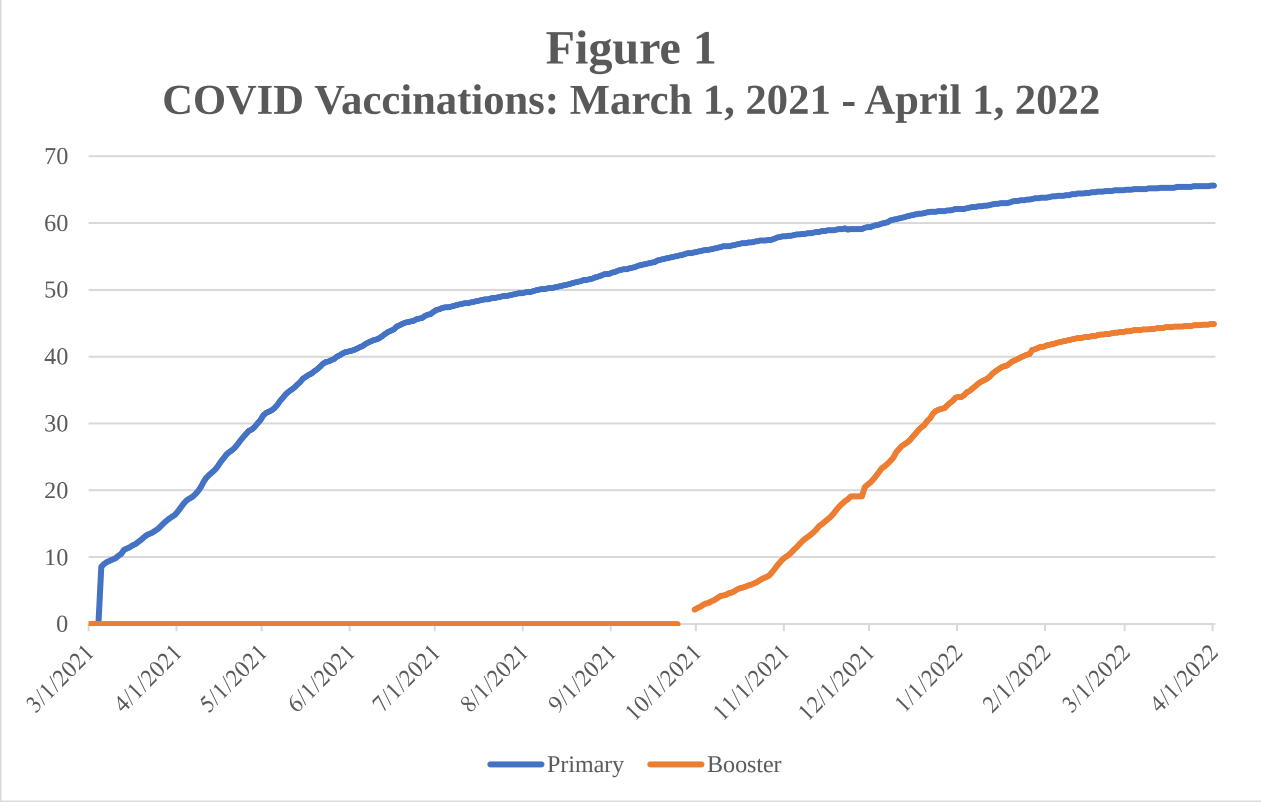
Model →	**[3.1]**	**[3.2]**	**[3.3]**	**[3.4]**
Median household income [*INCOME*]	0.119* (1.9)	0.126** (2.1)	0.115* (1.9)	0.108* (1.8)
Population ≥ 65 years old [*ELDERLY*]	0.546** (4.2)	0.534** (3.9)	0.521** (4.1)	0.513** (3.9)
Black population [*RACE*]	-0.203** (3.1)	-0.195** (3.2)	-0.140** (2.6)	-0.100** (2.2)
High school diploma only *[lowEDUCATION*]	0.174 (1.5)	0.158 (1.5)	0.212* (1.9)	0.267* (2.0)
Non-Metropolitan area [*Non-Metro*]	2.075** (2.1)	1.844** (2.1)	1.492* (1.9)	0.979** (2.1)
New COVID cases [*CovidCASES*]	-0.001 (0.1)	-0.001 (0.2)	0.001 (0.2)	-0.000 (0.1)
Pct. completed primary vaccine series [*PrimaryDose*]	0.255** (2.7)	0.267** (2.7)	0.256** (2.9)	0.271** (3.0)
Number of pharmacies [*nPharm*]	0.009 (1.3)			
Number of pharmacies, county land area adjusted.[1] [*nPharm_land*]		-0.002 (1.0)		
Decentralized public health care governance [*health_decent*]			4.548* (1.7)	4.153 (1.7)
Routine doctor visits [*doctor_visits*]				-0.325 (1.0)
F-Statistic	32.64**	33.60**	26.93**	24.44**
R-squared	0.30	0.30	0.33	0.34
Observations (counties)	3,125	3,096	3,125	3,125

