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RESEARCH REPORT

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Associations Between County-level Vaccination Rates and COVID-19 Outcomes Among Medicare Beneficiaries

Analysis of Medicare data and county vaccination rates indicates that COVID-19 vaccinations from January until May 2021 were associated with estimated reductions of approximately 265,000 COVID-19 infections and 39,000 deaths among Medicare beneficiaries.

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KEY POINTS

- COVID-19 vaccines are a key component in controlling the COVID-19 pandemic. Clinical data show vaccines are highly effective in preventing COVID-19 infections and severe outcomes including hospitalization and death.
- In this analysis of individual-level health data and county-level vaccination rates, we find that higher county vaccination rates were associated with significant reductions in the odds of COVID-19 infection, hospitalization, and death among Medicare fee-for-service (FFS) beneficiaries between January and May 2021.
- Comparing the rates of these outcomes to what our model predicts would have happened without any vaccinations, we estimate COVID-19 vaccinations were linked to estimated reductions of approximately 107,000 infections, 43,000 hospitalizations, and 16,000 deaths in our study sample of 25.3 million beneficiaries. These estimates correspond to estimated reductions of approximately 265,000 infections, 107,000 hospitalizations, and 39,000 deaths for the full Medicare population of 62.7 million people.
- After accounting for the potential underreporting of COVID-19 deaths in Medicare FFS claims data, and considering alternative models, the number of deaths prevented among the full Medicare population could plausibly range from 12,000 to 49,000 deaths.
- Reductions in cumulative weekly deaths were found nationally, for all racial and ethnic groups, and across all 48 states included in our sample.
- The difference in vaccination rates for those age 65 and older between the lowest (34%) and highest (85%) counties and states by the end of May highlights the continued opportunity to leverage COVID-19 vaccinations to prevent COVID-19 hospitalizations and deaths.

BACKGROUND

The United States introduced COVID-19 vaccinations starting in December 2020 after 20 million people had been infected and 352,000 lives were lost over the first 9 months of the COVID-19 pandemic.[1] Nearly 80 percent of these deaths were estimated to be among persons 65 and older who are also Medicare eligible based on age.[2] Medicare beneficiaries therefore are a high-risk group who are likely to see significant benefit from COVID-19 vaccinations. Understanding how the initial U.S. COVID-19 vaccination effort potentially reduced COVID-19 infections, hospitalizations, and deaths in the Medicare population can help inform continued efforts to improve vaccination rates and mitigate the harms from COVID-19.

COVID-19 vaccines were first made available to health care workers and nursing home residents; states then rolled out vaccines with different timelines and priority groups, but most prioritized seniors ages 65 and older. COVID-19 vaccines were made available without charge to all U.S. residents, including Medicare beneficiaries. Moderna and Pfizer first gained emergency use authorization in December, and both required two doses several weeks apart. Johnson and Johnson's single dose vaccine also received emergency use authorization and became available in February 2021. Initial clinical studies showed high efficacy of vaccines in preventing severe outcomes from COVID-19 and continued protection against the emerging Delta variants, although effectiveness may be somewhat lower.[3,4] The purpose of this study is to identify associations between COVID-19 infections, hospitalizations, and deaths among Medicare fee-for-service (FFS) beneficiaries and the proportion of the population fully vaccinated at the county-level between January and May 2021. We do so by using a combination of person-level Medicare FFS claims and Centers for Disease Control and Prevention (CDC) data on county-level vaccination rates. Based on these results, we then estimated the net reduction in infections, hospitalizations, and deaths among all 62.7 million Medicare beneficiaries associated with the first 5 months of the U.S.'s COVID-19 vaccine roll-out.

METHODS

Data and Study Period

The study period for developing the estimation model was based on Medicare FFS claims from September 6, 2020, to May 29, 2021 to capture the risk of COVID-19 outcomes both before vaccinations were available and with COVID-19 vaccinations from January-May 2021. The latter period was then used to calculate the difference in expected number of COVID-19 outcomes compared to if no vaccines were available. Data through the end of May 2021 reflect the most complete Medicare FFS claims data currently available from CMS that capture all relevant COVID-19 outcomes. Because Medicare beneficiaries received COVID-19 vaccinations from a variety of sites, many of which may not have generated a claim, Medicare FFS data do not fully capture vaccination status. County-level vaccination data were therefore used to illustrate the association of vaccinations with the estimated reduction of COVID-19 infections and deaths.

The study cohort for the regression model includes 25.3 million Medicare FFS who were continuously enrolled in Part A and B for 12 months prior to the study period until they reached an endpoint in the study period (death or disenrollment). The look-back period allows capture of relevant comorbidities.

Of note, Texas and Hawaii did not provide county-level estimates of vaccinations in the CDC data, so those two states were excluded from the estimation model. This reduced the study cohort from 27.3 million to 25.3 million beneficiaries.

Study Design

We employed a panel study design and combined individual-level Medicare claims data with weekly cumulative county-level vaccination rates from CDC to estimate the association between county-level COVID-19 vaccinations and weekly changes in COVID-19 outcomes among Medicare beneficiaries over time.[5] Our three outcomes were COVID-19 infections captured by ICD-10 diagnosis code for COVID-19 (U07.1), hospitalizations within three weeks, and deaths within nine weeks of the initial COVID-19 diagnosis. Deaths in Medicare were identified from updates to the Medicare enrollment data from the Social Security Administration/Railroad Retirement Board, or from discharge codes in facility claims or physician claims indicating death after an ambulance was called. The outcomes are measured weekly in association with the county vaccination rates in the same week.

Model Variables

The key study predictors were CDC county-level COVID-19 vaccination rates for adults ages 18-64 and those 65 years and older who were fully vaccinated (e.g. received two doses for Pfizer/Moderna and one dose for Johnson and Johnson vaccines). Our model included those measures as separate predictor variables, expressed in terms of cumulative share of the population to date fully vaccinated by the end of each week in the study period. These vaccination rates reflect both the likelihood that Medicare beneficiaries aged 65 and older were vaccinated, and the extent to which people around beneficiaries may be vaccinated, including whether beneficiaries younger than 65 eligible for Medicare due to a disability or end-stage renal disease were vaccinated. The model estimated weekly COVID-19 outcomes during the study period as a function of these variables, with the county vaccination rates as the key independent variables of interest. For each week, we then compared the estimated COVID-19 outcomes to a counterfactual scenario where vaccination rates were zero for all age groups from January to May 2021. The weekly difference between outcomes with and without vaccines was summed for each week from January to May 2021 to estimate the cumulative change nationally in COVID-19 outcomes associated with the introduction of COVID-19 vaccines at the end of December 2020. State-specific estimates were generated by summing the weekly differences for each of the 50 states including Puerto Rico and the District of Columbia. For the two states excluded from the estimation model, Texas and Hawaii, the estimated reduction in COVID-19 outcomes were imputed based on another state with a similar vaccination rate as part of reporting state-specific estimates.

The model, adapted from our previously published approach,[6] adjusted for beneficiary demographic and comorbid characteristics, as well as local area characteristics such as population density and the CDC's Social Vulnerability Index, both at the Census tract level. Beneficiary characteristics included age, sex, race/ethnicity, dual enrollment in Medicaid, long-term nursing home residency (>90 days in a skilled nursing facility), and disability or end-stage renal disease as the original reason for Medicare enrollment. The definition of long-term nursing home resident did not include beneficiaries living in assisted living facilities or other congregate housing. Beneficiary clinical characteristics were based on flags for hierarchical condition categories (HCC) for comorbidities considered relevant to COVID-19 and count of these comorbidities (0,1,2,3,4+) identified in the 12 months prior to the study period (see Appendix for details). The model also included state fixed effects to control for differences in states' COVID-19

mitigation efforts and other unmeasured demographic and health care differences across states that were stable over time.

Our main model used month fixed effects to adjust for any national temporal trends and fluctuations in COVID-19 outcomes over the course of the study period. In sensitivity analyses, we ran the model with data limited to January – May 2021 and replaced monthly fixed effects with weekly fixed effects to better control for changes in temporal trends. This sensitivity analysis also used categories of community vaccination rates in order to model both temporal trends and vaccination rates over time without a linear assumption (See Appendix for details).

In addition to nationwide and state-specific estimates, COVID-19 outcomes were examined by race/ethnicity, and nursing home status given the substantial disparities in COVID-19 outcomes that have been observed during the pandemic.[7]

Projections to the Full Medicare Population

We extrapolated the Medicare FFS study sample estimates to the entire Medicare population which includes both Traditional FFS Medicare and beneficiaries enrolled in Medicare Advantage plans. As our sample includes 25.3 million Medicare FFS beneficiaries and the total Medicare population is approximately 62.7 million beneficiaries, we used a factor of 2.48 (the ratio of total Medicare population to study cohort) to inflate the study cohort estimates to the total Medicare population.[8] We used a factor for each subgroup (based on the ratio of the total Medicare population to each subgroup population) to project our study cohort estimates to the racial/ethnic and nursing home subgroups. We also compared the demographic characteristics of the study cohort with the full Medicare population to check our assumptions and representativeness of the study sample (see Appendix).

Detailed methods on the regression models are available in the Appendix.

FINDINGS

Association between cumulative county-level COVID-19 vaccination rates and the risk of COVID-19 outcomes

At the start of the COVID-19 vaccine roll-out, weekly US vaccination rates for COVID-19 (e.g., proportion of population fully vaccinated) in January 2021 started from less than 1% in both 18-64 and 65+ age groups, then increased to a cumulative total of 47% and 80% respectively by the last week of May.

Table 1 shows the regression results for our key predictor variables. These results reflect the independent association between county-level COVID-19 vaccinations and observed changes in COVID-19 outcomes among Medicare beneficiaries over time, after controlling for beneficiary and local area characteristics, as well as state and month fixed effects to account for differences between states and temporal trends.*

For the risk of COVID-19 infection, a 10% increase in COVID-19 vaccination rate among those 65 and older was associated with an 11% decrease in the odds of COVID-19 infection (based on odds ratio [OR]=0.989, 95% confidence interval [CI] 0.988-0.991, P<0.001), with an estimated reduction between 9-12%.

