COVID-19 Vaccination and Decreased Death Rates: A County-Level Study in Pennsylvania

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Abstract

Introduction:

In this paper we examine the relationship between vaccination against COVID-19 and both the death rate from COVID-19 and the rate of COVID-19 spread. Our goal is determine if vaccination is associated with reduced death and/or spread of disease at the local level.

Methods:

*This analysis was conducted at the county level in the state of Pennsylvania, United States of America, with data that were collected during the first half of 2022 from the state of Pennsylvania's Covid Dashboard (*COVID-19 Data for Pennsylvania (pa.gov).

***Result**s:*

This study finds the vaccines to be highly effective in preventing death from Corona virus, even at a time when there was a mismatch between the vaccines and the prevalent variants. Specifically, a 1% increase in vaccination rate was found to correspond to a 0.751% decrease in death rate (95% confidence interval (0.236%, 1.266%)).

Given that, during this time period, the vaccines being used were not geared specifically toward the common variants at that time, we found no statistically significant relationship between disease spread and vaccination rate at the county level.

Conclusions:

These results support previous findings from across the world that Covid vaccination is highly efficacious in preventing death from the disease. Even during a time when vaccine design was not optimally matched with the prevailing strains, vaccination was found to reduce death rate. Hence, improving global vaccine availability is vitally important, in order to achieve necessary outcomes.

Key words: COVID-19, death rate, vaccines

1. Introduction

COVID-19 is a disease caused by the relatively new SARS-CoV-2. With the research that has been conducted previously, it is known that age and population density impact infection and death rate of COVID-19 (Roy & Ghosh, 2020).

Furthermore, clinical trials and follow up studies conducted during 2020 have shown great efficacy of COVID-19 vaccination against both disease infection and death. In particular, the original Moderna vaccine was found to have an overall efficacy of 94.1% with 100% efficacy against severe disease and death (Mahase, 2020). Similarly, Pfizer's original vaccine was found to have 95% efficacy after two doses (Badiani, Patel, Ziolkowski,, & Nielsen, 2020). Johnson and Johnson's original single dose vaccine was found to have only 66% efficacy against contracting disease but was found to have 100% efficacy regarding disease related death

(Livingston, Malain, and Creech, 2021). Related to this, Rzymski et al. (2021) find that despite experiencing decreasing immunity over time, vaccinated people remain highly protected against severe disease.

Vaccines were first introduced to the public in the United States on December 11, 2020, for emergency use in persons aged 16 years and older. Not until April 19th of 2021 was the vaccine available to all people aged 16 and older and May 17th was when the vaccine was available to children aged 5 and older (ASPA, 2022). Available vaccines in the US for COVID-19 at this time were developed by Pfizer-BioNTech, Moderna, and Johnson & Johnson (J&J/Janssen).

At the time these original vaccines were introduced, the alpha variant of COVID-19 was predominant, but, over time, were largely replaced with the beta, gamma, and delta variants (Safari and Elahi, 2022). The omicron variant was subsequently discovered in November of 2021, and quickly became the predominant strain worldwide (Gueye et al., 2022). Related to this, Krueger, et al. (2022) note that while many factors influence the spread of infection, waning immunity (due to time elapsed since immunization) and the emergence of additional variants are key contributors to the spread of infection.

The purpose of this research is to investigate the relationship between COVID-19 vaccination rate and both death rate and infection rate during the first half of 2022. As previously noted, during this time period, the alpha strain had largely been replaced with other, new variants of COVID-19 (Gueye et al. 2022; Safari and Elahi, 2022). Hence, the vaccines available at this time were not specifically targeting these new variants.

The purpose of this study is to determine the effect of these original (non-bivalent) vaccines against COVID-19 spread and death in Pennsylvania. This research examines COVID-19 data at the county level in the state of Pennsylvania, United States of America. In this study, we attempt to determine the effect of COVID-19 vaccination on both the spread of the disease and on the death rate caused by the disease. This is done by comparing the death and infection rates of each county prior to the introduction of widespread COVID-19 vaccination with corresponding rates after widespread vaccination.

In addition to the previously mentioned studies on COVID-19 vaccine efficacy, much other work has been done examining various aspects of the utility of these vaccines. Roghani (2021), for instance, conducted an analysis to determine the influence the vaccination had on daily cases, hospitalizations, and death rates in Tennessee. He found vaccine can reduce infection rate in all ages and can also reduce hospitalization rates and death rates in older populations.

Related to our work, research done in Taiwan examined the relationship between vaccine coverage and mortality rate. By analyzing vaccination rates and mortality rates from ninety different countries over a period of 25 weeks (November 2020 to April 2021), an increase of 10% in vaccine rates coverage was associated with a 7.6% reduction in mortality rate. This provides evidence supporting the idea that “vaccination is critical to preventing deaths among infected people” (Liang et al., 2021). It has even been found that vaccination against influenza is negatively correlated with COVID-19 deaths in Italy (Marín-Hernández, Schwartz, & Nixon, 2020). In the coming sections, we extend this work to examining the relationship between COVID-19 vaccination rate and death rate in Pennsylvania.

