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COVID Excess Mortality Percentage, Racial/Ethnic Disparities in COVID Mortality, and Vaccine Effectiveness: Evidence from Linked Mortality and Vaccination Records

Vladimir Atanasov
William & Mary

Paula Natalia Barreto Parra
University of Illinois, Urbana-Champaign

Lorenzo Franchi
Northwestern University

Jeffrey Whittle
Medical College of Wisconsin

John Meurer
Medical College of Wisconsin

Qian (Eric) Luo
George Washington University

Ruohao Zhang
Northwestern University

Bernard Black
Northwestern University and IPR

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Abstract

COVID-19 mortality rates rise strongly with age, but so do other natural causes of death. The researchers develop a new measure of the COVID-19 mortality burden, the COVID Excess Mortality Percentage (CEMP), defined as COVID-19 deaths as a fraction of all deaths from natural causes other than COVID. They use this measure to study COVID-19 mortality in Indiana and Wisconsin, including racial/ethnic disparities in mortality rates. They find very high disparities, especially in 2020, with CEMP ratios for Hispanics to non-Hispanic Whites as high as 9:1 for ages 50–59. They find very different CEMP patterns by age and race/ethnicity, in the pre-vaccine period (2020) and the vaccine-available period (April 2021–March 2022).

The researchers also report data on vaccine effectiveness (VE) in Milwaukee County, where they can link individual death records to vaccination records. Measuring VE based on CEMP controls for the potential for the vaccinated to be healthier and hence face lower COVID mortality risk without vaccination. VE measured this way is substantially lower than reported in many other studies (e.g., 60% for fully vaccinated (but not boosted) adults during 1Q 2022 (Omicron-dominant period) and 71% during 4Q 2021 (Delta-dominant period). Three-vaccine-dose VE is much higher, at around 90%, and similar for Moderna and Pfizer, but COVID mortality risk after two Pfizer doses is over twice the two-dose Moderna risk. The gap between two-dose and three-dose VE implies that tens of thousands of COVID decedents would likely have survived with a faster booster rollout.

The Online Appendix for this paper is available at http://ssrn.com/abstract=3706517.

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Introduction

We study mortality risk from COVID-19, racial/ethnic disparities in COVID-19 mortality rates, and the real-world effectiveness of the COVID vaccines, using a novel measure, the COVID Excess Mortality Percentage (CEMP), applied to a unique dataset: individual death records for all decedents in Wisconsin and Indiana (around 12 million persons), which we link to complete vaccination records for adults in Milwaukee County, Wisconsin (below simply Milwaukee) (around 720,000 persons).

COVID-19 is much more severe for the elderly. The COVID population fatality rate (PFR, the fraction of the population who died from COVID-19) is small for the young, but rises strongly with age, to over 6% for those aged 90+, and is generally higher for men than for women. Yet, mortality rates from other natural causes also rise steeply with age and are higher for men than women at a given age. One might then ask, *controlling for age and gender*, by what percentage did COVID-19 increase overall mortality from natural causes during the pandemic period? We develop two related measures: the COVID Mortality Percentage (COVID-19 deaths divided by all deaths from natural causes ($CMP_{natural}$), and the COVID *Excess* Mortality Percentage (CEMP) (COVID mortality relative to deaths from *other* natural causes (CEMP), but focus principally on CEMP.[1] We then use CEMP to study racial/ethnic disparities in COVID mortality, real-world vaccine effectiveness (VE) against different COVID variants, at different times, and the relative VE of the Moderna and Pfizer vaccines.

We report five main results. The first involves CEMP patterns over time. Over April-December 2020, before vaccines were available, CEMP is substantial even for younger adults. It rises gradually with age, but much less steeply than PFR, from about 8% for ages 20-39 to 20% for ages 80+, with a somewhat higher gradient for men than for women. In contrast, over April 2021-March 2022, after vaccines became widely available, CEMP is highest for ages 40-49, and drops as age increases. This hump-shaped pattern is partly explained by higher CEMP for the unvaccinated, combined with greater likelihood of the elderly to be vaccinated. However, even for the unvaccinated, CEMP has a different age pattern in 2021 – it is highest for ages 20-59, at around 20% for the full vaccine-available period, but falls as age increases.

Second, using the CEMP measure, we provide evidence of very large racial/ethnic disparities in COVID-19 mortality, especially in 2020 (pre-vaccine period). We consider four groups: non-Hispanic Whites (below, simply Whites), Blacks, non-Black Hispanics (below, Hispanics) and (Asian and other). We find that for Hispanics aged 50-59, CEMP in 2020 was 65% (9 times the percentage for non-Hispanic Whites); CEMP for Hispanics aged 40-49 was 46% (6.7 times the percentage for non-Hispanic Whites); with even higher levels and Hispanic/White ratios

[1] In prior work focusing on the elderly, we studied a measure that we called CMP, but might better be called $CEMP_{all}$ (COVID deaths divided by *all* deaths other than COVID deaths, rather than by *natural* non-COVID deaths). Barreto-Parra et. al (2022).

for men. Prior research has reported higher Black and Hispanic COVID-mortality rates, but none of this magnitude.[2] COVID-19 was the largest cause of natural death for Hispanics in 2020 up to at least age 69, easily beating heart disease, cancer, and everything else. Black/White ratios based on CEMP are lower than Hispanic/White ratios, but if measured based on relative PFRs, average around 5:1 in 2020 for both genders over ages 18-59.