We find an 11-12% decrease in COVID-19 hospitalizations and deaths for every 10% increase in county vaccination rates, and a similar decrease in infections among Medicare beneficiaries.

For COVID-related hospitalizations and deaths, a 10% increase in COVID-19 vaccinations in those ages 18-64 was associated with approximately an 11% (OR=0.989, 95% CI 0.982-0.995) and 12% (OR=0.988, 95% CI 0.978-0.999) decrease in the odds of COVID-19 hospitalizations and deaths, respectively, among Medicare beneficiaries infected with COVID-19 (P<0.05).

Table 1. Association between COVID-19 Vaccination Rates and COVID-19 Outcomes, Sept 2020 – May 2021: Regression Odds Ratios [OR]

Key Predictors of COVID-19 Outcomes	Risk of COVID-19 infection, OR (95% Confidence Interval)	Risk of COVID-19 hospitalization, OR (95% Confidence Interval)	Risk of COVID-19 death, OR (95% Confidence Interval)
Vaccination Rate 18-64	0.997 (0.994, 1.000)	**0.989**** (0.982-0.995)	**0.988*** (0.978-0.999)
Vaccination Rate 65+	**0.989**** (0.988-0.991)	1.003 (1.000-1.006)	1.002 (0.996-1.007)

Notes: *P<0.05. ** P< 0.001. Note: N = 25.3 million Medicare FFS beneficiaries. Models adjusted for beneficiary demographic characteristics, comorbidities, local county characteristics, and state and month fixed effects. Results are reported to 3 decimal places which translates to percentages to 1 decimal place.

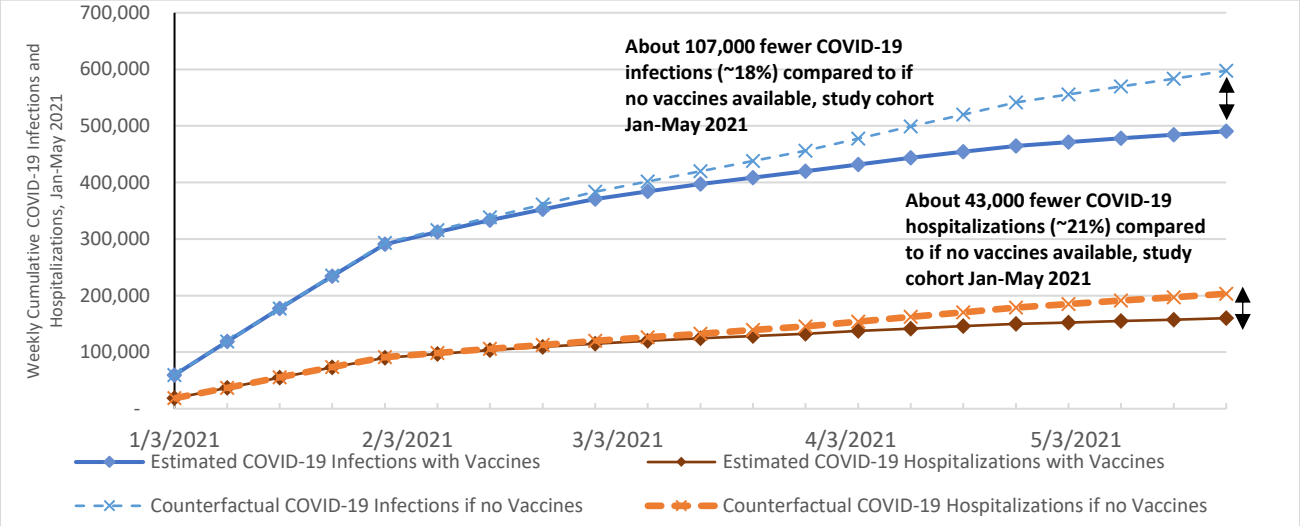
* Since the absolute risk of each outcome are all small, for simplicity the changes in odds are interpreted as changes in the rate of outcomes. The decrease in odds is calculated as the odds ratio for the vaccination rate minus 1 times 100%, e.g. 0.989-1 *100% = - 0.011 *100% = - 1.1%. A 10% increase in vaccination rate would therefore decrease odds of infection by 11%).

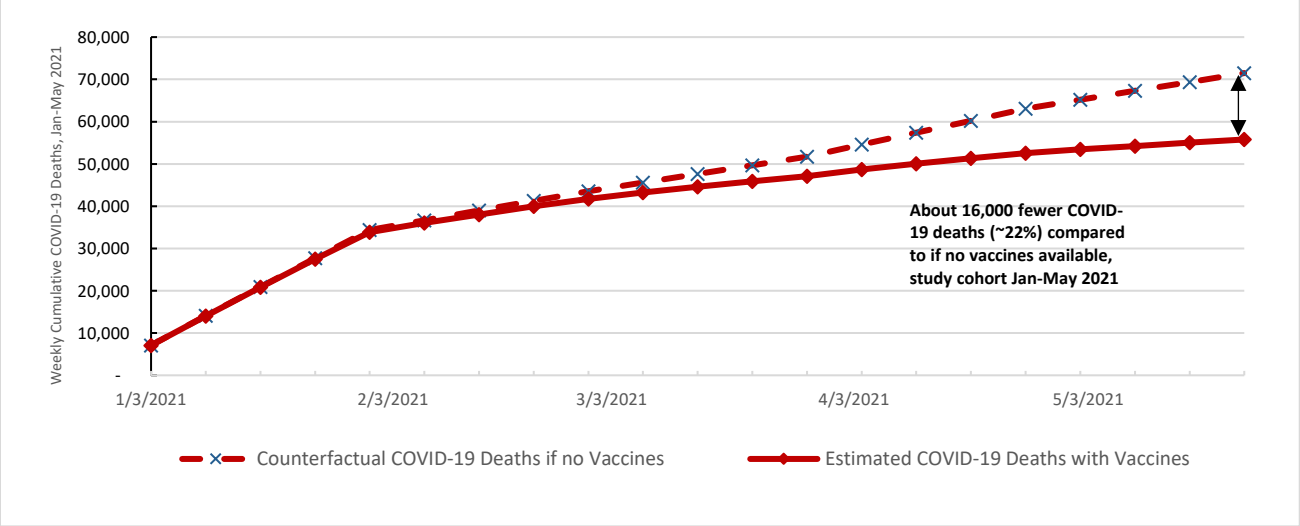
Estimated Vaccine-Associated Reduction in COVID-19 outcomes from January-May 2021 among Medicare Beneficiaries

Figure 1 shows the difference in COVID-19 infections and hospitalizations in our study sample with and without vaccines, based on the association with county-level vaccination rates in the regression models described above.

The solid blue, brown and red lines in Figure 1 plot the cumulative weekly number of COVID-19 infections, hospitalizations and deaths estimated by the model based on the observed association between COVID-19 vaccinations and outcomes. The dotted lines plot the COVID-19 outcomes as if no vaccines were available, termed the counterfactual scenario, by modeling zero vaccination rates. As can be seen in Figure 1, without the introduction of vaccines, there would have many more COVID-19 infections among Medicare beneficiaries. The initial roll-out of vaccinations from January-May flattened the curve of COVID-19 infections, hospitalizations and deaths.

Figure 1. Comparison of the cumulative weekly number of COVID-19 infections, hospitalizations, and deaths estimated with vaccines vs. counterfactual without vaccines in study cohort, January – May 2021





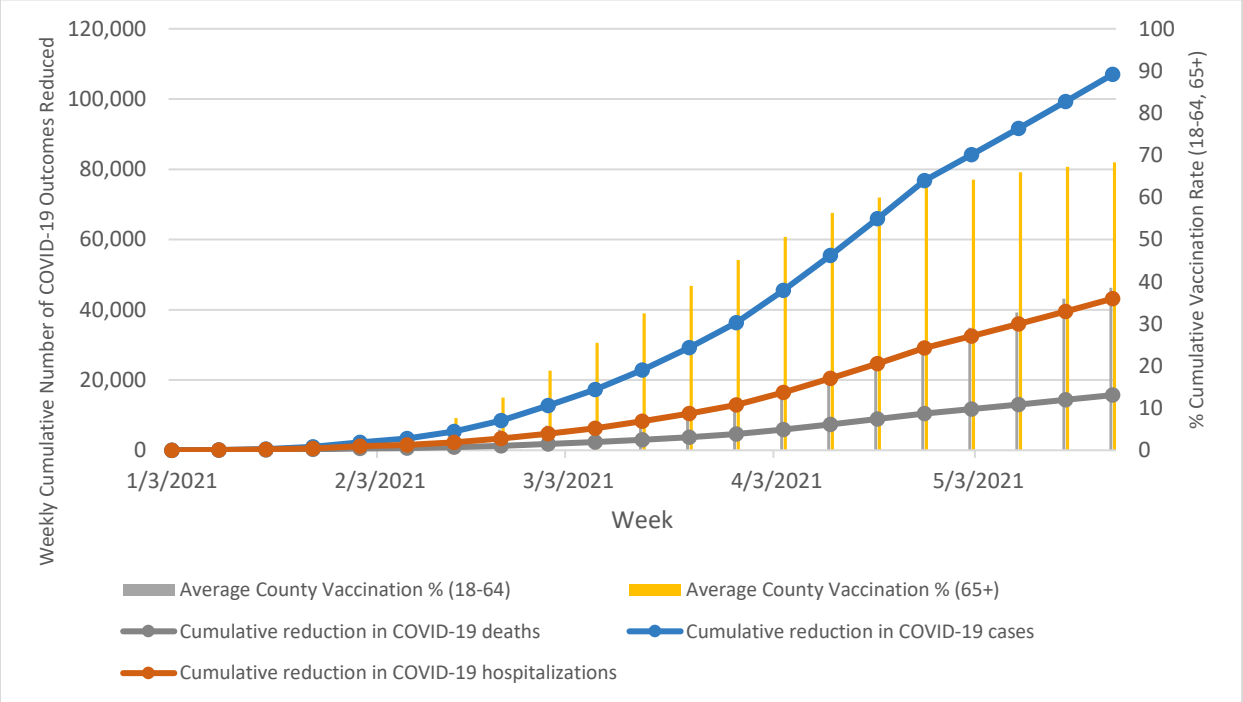
Notes: Cumulative weekly number of COVID-19 infections, hospitalizations and deaths without vaccines "counterfactual"

(dotted line) and number with vaccines estimated by the model (solid line). The scale for deaths is smaller than the scale for infections and hospitalizations. The weekly cumulative reductions in all three COVID-19 outcomes associated with COVID-19 vaccinations (the difference between these two lines) are shown in Figure 2.