2. Methods

As previously noted, the aim of this paper is to determine the relationship between vaccination rates for COVID-19 and both infection and death rates, a variety of data was collected from each county in the state of Pennsylvania, using the state of Pennsylvania's COVID dashboard (COVID-19 Data for Pennsylvania (pa.gov). To obtain vaccination rates for each county, we began by collecting cumulative data during the year 2021. Ultimately, we decided to focus on the number of fully vaccinated individuals. For the purposes of this study, "fully vaccinated" is defined as having received both doses of the Moderna and/or Pfizer vaccines, or a single dose of the J&J vaccine. To compute the vaccination rates for each county, the number of fully vaccinated individuals was simply divided by the population of the county.

Regarding our collection of data for infection rates, from each county we obtained the total number of cases in the year 2020 (pre-vaccination) and the total number of cases from the time span of January 2022 to June 2022 (post-vaccination). As of late 2021, COVID-19 vaccinations were available for people ages 5 and older. Increasing inclusion in early 2022, vaccinations were widely available for all persons aged 6 months and older ("History of COVID-19: Outbreaks and vaccine timeline", n.d.). Using the total number of COVID-19 cases in Pennsylvania during 2020 and the first half of 2022, a 2022:2020 case ratio was computed for each county. By looking at case ratios for individual counties, we eliminate the potentially confounding effects of differences that exist across counties regarding variable including demographics such as age, and population density. This, of course, assumes, that the structure of the counties themselves did not change substantially between 2020 and 2022. Additionally, most public health measures, such as stay at home orders, took place at the state level (Jacobsen and Jacobsen, 2020). Since all of our data were collected in a single state, the amount of bias introduced by any variability in public health measures should be minimal.

A similar process was used for the collection of death rates. The total number of mortalities due to COVID-19 during 2020 (pre-vaccination) was collected, as well as the total during the time period from January 2022 to June 2022 (post-vaccination). A 2022:2020 death ratio was then computed for each county. Note that, since the initial time period was 12 months, and the second time period was only 6 months, we would expect to see a case ratio and death ration of ½, if nothing (including vaccination status) had changed between the time periods. The fact that these time periods are of unequal duration, however, should have no effect on assessing *relationships* between vaccination status and death rate and case rate. If the vaccine has no effect on number of cases or number of deaths, we would then expect to find no relationship between a county's vaccination rate and case ratio or death ratio, respectively.

Using this data, linear regression analyses will be used to analyze the relationships between (1) vaccination rate and case rate, and (2) vaccination rate and death rate. These models happen to be simple linear regression models, since only one variable (vaccination rate) is being used to predict the dependent variable (case rate or death rate, for models (1) and (2), respectively). The key output from each of these models is a parameter estimate which will inform us about the relationship between vaccination rate and each dependent variable.

Specifically, the two hypotheses we wish to test are:

(1) $\mathbf{H_0}$: $B_1 = 0$

$\mathbf{H_1}$: $B_1 \neq 0$,

where B_1 is the parameter estimate of the slope in the equation: $Y = B_0 + B_1X$. In this equation, Y is the county's 2022:2020 case ratio, and X is the county's vaccination rate. Hypothesis two is:

(2) $\mathbf{H_0}$: $B_1 = 0$

$\mathbf{H_1}$: $B_1 \neq 0$,

where B_1 is the parameter estimate of the slope in the equation: $Y = B_0 + B_1X$. In this equation, Y is the county's 2022:2020 death ratio, and X is the county's vaccination rate. Both hypotheses will be tested at the 0.05 level of significance. Completed regressions will be tested to ensure the normality (normal probability plot) and homoskedasticity of the residuals (using White's test). These tests will be performed because linear regression models assume that residuals (model errors) are normally distributed, and that the variability of these errors constant (not related in any way to the values of either of the variables in the model). If either of these assumptions do not hold, corrective action must be taken.

3. Results

We begin our results by presenting descriptive statistics for the variables used in each model in Table 1, below. This table shows the sample size, mean, and standard deviation for the number of infections during each time period, the number of deaths during each time period, and the proportion of fully vaccinated people in each county. Note that average vaccination rate in the table below does not weigh each county according to its population. The true total vaccination rate for the state of Pennsylvania at this point in time was 58.78%. Original source data are included in Appendix A.

Insert Table 1 Here

Using SPSS, version 22, two linear regressions were performed to test the aforementioned hypotheses. We will first discuss the analysis of the infection rate data. Using these data, no statistically significant relationship appeared to exist between vaccination rate and case rate. However, this original regression exhibited heteroskedasticity. Specifically, the size of the model's errors (residuals) were correlated with the infection rates.

To account for the heteroskedasticity, we performed a weighted least square regression to obtain the results shown in Table 2, below. This revised model confirms our previous conclusion that the relationship between vaccination rates and infection rates is not statistically significant.