Third, we contribute to the literature on the effectiveness of COVID-19 vaccines in preventing death. Many studies report evidence on VE against infection, hospitalization, and death. See reviews by Feikin et. al (2022), and Black and Thaw (2022). However, most studies compare vaccinated people with confirmed COVID-19 infection to infected but unvaccinated people, and have limited controls for individual characteristics, often only age and gender. These studies are subject to selection bias. Suppose that health-conscious people are both (i) more likely to be vaccinated, and (ii) more likely to be tested for COVID-19. Then the vaccinated could appear to have higher COVID-19 survival rates, partly reflecting the protective effect of vaccination, but also their (unobserved) better health and hence lower COVID risk even if not vaccinated, and their tendency to get tested when less severely ill, seek earlier treatment, or both.[3]

We address the potential for the unvaccinated to be unobservably at higher risk of COVID mortality, independent of vaccination status, by studying the impact of vaccination on CEMP. If the unvaccinated are less healthy, they will have higher natural, non-COVID mortality. By studying the effect of vaccination on CEMP, rather than directly on COVID-19 mortality, we control for unobserved health characteristics, to the extent reflected in deaths from other natural causes.

Our VE estimates, which by construction are weighted by the number of COVID decedents, are often well below those reported in other studies. For example, during 2H 2021, when the Delta variant was dominant, we estimate VE for one, two, and three vaccine doses at 55%, 79%, and 89%.[4] In contrast, prior VE estimates for two mRNA vaccine doses against the Delta variant range from 88-94% (Black and Thaw, 2022, Table 3). It is instructive to consider the remaining risk after vaccination: remaining risk (RR) = (100% - VE). We estimate remaining risk after two mRNA doses of 21%, versus prior estimates of 6-12%. During 1Q 2022. a period of Omicron dominance, we observe VE for one, two, or three doses in reducing $CMP_{natural}$ of 58%, 64%, and 90%, and thus remaining risk of 42%, 36%, and 10%. This suggests large value (72% reduction in RR) from a booster dose. The gap between two-dose and three-dose VE implies that tens of thousands of COVID decedents would likely have survived with a faster booster rollout.

[2] See, e.g., Alsan, Chandra and Simon (2021) (reporting Black/White, Hispanic/White, and Asian/White excess mortality ratios for 2020); Andrasfay and Goldman (2021) (reporting declines in life expectancy in 2020).

[3] Some studies start with a sample of hospitalized patients. This avoids selection bias in who received COVID testing, but is subject to other selection concerns. Suppose that health-conscious, vaccinated persons seek hospital care earlier than unvaccinated persons, or go to different hospitals and thus receive different treatment. Then the lower in-hospital mortality of the vaccinated could reflect a combination of vaccine protection, differences in behavior, and differences across hospitals in COVID-19 mortality rates.

[4] Based on equal weighted average across 3Q 2021 (no boosters yet), and 4Q 2021 (boosters rolled out, initially for the elderly, healthcare workers, and other high-risk groups).

Fourth, for younger persons. we report a strong protective effect of two vaccine doses, and even stronger protection from a booster dose. We find only one death among 213,000 two-dose recipients aged 49 or less, and **zero** deaths among 271,000 three-dose recipients aged 59 or less.

Fifth, we compare VE for the Pfizer **(**BNT162b2) and Moderna (mRNA1273) vaccines. We find substantially greater VE for two Moderna doses than for two Pfizer doses (81% vs. 59% over Oct. 2021 – March 2022). Put differently, the RR for two Pfizer doses is over twice that for Moderna. For three-dose recipients, in contrast, VE is similar: Moderna has a smaller, statistically insignificant edge, at 92% versus 88%.

II. Data and Methods

Our analysis of $CMP_{natural}$ and CEMP relies on Indiana and Wisconsin mortality records. We obtain de-identified mortality records for all decedents in Wisconsin and Indiana for 2020 through the first quarter of 2022, including 5-digit residence zip code, age at death in years, manner of death, and text fields indicating the primary cause of death, contributing causes, and other significant conditions. We use text analysis of these text fields cause of death se fields to identify which natural deaths are due to COVID-19; this approach counts more COVID-19 deaths than the cause-of-death coding by the National Center for Health Statistics (NCHS), reported as ICD-10 codes in the mortality records. We define natural deaths as those with manner of death = natural, pending, or undetermined. The remaining manner-of-death categories, which we exclude in counting natural deaths, are accident, homicide, and suicide. We obtain population counts for 2020 from the American Community Survey.