To get an estimate of the total number of COVID-19 outcomes prevented by the introduction of vaccinations, we summed the weekly differences between the estimated and counterfactual number of outcomes represented by the dashed versus solid lines in Figure 1. Figure 2 summarizes the total number of COVID-19 prevented among the study cohort over time. It shows that as the vaccinations are rolled out, more COVID-19 outcomes are prevented. The figure plots the estimated weekly cumulative reduction in COVID-19 outcomes in our sample associated with county-level vaccination rates. The three lines in the figure show COVID-19 related outcomes: infections in blue, hospitalizations in orange, and deaths in grey. The bars in the figure show county-level vaccination rates increasing over time: ages 18-64 in the grey bar, and ages 65+ in the yellow bar.

The figure shows the cumulative estimated reduction in the number of COVID-19 infections, hospitalizations, and deaths compared to what they would have been among our study cohort in the absence of vaccination, starting in early February and continuing throughout the initial vaccination roll-out period.

Figure 2. Estimated Reduction in COVID-19 Outcomes in Association with COVID-19 Vaccinations Among the Medicare Study Sample (N=25.3 million)



Notes: Reductions in cumulative COVID-19 cases, hospitalizations, and deaths are weekly differences between estimated and predicted counts for each outcome with and without vaccines between January and May 2021 in the Medicare study cohort (N=25.3 million). This included 48 states and Puerto Rico and District of Columbia in the estimation model and excluded Texas and Hawaii. Average vaccine rates for the proportion of the population ages 18-64 and 65+ fully vaccinated are at the county level and come from the CDC vaccine data https://www.cdc.gov/coronavirus/2019-ncov/vaccines/distributing/about-vaccine-data.html

Table 2 shows the estimated reduction in COVID-19 outcomes among Medicare beneficiaries in our sample related to county-level COVID-19 vaccinations from January 2021-May 2021.

By the end of May when 68% of people 65 and over on average had been vaccinated in the U.S., our model estimated potentially 107,000 fewer infections, 43,000 fewer hospitalizations, and 16,000 fewer deaths in the study sample (Table 2).

This represents an estimated 18% reduction in COVID-19 infections, 21% reduction in COVID-19 hospitalizations, and 22% reduction in COVID-19 deaths based on the number of potential COVID-19 outcomes (the counterfactual scenario) that we project would have occurred in the absence of vaccines from January to May 2021.

Vaccinations were associated with roughly a 1/5 reduction in COVID-19 infections among Medicare beneficiaries, as well as COVID-19 related hospitalizations and deaths.

For example, without vaccines, we would have expected 598,000 COVID-19 infections in the study sample; instead with vaccinations, there were about 491,000 infections, resulting in 107,000 fewer infections. The percent reduction is then calculated as the number of COVID-19 infections prevented divided by the number of infections expected without vaccines (107,000/598,000=18%).

Table 2. Estimated Reductions in COVID-19 Outcomes in Association with COVID-19 Vaccinations Among Medicare Study Cohort and Projected to Full Medicare Population (Jan-May 2021)

	COVID-19 Infections	COVID-19 Hospitalizations	COVID-19 Deaths
STUDY COHORT	**N=25.3 million Medicare FFS beneficiaries**		
If no vaccines available, number (predicted with zero vaccination rate)	598,000	203,000	71,000
Model estimated outcomes with vaccines, number	491,000	160,000	56,000
Estimated reduction in number of COVID Outcomes* (percent reduction)	**107,000 (17.9%)**	**43,000 (21.2%)**	**16,000 (22.0%)**
FULL MEDICARE POPULATION	**N=62.7 million Medicare beneficiaries**		
If no vaccines available, number (predicted with zero vaccination rate)	1,481,000	504,000	177,000
Model estimated outcomes with vaccines, number	1,216,000	397,000	138,000
Estimated reduction in number of COVID Outcomes* (percent reduction)	**265,000 (17.9%)**	**107,000 (21.2%)**	**39,000 (22.0%)**

Notes: Estimates are predicted based on probabilities for the outcome from regression models with cumulative county-level weekly vaccination rates for adults ages 18-64 and 65+, controlling for beneficiary demographic characteristics, comorbidities, local county characteristics, and state and month fixed effects. 48 states and Puerto Rico and District of Columbia were included in the estimation model. Texas and Hawaii were excluded from the model due to lack of county-level vaccination rate data. COVID-19 infections are identified using ICD-19 diagnosis U07.1 for COVID-19. Hospitalizations are within 3 weeks and deaths are within 9 weeks of the initial COVID-19 diagnosis. Numbers may not sum precisely due to

rounding. All regression estimates are rounded to the nearest hundred for estimates below 10,000 and to the nearest thousand for numbers above 10,000. *Reductions in Outcome = weekly number without vaccinations – weekly number with vaccinations, summed for each week from January-May 2021. The percent reduced is calculated as the reduction in outcomes divided by the number of outcomes if no vaccinations were available (counterfactual).

Table 2 includes projected estimates for the full Medicare population, including 26 million Medicare Advantage enrollees and other FFS beneficiaries who did not meet our primary sample inclusion criteria. To estimate the number of COVID-19 outcomes reduced in association with vaccinations among all Medicare beneficiaries, we projected the reduction in COVID-19 outcomes among the study cohort to the entire Medicare population of 62.7 million beneficiaries.[8] For simplicity, assuming that all Medicare beneficiaries had the same COVID-19 risks and vaccine uptake as those in our FFS study cohort, we estimate that vaccinations were associated with approximately 265,000 fewer COVID-19 infections, 107,000 fewer COVID-19 hospitalizations, and 39,000 fewer COVID-related deaths among all Medicare beneficiaries by the end of May.

An alternative model with week fixed effects and modeled vaccination rates as a categorical variable estimated a smaller reduction in COVID-19 outcomes than the main model. This provides a lower bound on the estimated reductions in COVID-19 outcomes associated with COVID-19 vaccinations. Among the study cohort in this model, COVID-19 vaccinations were associated with estimated reductions of 35,000 infections, 14,000 hospitalizations and 4,900 deaths. When projected to the full Medicare population, these lower bound estimates from the alternate model suggest COVID-19 vaccination prevented at least 87,000 infections, 34,000 hospitalizations and 12,000 deaths among all Medicare beneficiaries.

These sensitivity analyses confirm the negative association between COVID-19 vaccination rates and reduction in COVID-19 outcomes, especially hospitalizations and deaths, but show the magnitude of the estimated reductions depends on the model assumptions and the comparison group selected. The alternate model may have smaller estimated reductions in COVID-19 outcomes because including weekly fixed effects may have absorbed much of the variation in vaccination rates compared to using month fixed effects. Another potential reason for the smaller estimated reductions may be that the 20 indicators for weekly temporal changes are collinear with the 32 indicators for vaccination rates, and this may have led to less stable estimates of the concurrent impact of changes in vaccination rates and time (see Appendix for detailed methods on sensitivity analyses).

Impacts of COVID-19 Vaccines on Demographic Subgroups

Table 3 shows these results for demographic subgroups in the study cohort. COVID-19 vaccination rates were associated with an estimated 17-21% reduction in COVID-19 infections and an estimated 21-25% reduction in COVID-19 deaths across racial and ethnic groups among Medicare beneficiaries. Note that the estimates for smaller subgroups are more imprecise due to small sample size.

The largest percent reduction appeared to be for American Indians and Alaska Natives (AI/AN), with an estimated reduction in infections of 21%, compared to 18% among White beneficiaries, and reduction in deaths of 25% compared to 22% among White beneficiaries. The largest estimated number of reductions in COVID-19 outcomes were among White beneficiaries, who comprised about 81% of the study cohort (see Appendix table 3 for breakdown of study cohort by race/ethnicity compared to Medicare population).