Insert Table 2 Here

The results presented in table 2 show that no statistically significant relationship appears to exist between vaccination rate and a county's case rate. Specifically, it is particularly interesting to note that the p-value (0.133) for the vaccination rate (vaxrate) is > 0.05. The confidence interval for this (insignificant) parameter is (-0.183, 1.459), which clearly contains zero. Hence, we fail to reject the null hypothesis for our first hypothesis test. There is no statistically significant evidence of a relationship between vaccination rate and case rate.

When analyzing the relationship between vaccination rates and death rates, we used a linear regression analysis with the ratio of deaths post-vaccination to deaths pre-vaccination as the dependent variable and vaccination rates as the independent variable. The first regression analysis shown in Table 3 produces a slope estimate for the vaccination rate of -0.858, which is statistically significant at the 0.05 level.

Insert Table 3 Here

Although the regression above produced statistically significant results, the residuals did not appear to be normally distributed.

To correct this issue, we conducted a second regression using the natural logarithm of both variables, which is shown in Table 4. Taking the natural logarithm of each variable provided us with model errors that were approximately normally distributed.

Again, in this revised model, the results were statistically significant. In summary, this revised model shows that, as vaccination rate increases, death rate decreases in a statistically significant way. As will be shown, since logarithmic transformations were used, the interpretation of the relationships between the variables is slightly more complex. This is because we are no longer examining a straight line (linear) relationship. Specifically, the parameter estimate for the natural logarithm of vaccination rate (lnvaxrate) was -0.751, with a p-value of 0.006. The 95% confidence interval for this parameter estimate is (-0.236%, -1.266%). This implies that a 1% increase in vaccination rate is associated with, on average, a 0.751% decrease in death rate in the counties of Pennsylvania.

Insert Table 4 Here

In summary, using a weighted least square model, we found no statistically significant relationship between vaccination rate and infection rate. Using a log-log model, we found a highly statistically significant, inverse relationship between vaccination rates and death rates.

4. Conclusions

In this paper, we examined two relationships: namely the relationship between COVID-19 vaccination rates and death rates, and the relationship between vaccinations rates and infection rates. Since we compared the ratio of cases in various counties of PA before and after the availability of vaccinations, confounding variables such as demographics should not affect our results (assuming that the counties, themselves, did not substantially change during the course of that year). Our research concludes that there is not a statistically significant relationship between vaccination rates and infection rates. This implies that vaccination rates did not appear to have any statistically significant effect on the spread of COVID-19 infection in the community during the time of this study (when, we note, the vaccinations were not geared specifically toward the prevalent viral strains). However, we did find a strong negative relationship between vaccination and death rate which is highly (p-value = 0.006) statistically significant. Our findings show that on average, a 1% increase in COVID-19 vaccination rate, is associated with a 0.75% decrease in death rate.

We can conclude that COVID-19 vaccination substantially protect individuals from COVID-19 related death, however receiving the vaccination does not appear to protect people from spreading the virus to others. This failure to reduce community spread, however, may be due to the fact that the vaccines under study at the time of this paper were not specifically geared toward the prevalent viral strains that that time.

The relationship we found between vaccination rates and death rates is nearly identical to the results found from research conducted in Taiwan during 2021. The research in Taiwan shows that an increase of 10% in vaccination rates is associated with a 7.6% decrease in death rate (Liang et al., 2021). Scaling this down, it would imply that a 1% increase in vaccination rate would be associated with a 0.76% decrease in death rate. This 0.76% decrease compares favorably to the 0.75% decrease found in this study. Based on the results of Liang et al. (2021) and those found in this study, it appears that geography does not have an effect on the relationship between vaccination rates and death rates. Hence, we believe it is reasonable to assume this statistical relationship holds true worldwide (at least for locations receiving the vaccines available in the US and Taiwan). Thus, extending our results and the results of Liang et al. (2021) have worldwide, international implications.

It is our hope that these results encourage the public in general, and those at high risk for death from COVID-19 in particular, to maintain their vaccination status. Additionally, the combination of the two main findings of this study may encourage public health organizations to emphasize self-protection as a reason for COVID-19 vaccination in their messaging. As can be seen, improving global coverage of vaccine availability is vitally important to achieving the required health outcome of reduced death from disease.

The primary limitation of this study is that the data were collected in one geographic area, namely the state of Pennsylvania. That said, the fact that these results compare similarly to that of Liang et al. (2021) lead us to believe that the results may apply in any area where the same vaccines are available and viral strains are prevalent.

One future area for research involves analyzing the individual vaccinations for COVID-19 (Moderna, etc.) and establishing individual relationships for each vaccination regarding vaccination rate and both death rate and infection rate. An additional area for study would be to perform a similar analysis during a time period when the prominent vaccines are more closely aligned with the common variants at that time. A final area for further research would be to apply this analysis on COVID-19 to data from different countries to confirm the implication that the relationship found through our research can be generalized.

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Insert Appendix A Here