Notes: See Table 2.
1. *Counties in the state of Alaska excluded.*

Table 5
Completion of COVID primary and booster vaccination: Quantile Analysis

	Full Sample		Quantiles	
Panel A: Dependent variable = *PrimaryDose*				
	OLS	**q25**	**q50**	**q75**
Median household income [*INCOME*]	0.205** (3.7)	0.259** (8.1)	0.302** (14.9)	0.269** (13.4)
Population ≥ 65 years old [*ELDERLY*]	0.222* (1.9)	0.198** (3.5)	0.342** (5.7)	0.412** (7.6)
Black population [*RACE*]	0.044 (1.1)	0.083** (4.8)	0.093** (6.7)	0.044** (2.8)
High school diploma only [*lowEDUCATION*]	-0.505** (5.3)	-0.362** (7.8)	-0.460** (15.7)	-0.554** (11.9)
Non-Metropolitan area [*Non-Metro*]	-2.580** (2.5)	-2.183** (3.4)	-3.011** (5.8)	-2.313** (4.1)
New COVID cases [*CovidCASES*]	0.007 (1.5)	0.003 (0.9)	0.009** (4.4)	0.014** (4.7)
Number of Counties	3,125		3,125	
R-sq./Pseudo R-sq.	0.26	0.11	0.17	0.20
Panel B: Dependent variable = *BoosterDose*				
Median household income [*INCOME*]	0.121* (1.9)	0.143** (5.7)	0.141** (7.3)	0.158** (7.3)
Population ≥ 65 years old [*ELDERLY*]	0.538** (4.1)	0.495** (10.9)	0.604** (12.1)	0.703** (15.7)
Black population [*RACE*]	-0.200** (3.1)	-0.187** (9.4)	-0.163** (12.1)	-0.142** (10.9)
High school diploma only [*lowEDUCATION*]	0.163 (1.5)	0.294** (9.2)	0.117** (3.8)	0.031 (0.9)
Non-Metropolitan area [*Non-Metro*]	1.883** (2.1)	1.735** (3.5)	1.928** (5.0)	1.270** (3.3)
New COVID cases [*CovidCASES*]	-0.001 (0.1)	-0.002 (0.5)	0.001 (0.9)	0.004** (2.3)
Pct. completed primary vaccine series [*PrimaryDose*]	0.263** (2.7)	0.265** (12.7)	0.295** (16.5)	0.262** (13.0)
Number of Counties	3,125		3,125	
R-sq./Pseudo R-sq.	0.30	0.16	0.22	0.23

Notes: Variable definitions are provided in Table 1.
All models included a constant term (not reported).
q50 represents the median regression.
Reference model (full sample) reflects results estimated via Ordinary Least Squares from Models 1.1 and 1.2, with absolute t-statistics based on robust state-level clustered standard errors in parentheses.
Absolute value of t-statistics is in parentheses based on bootstrapped standard errors (200 replications) in the quantile regressions.
* denotes statistical significance at the 10% level, and ** denotes significance at the 5% level (or better).



Source: https://data.cdc.gov/Vaccinations/COVID-19-Vaccination-Trends-in-the-United-States-N/rh2h-3yt2