Table 3. Reductions in COVID-19 Outcomes in Association with Vaccination Among Medicare Study Cohort (January – May 2021), by Race/Ethnicity

Race/ Ethnicity	Study Cohort: If no vaccines available	Study Cohort: Based on actual vaccination rates	Study Cohort: Estimated reduction* in COVID-19 Outcomes	Projected to Total Medicare: Projected reduction in COVID-19 Outcomes	Projected to Total Medicare: Percent reduction**
COVID-19 Infections					
Study Cohort (N=25.3 million)	598,000	491,000	107,000	265,000	17.9%
White (N=20.6 million)	479,000	393,000	86,000	193,000	17.9%
Black (N=2.0 million)	51,000	42,000	8,800	29,000	17.3%
Hispanic (N=1.2 million)	36,000	30,000	6,400	29,000	17.7%
Asian (N=676,441)	12,000	9,900	2,300	7,600	18.7%
AI/AN (N=145,488)	5,500	4,400	1,100	2,000	20.5%
Other (N=737,449)	13,000	11,000	2,500	6,300	18.5%
COVID-19 Hospitalizations					
Study Cohort (N=25.3 million)	203,000	160,000	43,000	107,000	21.2%
White (N=20.6 million)	155,000	122,000	33,000	74,000	21.4%
Black (N=2.0 million)	22,000	18,000	4,000	15,000	19.9%
Hispanic (N=1.2 million)	14,000	11,000	3,000	13,700	20.9%
Asian (N=676,441)	5,500	4,300	1,200	4,000	21.8%
AI/AN (N=145,488)	2,200	1,700	500	1,000	23.8%
Other (N=737,449)	4,000	3,100	900	2,300	22.4%
COVID-19 Deaths					
Study Cohort (N=25.3 million)	71,000	56,000	16,000	39,000	22.0%
White (N=20.6 million)	56,000	44,000	12,000	28,000	22.0%
Black (N=2.0 million)	6,600	5,200	1,400	4,600	20.9%
Hispanic (N=1.2 million)	4,900	3,800	1,100	5,000	21.9%
Asian (N=676,441)	1,800	1,400	400	1,400	23.3%
AI/AN (N=145,488)	900	700	200	400	24.8%
Other (N=737,449)	1,000	800	200	600	23.5%

Notes: Estimates are predicted based on probabilities for the outcome from primary regression models with cumulative county-level weekly vaccination rates for ages 18-64 and 65+, controlling for beneficiary demographic characteristics, comorbidities, local county characteristics, and state and month fixed effects. These estimates assume that the overall model applies to racial/ethnic groups. The total Medicare estimates are projected from study cohort estimates by multiplying them by a factor for each subgroup (the ratio of total Medicare population to Medicare beneficiary counts in our sample). Numbers may not sum precisely due to rounding. All regression estimates are rounded to the nearest hundred for estimates below 10,000 and to the nearest thousand for numbers above 10,000. AI/AN = American Indians and Alaska Natives. *Reductions in Outcome = weekly number without vaccinations – weekly number with vaccinations, summed for each week from January-May 2021. **Percent reduction is calculated as the proportion of estimated reduction in outcomes divided by the number of outcomes if no vaccines were available (counterfactual).

We estimated reductions of 29,000 infections and nearly 4,600 deaths among Black beneficiaries in the total Medicare population, reductions of 29,000 infections and nearly 5,000 deaths among Hispanic beneficiaries, reductions of nearly 7,600 infections and 1,400 deaths among Asian beneficiaries, and reductions of 2,000 infections and 400 deaths among AI/AN beneficiaries in the total Medicare population.

Impacts of COVID-19 Vaccines on Nursing Home Residents

Another group at high-risk of COVID-19 infections and death are long-term nursing home residents, who were disproportionately affected by COVID-19.[9] For long-term nursing home residents identified in this study sample, Table 4 shows COVID-19 vaccinations were associated with estimated reductions of about 8,400 infections, 1,900 hospitalizations and 2,200 deaths in the study cohort, which translates to an estimated reduction of nearly 21,000 infections, 4,900 hospitalizations and 5,600 deaths when projected to the total Medicare population. Compared with beneficiaries living in the community, long-term nursing home residents were less likely to be hospitalized than beneficiaries living in the community, presumably because they are already in a health care setting.

Table 4. Reductions in COVID-19 Outcomes in Association with Vaccination for Nursing Home Residents vs. Community-dwelling Medicare Beneficiaries (January – May 2021)

	Study Cohort			Projected to Total Medicare	
Nursing Home Status	If no vaccines available	Based on actual vaccination rates	Estimated reductions* in COVID-19 outcome	Projected reductions* in COVID-19 outcome	Percent reduction**
COVID-19 Infections					
Study Cohort	598,000	491,000	107,000	265,000	17.9%
Community N=24.9 million	543,000	444,000	99,000	244,000	18.2%
Nursing Home N= 330,524	55,000	47,000	8,400	21,000	15.3%
COVID-19 Hospitalizations					
Study Cohort	203,000	160,000	43,000	107,000	21.2%
Community	193,000	152,000	41,000	102,000	21.4%
Nursing Home	10,000	8,300	1,900	4,900	18.8%

Nursing Home Status	Study Cohort: If no vaccines available	Study Cohort: Based on actual vaccination rates	Study Cohort: Estimated reductions* in COVID-19 outcome	Projected to Total Medicare: Projected reductions* in COVID-19 outcome	Projected to Total Medicare: Percent reduction**
COVID-19 Deaths					
Study Cohort	71,000	56,000	16,000	39,000	22.0%
Community	60,000	46,000	14,000	33,000	22.7%
Nursing Home	12,000	9,800	2,200	5,600	18.4%

Notes: Estimates are predicted based on probabilities for the outcome from the primary regression models with cumulative county-level weekly vaccination rates for ages 18-64 and 65+, controlling for beneficiary demographic characteristics, comorbidities, local county characteristics, and state and month fixed effects. These estimates assume that the overall model applies to nursing home and community-dwelling residents. The total Medicare estimates are projected from study cohort estimates by multiplying them by a factor for each subgroup (the ratio of total Medicare population to Medicare beneficiary counts in our sample). Numbers may not sum precisely due to rounding. All regression estimates are rounded to the nearest hundred for estimates below 10,000 and to the nearest thousand for numbers above 10,000. *Reductions in Outcome = weekly number without vaccinations – weekly number with vaccinations, summed for each week from January-May 2021. **Percent reduction is calculated as the proportion of estimated reduction in outcomes divided by the number of outcomes if no vaccines were available (counterfactual).

State Estimates of Vaccine-Related Reductions in COVID-19 Outcomes

State-specific estimates were generated for all 50 states based on the state indicator in the estimation model. Table 5 shows state-specific estimates of reductions in COVID-19 outcomes for the 20 most populous states in our sample (excluding Texas) and projected to the total Medicare population. Nationally, on average this study found COVID-19 vaccinations were associated with a reduction of 420 COVID-19 infections per 100,000 beneficiaries, a reduction of 170 COVID-related hospitalizations per 100,000 beneficiaries and a decrease of 60 COVID-related deaths per 100,000 beneficiaries, with a range of results reflecting the range of initial vaccination rates.

Results for all 50 states, Puerto Rico and D.C. per 100,000 Medicare beneficiaries are shown in the Appendix, including imputed estimates for Texas and Hawaii. However, estimates for smaller states should be interpreted cautiously.

Table 5: State-specific Estimates of COVID-19 Reductions Associated with COVID-19 Vaccinations for Top 20 Most Populous States, Study Cohort and Projected to Total Medicare Population

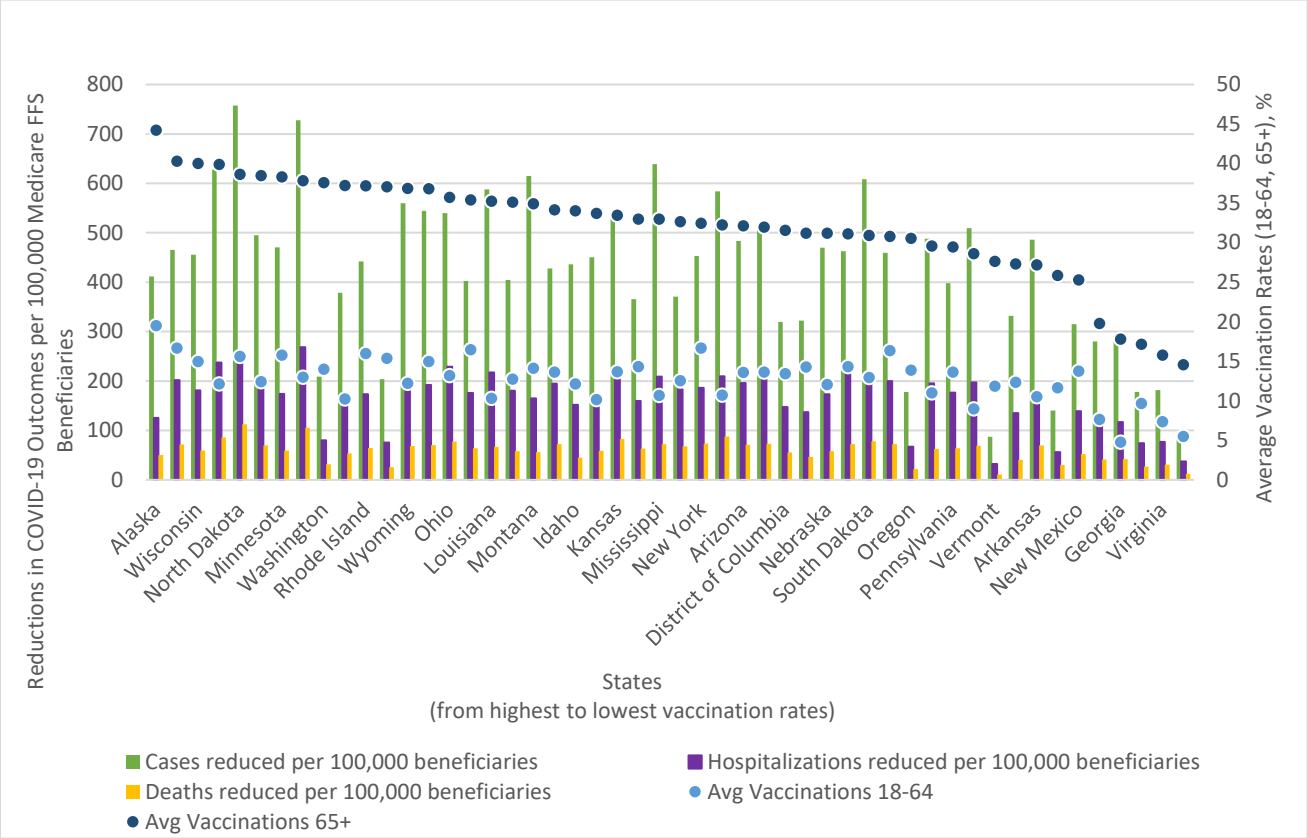
State	Study Cohort	COVID Vaccination Rates at end of May, 2021		Study Cohort N= 25.3 million			Projected to Total Medicare N=62.7 million		
		State Vaccination Rate 18-64, %	State Vaccination Rate 65+, %	Estimated reduction in COVID Infections*	Estimated reduction in COVID Hospitali-zations*	Estimated reduction in COVID Deaths*	Projected Reduction in COVID Infections	Projected Reduction in COVID Hospitali-zations	Projected Reduction in COVID Deaths
Total US	**25,295,000**	**38.5**	**68.3**	**107,000**	**43,000**	**16,000**	**265,000**	**107,000**	**39,000**
California	2,439,000	45.7	69.0	8,900	3,900	1,500	22,000	9,700	3,800
Florida	1,810,000	35.0	73.9	6,900	2,700	1,000	17,000	6,700	2,400
New York	1,450,000	50.6	73.1	6,600	2,700	1,100	16,000	6,700	2,600
Illinois	1,167,000	41.1	69.0	5,400	2,500	800	13,000	6,200	2,100
Pennsylvania	1,115,000	40.7	71.7	4,400	2,000	700	11,000	4,900	1,800

State	Study Cohort	COVID Vaccination Rates at end of May, 2021		Study Cohort N= 25.3 million			Projected to Total Medicare N=62.7 million		
		State Vaccination Rate 18-64, %	State Vaccination Rate 65+, %	Estimated reduction in COVID Infections*	Estimated reduction in COVID Hospitali-zations*	Estimated reduction in COVID Deaths*	Projected Reduction in COVID Infections	Projected Reduction in COVID Hospitali-zations	Projected Reduction in COVID Deaths
Ohio	935,000	39.1	74.3	5,000	2,100	700	13,000	5,300	1,800
North Carolina	913,000	36.1	71.5	4,500	1,700	600	11,000	4,200	1,600
Virginia	860,000	22.1	34.9	1,600	700	300	3,900	1,600	700
Michigan	803,000	40.7	73.0	3,400	1,600	600	8,500	3,900	1,400
New Jersey	782,000	48.5	70.5	3,600	1,600	600	8,900	3,900	1,400
Massachusetts	746,000	46.7	70.0	2,400	1,000	300	6,000	2,500	900
Georgia	712,000	14.9	34.4	2,100	800	300	5,100	2,100	700
Maryland	672,000	49.6	79.3	2,700	1,200	400	6,700	2,900	1,100
Washington	662,000	43.6	77.7	1,400	500	2090	3,400	1,300	500
Indiana	611,000	36.7	76.4	3,800	1,500	500	9,500	3,600	1,300
Tennessee	593,000	31.1	67.1	3,500	1,200	500	8,600	3,100	1,300
Arizona	570,000	37.6	67.4	2,800	1,100	400	6,800	2,800	1,000
South Carolina	567,000	30.3	67.8	2,600	900	300	6,300	2,300	800
Missouri	552,000	29.9	63.6	2,700	1,100	300	6,700	2,700	900
Wisconsin	487,000	44.3	83.1	2,200	900	300	5,500	2,200	700

Notes: Estimates are predicted based on probabilities for the outcome from primary regression models with cumulative county-level weekly vaccination rates for ages 18-64 and 65+, controlling for beneficiary demographic characteristics, comorbidities, local county characteristics, and state and month fixed effects. The total Medicare estimates are projected from study cohort estimates by multiplying them by a factor of 2.45 (the ratio of total Medicare population to Medicare beneficiary counts in our sample). *Reductions in Outcome = weekly number without vaccinations – weekly number with vaccinations, summed for each week from January-May 2021. Numbers may not sum precisely due to rounding. All estimates are rounded to the nearest hundred for estimates below 10,000 and to the nearest thousand for numbers above 10,000. Estimates below 100 are rounded to the nearest ten and masked if below 50 for protection of privacy. Texas and Hawaii are not included in the estimation model or this table, as they lacked county-level vaccination rate. Estimates for those two states are imputed and included in the Appendix.

Figure 3 compares the estimated cumulative reduction in COVID-19 outcomes per 100,000 Medicare beneficiaries in each state to average vaccination rates from January to May 2021. As expected, there was generally a greater reduction in cumulative COVID-19 infections, COVID-related hospitalizations, and deaths per 100,000 beneficiaries related to vaccination in states with higher average vaccination rates. The figure also shows a steeper gradient at low levels of vaccination, as the projected reductions in COVID-19 outcomes rise more dramatically on the right side of the figure, in states with lower vaccination rates compared to those with higher rates.

Figure 3. Reductions in COVID-19 Outcomes per 100,000 Beneficiaries Associated with COVID-19 Vaccinations, By State Vaccination Rates Among Adults 65 and older



Notes: This figure shows the estimated reductions in COVID-19 infections, hospitalizations, and deaths for each state calculated per 100,000 Medicare FFS beneficiaries. The estimated reductions are the cumulative weekly differences in counts for each outcome estimated by the model with and without vaccines from January to May 2021. Average vaccine rates for ages 18-64 and 65+ are at the county level from the CDC data. *This figure does not show Hawaii and Texas as the they were excluded from the model sample due to lack of data on county vaccination rates; however, these were imputed using estimated vaccine effectiveness from a state with a similar vaccination rate and shown in the Appendix.

In addition to comparing states, we examined counties by their vaccination levels. After dividing counties into thirds based on their vaccination rates at the end of May among those 65 and older, counties in the top and middle thirds had an average vaccination rate of 70-80% compared with 51% for counties in the lowest third of vaccination rates; for vaccination rates among adults 18-64, these were 39-47% in middle and top thirds vs. 27% in the lowest third. Comparing the top and middle third vaccination rate counties with the lowest third counties, the average reduction in COVID-19 outcomes was 446-450 vs. 361 infections, 179-184 vs. 143 hospitalizations, and 65-67 vs. 52 deaths per 100,000 Medicare beneficiaries. This suggests that if low vaccination counties increased their vaccination rates among adults 65 and older by about 19%-30% (e.g., from 51% to >70%) they could potentially prevent another 84-89 infections, 36-41 hospitalizations and 12-14 deaths per 100,000 beneficiaries (see Appendix Table 2).

Discussion

In this population-level regression analysis, we found that county-level COVID-19 vaccination rates were significantly associated with reductions in the odds of COVID-19 infections and severe outcomes among Medicare beneficiaries. Of note, we found a strong negative linear relationship between county-level vaccination rates and COVID-19 outcomes among Medicare beneficiaries, which appeared to taper off at higher vaccination rates, as supported by sensitivity analyses. This suggests that initial increases in vaccination rates are likely very effective and even a modest increase in vaccination rates has a large payoff; accordingly, increasing vaccination rates in low vaccination rate counties may have a larger impact on mitigating COVID-19 harms than further increasing rates in counties that already have high vaccination rates.

Initial increases in vaccination rates are likely very effective and even a modest increase in vaccination rates has a large payoff; accordingly, increasing vaccination rates in low vaccination rate counties may have a larger impact on mitigating COVID-19 harms than further increasing rates in counties that already have high vaccination rates.

Furthermore, our study shows that both vaccination rates for those ages 65 and older and those 18-64 had a significant relationship with improved COVID-19 outcomes among the Medicare FFS study cohort, especially reductions in severe outcomes. This suggests that to protect Medicare beneficiaries, a high vaccination rate among those 65 and older on its own is not as effective as high vaccination rates among all adults.

Based on the negative association between county vaccination rates and corresponding COVID-19 outcomes in 2021, we then estimated that without COVID-19 vaccinations more than half a million Medicare FFS beneficiaries in the study cohort might have had a COVID-19 infection between January-May 2021, nearly 203,000 of those might have been hospitalized with COVID-19, and about a third of those hospitalized (about 71,000) might have died. Projected to the full Medicare population, our study estimated vaccinations were associated with approximately a quarter of a million (265,000) fewer Medicare beneficiaries with COVID-19 infection, 107,000 fewer COVID-19 hospitalizations, and 39,000 fewer COVID-related deaths among all Medicare beneficiaries by the end of May 2021.

COVID-19 vaccinations were associated with about a quarter of a million fewer COVID-19 infections, 107,000 fewer COVID-19 hospitalizations, and 39,000 fewer COVID-19 related deaths among all Medicare beneficiaries by the end of May 2021.

Other studies have also found significant reductions in deaths associated with COVID-19 vaccinations in 2021.[10,11] However, those studies did not examine the relationship between vaccinations and COVID-19 outcomes in the Medicare population, and our study used rich individual-level claims data to control for potential confounders and other factors not measured in prior studies. As discussed earlier, our estimates likely reflect both higher vaccination rates among the Medicare population and lower risks of infection in seniors, who may have taken more measures to limit social contacts and restrict mobility in the fall of 2020 than the younger adult population. Other reasons for differences in

our estimates relative to other studies may be due to different analytical methods and data.

In summary, we found that the initial roll-out of COVID-19 vaccinations in 2021 was associated with an 18% reduction in infections among Medicare beneficiaries who might have had a COVID-19 infection and was associated with 21-22% reductions in hospitalizations and deaths compared to if no vaccines were available.

Implications of Study Findings for the Future

These study findings reflect the relationship between the initial vaccine roll-out on and reductions in COVID-19 infections and severe outcomes. Vaccination rates have continued to rise over the summer, and with the surge in cases from the Delta variant, the importance of vaccination has likely grown substantially given the Delta variant is more than twice as contagious as previous variants and has a higher transmission rate among unvaccinated people.[12] As of September 7, 2021, CDC data show about 64% of adults 18 to 64 have been vaccinated, nearly twice as high as the vaccination rates at the end of May, and nearly 82% of people aged 65 and older are fully vaccinated, about 20% higher than rates at the end of the study. Further study of population-level impacts can help assess the effectiveness of COVID-19 vaccines against severe illness with the Delta variant, as a complement to recent clinical studies. Those who remained unvaccinated (or only partially vaccinated) are at far higher risk of COVID-19 infection and severe outcomes.[13]

Health Equity Implications of COVID-19 Vaccinations

Vaccinations were associated with reduced risks of COVID-19 among Black, Hispanic, Asian, and AI/AN beneficiaries. We estimated COVID-19 vaccinations were associated with reductions of approximately 19,000 infections, 9,000 hospitalizations and 3,000 deaths among Medicare beneficiaries in the study cohort from these communities. Projected to the full Medicare population, we estimated COVID-19 vaccinations were associated with reductions of 68,000 infections, 33,000 hospitalizations, and 11,000 deaths among Black, Hispanic, Asian, and AI/AN Medicare beneficiaries.

Study Limitations

Our model has important limitations. These estimates are likely a conservative estimate of the initial vaccine rollout period as they reflect the lower rate of COVID-19 vaccination during the early vaccination ramp-up period, and before Delta variant started in late June. While vaccinations among adults 65 and older have increased to more than 80% by the end of August,[14] these results may not be as applicable for the summer months. For these reasons, we did not project our findings beyond the study period.

Another important limitation of our study is the apparent undercount of COVID-19 related deaths in Medicare FFS claims. This may result from delays in death data from the Social Security Administration/Railroad Retirement Board used to update the CMS beneficiary enrollment file, as well as technical differences in how we are classifying COVID-19 related deaths compared to the CDC. Updates to data on death in Medicare claims are lagged by 2-3 months.[15] We used any death within 9 weeks of COVID-19 diagnosis to identify COVID-19 related deaths. However, claims data do not include information on cause of death, and some deaths that occurred may not have had an associated COVID-19 diagnosis. These factors may have caused baseline COVID-19 death counts in our study to be underestimated, reducing our model's estimated change in deaths. CDC's provisional count for COVID-

19 deaths reports nearly 162,000 deaths among adults 65 and older from January to May 2021. Our estimates projected to the full 62.7 million Medicare population would yield about 139,000 COVID-19 deaths in seniors, roughly 15% below the CDC reported counts; in addition, 15% of Medicare beneficiaries are under age 65, suggesting our dataset may have undercounted COVID-19 related deaths by as much as 26%.[16,†] Applying the proportional reduction in deaths we found associated with vaccinations to the CDC numbers would imply as many as 49,000 Medicare deaths prevented.[‡] After accounting for the potential underreporting of COVID deaths in Medicare FFS claims data, and considering alternative models, the number of deaths prevented among the full Medicare population could plausibly range from 12,000 to 49,000 deaths.

There are important confounders that were not accounted for this study, worthy of consideration in future refinements to the model and sensitivity analyses. First, we did not have complete individual-level data on vaccination status, even though we had individual-level outcomes and covariates. Second, we lacked information on transmission risks based on household composition such as whether the beneficiary lives alone or lives with a family member who may be working in the community and therefore at higher risk of COVID-19 infection. Third, we included state fixed effects but did not specifically include information about the timing of state mitigation efforts that could have influenced the observed association with COVID-19 outcomes. Not including these confounders could have inflated our estimates of the potential reduction in COVID-19 associated with vaccinations, if county and state mitigation efforts were positively correlated with differential county vaccination rates.

Finally, to project the estimated reduction in COVID-19 outcomes from the FFS study cohort to the full Medicare population and subgroups, we assumed the risks of COVID-19 in the study cohort are the same in the full Medicare population. However, beneficiaries enrolled in Medicare Advantage – who make up 40% of the Medicare population – are more likely than FFS beneficiaries to be older, Black or Hispanic, lower-income, and medically complex.[17] Our study also sought to identify frail long-term nursing home residents but may not have fully captured them using Medicare data. This could underestimate the potential reductions in COVID-19 infections and severe outcomes among higher-risk beneficiaries in Medicare Advantage, long-term nursing home residents or FFS beneficiaries who did not meet the study inclusion criteria, who would have a higher baseline risk of COVID-19. Our estimates should be considered conservative for this group.

Our sensitivity analyses confirm the association between COVID-19 vaccinations and reduction in COVID-19 infections, hospitalizations, and deaths. In future research, additional sensitivity analyses and model refinements can assess how different study assumptions may revise these modeled estimates.

[†] If we assume beneficiaries under 65 had similar risks as those over 65, this would imply that the 162,000 deaths reported by the CDC among those 65 and older would correspond to 186,000 deaths when adding in the 15% of Medicare beneficiaries under 65 (115%*162,000). Compared to 186,000 deaths, our implied total of 138,250 Medicare deaths would be a 26% underestimate. While beneficiaries under 65 are younger, which is associated with lower risk of severe COVID-19 outcomes, those under 65 qualify for Medicare via disabilities, which would indicate higher-than-average risk.

[‡] To account for the 26% underestimate, 126% * 38,945 = 49,070 estimated reduction in deaths in the full Medicare population.

Conclusion

Consistent with evidence on the clinical effectiveness of COVID-19 vaccinations, our population-level regression-based estimates indicate that COVID-19 vaccinations were associated with thousands of fewer deaths among the Medicare population during the pandemic in early 2021. As cumulative vaccination rates continue to increase over time, more beneficiaries are expected to be saved from COVID-related hospitalizations and deaths. The difference in vaccination rates for those age 65 and older between the lowest (34%) and highest (85%) states by the end of May highlights the continued opportunity to leverage COVID-19 vaccinations to prevent unnecessary hospitalizations and premature deaths.

APPENDIX: SUPPLEMENTAL ANALYSES

Appendix Table 1. State Estimates of Reductions in COVID-19 Outcomes per 100,000 Medicare beneficiaries Associated with Vaccination, Study Cohort and Projected to Total Medicare Population

State	Study Cohort	COVID-19 Vaccination Rates at end of May, 2021		Study Cohort (N=25.3 million)			Projected to Total Medicare (N=62.7 million)		
		State Vaccination Rate 18-64, %	State Vaccination Rate 65+, %	Reductions in COVID Infections per 100,000 beneficiaries	Reductions in COVID Hospitali-zations per 100,000 beneficiaries	Reductions in COVID Deaths per 100,000 beneficiaries	Projected Reductions in COVID Infections	Projected Reductions in COVID Hospitali-zations	Projected Reductions in COVID Deaths
Total US	**25,295,000**	**38.5**	**68.3**	**420**	**170**	**60**	**265,000**	**107,000**	**39,000**
Alabama	410,000	25.3	61.0	510	200	70	5,200	2,000	700
Alaska	82,000	43.3	72.9	410	130	50	800	200	100
Arizona	570,000	37.6	67.4	480	200	70	6,800	2,800	1000
Arkansas	347,000	27.1	57.1	490	170	70	4,200	1,400	600
California	2,439,000	45.7	69.0	370	160	60	22,000	9,700	3,800
Colorado	375,000	36.9	40.8	180	70	30	1,700	700	250
Connecticut	266,000	55.8	84.3	470	200	72	3,100	1,300	500
Delaware	137,000	40.4	76.2	410	180	60	1,400	600	200
District of Columbia	48,000	48.3	69.2	320	150	60	400	200	100
Florida	1,810,000	35.0	73.9	380	150	50	17,000	6,700	2,400
Georgia	712,000	14.9	34.4	290	120	40	5,100	2,100	700
Hawaii*	100,000	50.1	50.1	90	<50	<50	110	50	<50
Idaho	167,000	32.2	71.1	440	150	50	1,900	600	200
Illinois	1,167,000	41.1	69.0	460	220	70	13,000	6,200	2,100
Indiana	611,000	36.7	76.4	630	240	90	9,500	3,600	1,300
Iowa	377,000	43.3	80.9	540	190	70	5,100	1,800	700
Kansas	332,000	37.0	71.3	530	210	80	4,300	1,700	700
Kentucky	427,000	36.7	69.1	520	210	70	5,500	2,200	800
Louisiana	361,000	27.9	66.2	590	220	70	5,300	1,900	600
Maine	149,000	51.2	83.8	200	80	30	800	300	100
Maryland	672,000	49.6	79.3	400	180	60	6,700	2,900	1,100
Massachusetts	746,000	46.7	70.0	320	140	50	6,000	2,500	900
Michigan	803,000	40.7	73.0	430	190	70	8,500	3,900	1,400
Minnesota	384,000	45.9	79.9	470	170	60	4,500	1,600	600
Mississippi	354,000	27.7	66.0	640	210	70	5,600	1,800	600
Missouri	552,000	29.9	63.6	490	200	60	6,700	2,700	900
Montana	150,000	36.2	70.5	620	170	60	2,300	600	200
Nebraska	218,000	38.1	68.5	470	170	60	2,500	900	300
Nevada	226,000	36.6	67.4	370	180	70	2,100	1,000	400

State	Study Cohort	State Vaccination Rate 18-64, %	State Vaccination Rate 65+, %	Reductions in COVID Infections per 100,000 beneficiaries	Reductions in COVID Hospitali-zations per 100,000 beneficiaries	Reductions in COVID Deaths per 100,000 beneficiaries	Projected Reductions in COVID Infections	Projected Reductions in COVID Hospitalizations	Projected Reductions in COVID Deaths Averted
New Hampshire	182,000	32.1	69.4	90	<50	<50	400	200	100
New Jersey	782,000	48.5	70.5	460	200	70	8,900	3,900	1,400
New Mexico	188,000	41.6	60.3	310	140	50	1,500	600	200
New York	1,450,000	50.6	73.1	450	190	70	16,000	6,700	2,700
North Carolina	913,000	36.1	71.5	500	190	70	11,000	4,200	1,600
North Dakota	84,000	37.0	70.4	760	260	110	1,600	500	200
Ohio	935,000	39.1	74.3	540	230	80	12,000	5,300	1800
Oklahoma	415,000	32.4	67.3	730	270	110	7,500	2,800	1100
Oregon	345,000	40.3	73.9	180	70	<50	1,500	600	200
Pennsylvania	1,115,000	40.7	71.7	400	180	60	11,000	4,900	1,800
Puerto Rico	64,000	35.9	63.1	140	60	<50	200	100	<50
Rhode Island	78,000	51.4	85.2	440	170	70	900	300	100
South Carolina	567,000	30.3	67.8	450	160	60	6,300	2300	800
South Dakota	108,000	38.1	64.2	610	220	80	1,600	600	200
Tennessee	593,000	31.1	67.1	580	210	90	8,600	3,100	1,300
Texas*	1,873,000	50.1	50.1	520	210	80	24,000	9,700	3,600
Utah	178,000	36.6	57.6	330	140	40	1,500	600	200
Vermont	102,000	37.7	66.7	90	30	<50	200	100	<50
Virginia	860,000	22.1	34.9	180	80	<50	3,900	1,600	700
Washington	662,000	43.6	77.7	210	80	<50	3,400	1,300	500
West Virginia	207,000	18.2	37.4	280	110	<50	1,400	600	200
Wisconsin	487,000	44.3	83.1	460	180	60	5,500	2,200	700
Wyoming	89,000	30.2	67.4	560	210	70	1,200	500	200

Notes: Estimated reductions in COVID-19 infections, hospitalizations, and deaths for each state are cumulative weekly differences between estimated and predicted counts for each outcome between January and May 2021 and calculated per 100,000 Medicare FFS beneficiaries. Estimates are predicted based on probabilities for the outcome from primary regression models with cumulative county-level weekly vaccination rates for ages 18-64 and 65+, controlling for beneficiary demographic characteristics, comorbidities, local county characteristics, and state and month fixed effects. The total Medicare estimates are projected from study cohort estimates by multiplying them by a factor of 2.45 (the ratio of total Medicare population to Medicare beneficiary counts in our sample). Numbers may not sum precisely due to rounding. All estimates are rounded to the nearest hundred for estimates below 10,000 and to the nearest thousand for numbers above 10,000. Estimates below 100 are rounded to the nearest ten and masked if below 50 for protection of privacy.

*Estimates for Texas and Hawaii are imputed based on a state with a similar vaccination rate (California). The imputed number of reduction in outcomes is the difference in the imputed counterfactual and actual number of outcomes for these 2 states. These two states were not included in the estimation model study cohort. In addition, the vaccination rates for these two states shown are based on all adults 18+.

** Note: estimates for states with smaller populations are less precise, in particular for deaths. See predicted/actual ratios for outcomes by state in the Appendix Figure 2.

Appendix Table 2. Estimated COVID-19 Outcomes Reduced per 100,000 Beneficiaries by County Vaccination Levels

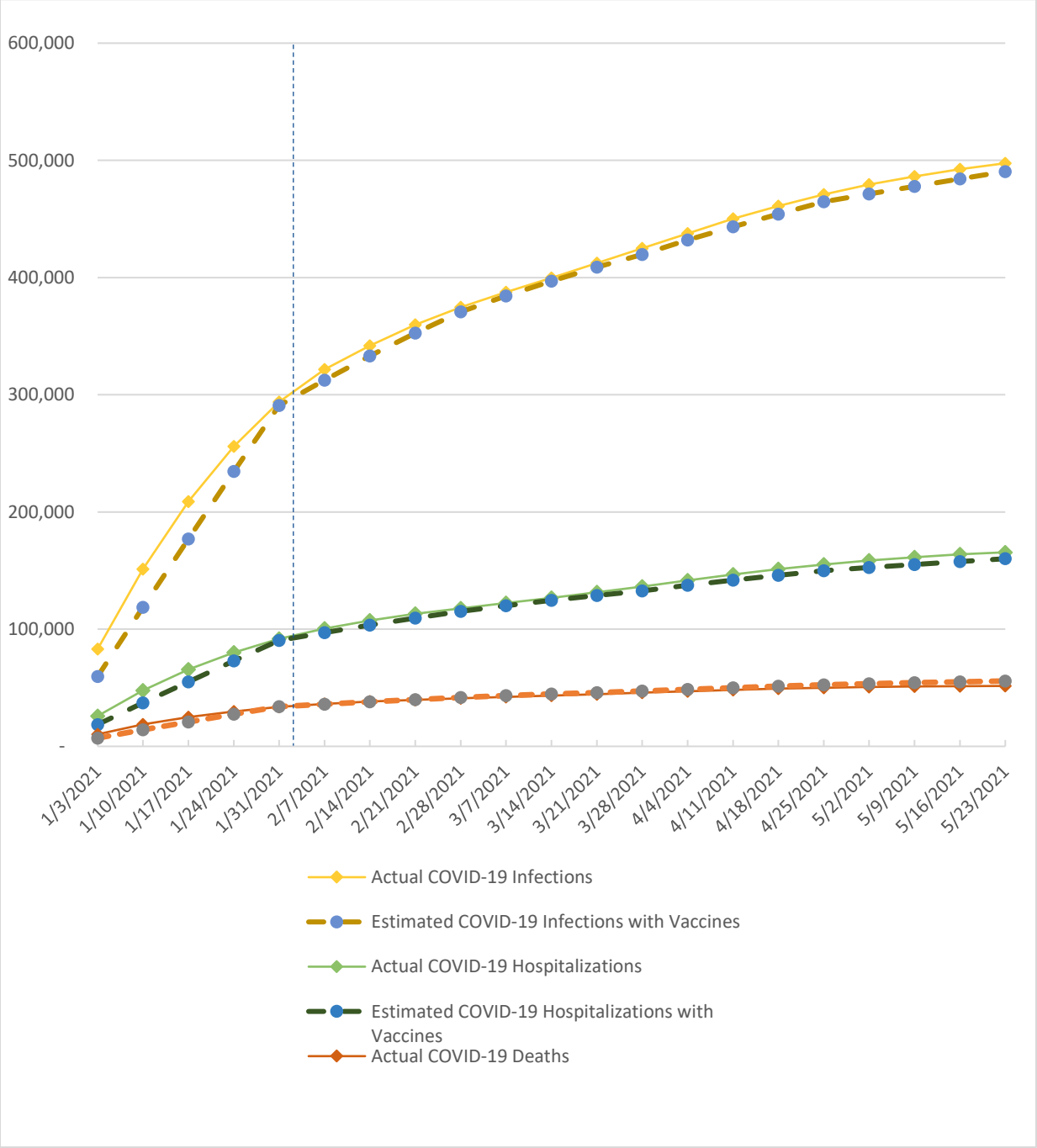
County Vaccination Levels	County Vaccination Rates at end of May		Reductions per 100,000 Beneficiaries		
	Ages 18-64	Ages 65+	COVID-19 Infections	COVID-19 Hospitalizations	COVID-19 Deaths
All US Counties N=25.3 million beneficiaries	39%	68%	423	171	62
High Vaccination Rate Counties N=8.9 million	47%	80%	450	179	65
Medium Vaccination Rate Counties N=9.2 million	39%	70%	446	184	67
Low Vaccination Rate Counties N=7.1 million	27%	51%	361	143	52

Appendix Table 3. Medicare beneficiary characteristics in the study cohort and full Medicare population

	Study cohort N=25.3 million		Total Medicare Population N=62.7 million	
	Number in Subgroup	Percent of subgroup relative to study cohort	Number in Subgroup	Percent of subgroup relative to total Medicare population
Race				
White	20,561,000	74 %	46,199,000	81%
Black	1,992,000	11%	6,636,000	8%
Hispanic	1,184,000	9%	5,471,000	5%
Asian	676,000	4%	2,247,000	3%
AI/AN	145,000	0.4%	264,000	0.6%
Other	737,000	3%	1,883,000	3%
Nursing home status				
Resides in community	24,965,000	99%	61,860,000	99%
Nursing home resident	331,000	1%	840,000	1%

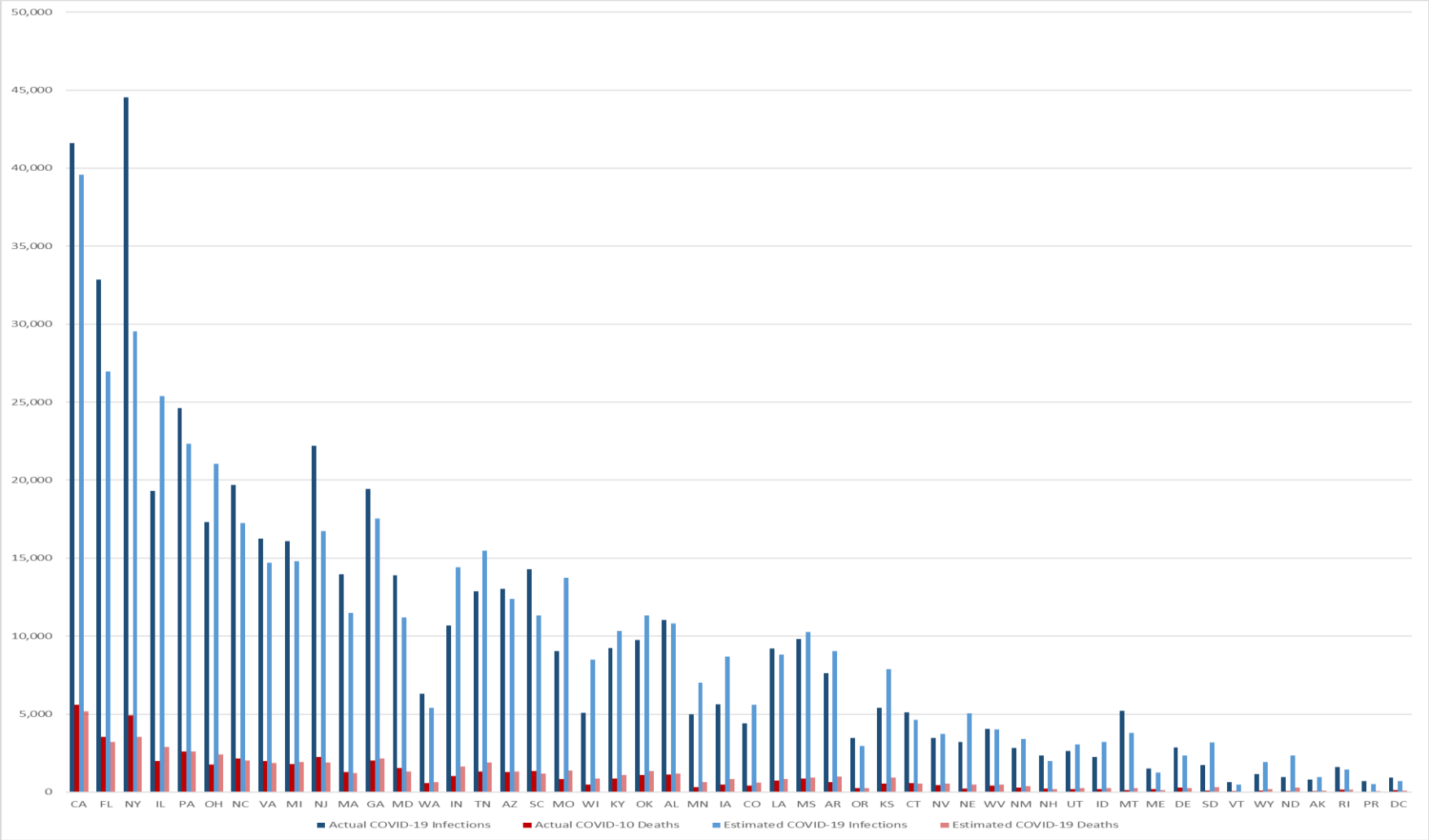
Notes: Numbers may not sum precisely due to rounding. All estimates are rounded to the nearest hundred for estimates below 10,000 and to the nearest thousand for numbers above 10,000. AI/AN = American Indians and Alaska Natives. Long-stay nursing home residents are those who have been in a skilled nursing facility for greater than 90 days and not discharged to the community for more than 14 days, identified using nursing home assessment data and Medicare claims.

Appendix Figure 1. Comparison of the cumulative weekly number of COVID-19 outcomes: actual observed vs. estimated by model with vaccines in study cohort, January – May 2021 (main model)



This figure shows our estimation model closely predicts the number of COVID-19 outcomes compared to the number that actually occurred. In addition, the curves start to become less steep after the end of January suggesting vaccinations are slowing down the transmission of COVID-19 infections and therefore also slowing down COVID-19 related hospitalizations and deaths.

Appendix Figure 2. Comparison of the cumulative number of COVID-19 outcomes - actual observed vs. estimated by model with vaccines in study cohort, by state (main model)



APPENDIX: DETAILED METHODOLOGY AND ASSUMPTIONS

Model Covariates

The key predictors were CDC's weekly county-level cumulative vaccination rates (18-64 and 65+) in the model; included as a continuous variable in the main model and as a categorical variable in the alternate model.

Beneficiary characteristics included age, sex, race/ethnicity, dual enrollment in Medicaid, and disability or end-stage renal disease as the original reason for Medicare enrollment. Medicare beneficiaries residing long-term in a nursing home are identified as they are at higher risk of poor outcomes. This captures beneficiaries who have been in a nursing home for at least 90 days until they return to the community for at least 14 days.

The study included a 12-month look-back period to capture comorbidities using hierarchical condition categories (HCC) from August 2019 to September 2021. Comorbidities HCC flags include: chronic kidney disease, ESRD, chronic obstructive pulmonary disorders (COPD), other respiratory disease, cardiac disorder, diabetes, immune deficiency, severe neurologic condition, cancer, hypertension, dementia (including Alzheimer's), breast/prostate cancer, HIV/AIDS, obesity. In addition to individual condition flags, the models included a count of these comorbidities (0,1,2,3,4+).

Local area characteristics includes log tract density - the log of the population density at the census tract level based on American Community Survey 2017 data), with extreme values trimmed. Density is calculated as the number of persons living in a census tract divided by the square mileage of that tract. For tracts without density data, values were imputed.

To capture differences in population demographics and resources, the study included CDC's Social Vulnerability Index (SVI) at the census tract level, which include four SVI themes: socioeconomic status, household composition & disability, minority status & language, and housing type and transportation.

The model included state fixed effects (to control for fixed differences across states such as state-level mitigation policies that are in place throughout the study period) and month fixed effects to control for temporal trends unrelated to cumulative county vaccination rates. We considered county fixed effects but we opted for state-level instead due to concerns with model convergence and over-parameterization. As discussed earlier, Texas and Hawaii were excluded from the model due to the lack of county-level vaccination data. To estimate potential reduction in COVID-19 outcomes for these two states, we took the state-wide reported vaccination rate, and used a state with a similar vaccination rate (California) to estimate COVID-19 outcomes based on the size of the Medicare population in each of the two states.

Sensitivity Analyses

In sensitivity analyses, we ran an alternate model with data from January – May 2021 since data prior to the availability of vaccines do not contribute to the estimated effect of vaccinations on COVID-19. Both temporal trends and vaccination rates over time are modeled non-parametrically without a linear assumption. We modeled the relationship between vaccination rates and COVID-19 outcomes over time using 17 categories of community vaccination rates (starting at 0%, then increments of 2% up until 10%;

followed by increments of 5% until 60%). We replaced monthly fixed effects with weekly fixed effects to better control for changes in temporal trends. Otherwise, all other variables in the model and the forms of the regression models were the same as the main analysis.

The estimates from this alternate model were lower than the main model and provide a lower bound on the estimated reductions in COVID-19 outcomes associated with COVID-19 vaccinations. Among the study cohort in this model, COVID-19 vaccinations were associated with an estimated reduction of 35,000 infections (vs. 107,000 estimated by the main model), a reduction of 14,000 hospitalizations (vs. 43,000) and 4,900 deaths (vs. 15,000). When projected to the full Medicare population, these alternate model estimates suggest COVID-19 vaccination prevented at least 87,000 infections, 34,000 hospitalizations and 12,0000 deaths among all Medicare beneficiaries. All estimates are rounded.

The data was prepared, and analyses conducted by Acumen LLC under the supervision of ASPE.

Detailed Methodology

Main analysis: The specific regression models and approaches to estimating the number of COVID-19 outcomes based on vaccination rates and the counterfactual without vaccines are described next.

I. Estimation

We estimated three models:

(i) the probability of a COVID-19 diagnosis,

(ii) the probability of death within 3 weeks of a COVID-19 diagnosis, and

(iii) the probability of a hospitalization within 9 weeks of a COVID-19 diagnosis.

From these models we obtain the predicted number of deaths and hospitalizations for each state based on actual vaccination rates and the corresponding numbers based on the counterfactual of zero vaccinations.

The COVID-19 diagnosis model was estimated by a discrete time hazard model of the probability of a diagnosis at the beneficiary-week level and the hospitalization and mortality models by logits.

Study period: 9/6/2020 to 5/29/2021, yielding 38 (week) periods.

1. Probability of a COVID-19 diagnosis

Data: Beneficiary-period level dataset for entire Medicare FFS population, restricted to those who were continuously enrolled during the 38-week study period and the lookback period from Aug 2019 to Sep 2020 used for measuring comorbidities. Beneficiaries will contribute observations from the first period until the period in which they first receive a COVID-19 diagnosis (first time during the study period). Beneficiaries are censored in subsequent periods. Beneficiaries who do not receive a COVID-19 diagnosis during the study period will contribute observations for all 38 periods.

Outcome: COVID-19 diagnosis in the period (binary)

Model: Discrete-time hazard model, estimated by a logit

2. Probability of First Hospitalization Conditional on COVID-19 Diagnosis

Data: Beneficiary-period level datasets for those beneficiary-periods in which a COVID-19 diagnosis first occurs.

Outcome: Hospitalization within 3-weeks of the COVID-19 diagnosis

Model: Logit

3. Probability of Mortality Conditional on COVID-19 Diagnosis

Data: Beneficiary-period level datasets for those beneficiary-periods in which a COVID-19 diagnosis first occurs.

Outcome: Mortality within 9-weeks of the COVID-19 diagnosis

Model: Logit

II. Predicting Outcomes and Counterfactual Outcomes

Prediction:
From the results of these models, we predicted the probability of contracting COVID-19 in each period:

P(COVID in period t), the probability of hospitalization conditional on contracting COVID: P(hospitalization | COVID in period t), and the probability of death conditional on contracting COVID: P(death | COVID in period t) based on observed covariates, including observed vaccination rates.

We also predicted *counterfactual* hazards and probabilities based on observed covariates except for vaccination rates, which were set to zero.

The probability of contracting COVID in each period was constructed from the estimates of the hazard model: P(COVID in period t) = S(t-1)*h(t), where S(t) is the probability of not contracting COVID prior to period t (the survival probability) and h(t) is the hazard of contracting COVID in period t.

From these values we predicted the probability of hospitalization for each beneficiary in each period as P(hospitalization with COVID-19 in period t) = P(COVID in period t) * P(hospitalization | COVID in period t). We similarly predicted the *counterfactual* probability of hospitalization. Summing these predicted probabilities over beneficiaries and periods by state yielded an estimated number of hospitalizations over the study period by state and the *counterfactual* number of hospitalizations over the study period by state (setting vaccination rates equal to zero).

We predicted the probability of death for each beneficiary in each period as P(death with COVID-19 in period t) = P(COVID in period t) * P(death | COVID in period t) and similarly predicted the *counterfactual* probability of death. Summing these predicted probabilities over beneficiaries and periods by state

yielded an estimated number of deaths over the study period by state and the *counterfactual* number of deaths over the study period by state (setting vaccination rates equal to zero).

The probabilities predicted above were also aggregated along other beneficiary categories of interest including state, race/ethnicity and long-term nursing home residents.

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