We define $CMP_{natural}$ and CEMP as:

$$CMP_{natural,agrdv} = \frac{COVID\ deaths_{agrdv}}{Natural\ deaths_{,agrdv}}$$

$$CEMP_{agrdv} = \frac{COVID\ deaths_{agrdv}}{Natural\ deaths_{agrdv} - COVID\ deaths_{agrdv}} \quad (1)$$

Here a is age in years; g is gender, r is race/ethnicity group, d = number of vaccine doses, and v = vaccine type. Vaccination is studied only in some analyses, and subcategories are combined in some analyses.

We also report data on annualized population fatality rates for COVID-19 deaths and other natural, non-COVID deaths, defined as:

$$\text{PFR}_{agr} = \frac{COVID\ deaths_{agr}}{Population_{agr}} \times \frac{\mathbf{12}}{\#\mathbf{Months}}$$

$$\text{Non-COVID Natural Mortality Rate}_{agr} = \frac{Non-Covid\ natural\ deaths_{agr}}{Population_{agr}} \times \frac{\mathbf{12}}{\#\mathbf{Months}}$$

Our analysis of VE and how vaccination affects CEMP relies on data from Milwaukee County, Wisconsin, for which we can link mortality and vaccination records. We obtain complete vaccination records for Milwaukee for January 1, 2021, through March 31, 2022, including vaccination dates and vaccine type. We link multiple vaccinations for the same person, and link mortality to vaccination records, using anonymized identifiers based on last name, first name, gender, and date of birth. We treat vaccine doses as effective beginning 14 days after they were

given. When studying VE, we exclude decedents with known severe immunosuppression, identified from death certificates.

Moderna and Pfizer were approved as two-dose initial series; J&J was approved as a single dose. However, we measure VE based on number of doses, thus treating one dose of the J&J vaccine as equivalent to one dose of the mRNA vaccines (Moderna and Pfizer). This is consistent with our reading of the literature on relative VE for the J&J vaccine versus the mRNA vaccines. Because the J&J vaccine accounted for only around 5% of vaccinations, results would be similar if we treated one J&J dose as equivalent to two mRNA doses.

We define vaccine effectiveness (VE) as:

$$VE_{agrdv} = \frac{(CEMP_{agr,unvax} - CEMP_{agrdv})}{CEMP_{agr,unvax}} \qquad (2)$$

By using non-COVID natural deaths in the denominator when measuring CEMP, we implicitly assume that the mortality rate for non-COVID natural deaths is a reasonable proxy for health for a given population, defined by age*gender*race/ethnicity. A U.K. study by Bhaskaran et. al (2021) provides supporting evidence that several risk factors for COVID mortality also predict non-COVID mortality.

The CEMP measure implicitly assumes that COVID-19 infection does not meaningfully affect non-COVID mortality. This is not completely true; COVID infection predicts higher post-infection mortality from other causes (e.g., Xie et. al, 2022). This will cause some downward bias in CEMP values. If this downward bias is similar for the vaccinated and unvaccinated, estimates of VE should still be unbiased. However, the downward bias in CEMP will plausibly be larger for the unvaccinated, since COVID-19 will on average be more severe for the unvaccinated. If so, then VE estimates based on CEMP will be somewhat *above* the VE we would estimate if we could attribute to COVID-19 the extra natural deaths among the previously infected.

We generally report results for two time periods: a "pre-vaccine" period from April-December 2020, and a "vaccine-available period" from April 2021-March 2022. We begin our analysis in April 2020. COVID-19 was declared a national emergency in mid-March 2020, but COVID mortality relative to other causes was low for March 2020 as a whole. Including March in the pre-vaccine period would reduce CEMP levels, relative to those we report but would not change our main conclusions. We exclude the first quarter of 2021 (1Q 2021), a period when vaccines were being rolled out, initially to the elderly and healthcare workers, but were not yet widely available. We report results for this period in the Appendix.

III. CEMP Patterns by Age in the Pre-Vaccine and Vaccine-Available Periods

Table 1 provides data on CEMP by age range and gender for the pre-vaccine period (Panel A) and the vaccine-available period (Panel B) for Indiana and Wisconsin combined. It provides counts for COVID and natural non-COVID deaths; CEMP is the ratio of the two counts. It also provides data on population, the COVID PFR, and the natural mortality rate excluding COVID deaths; CEMP also equals PFR divided by the non-COVID natural mortality rate. See Appendix for data on Wisconsin and Indiana.

Consider first the pre-vaccine period. Overall, CMEP averages 16.65% for women and is slightly higher, at 18.06% for men. Apart from the very low levels for children, who rarely die of COVID, there is a strong age gradient for both PFR and non-COVID natural mortality. CEMP,

which is the ratio of the two, rises gently with age, from 9% for ages 18-39 to 21% (average for both genders) for ages 90+.

Consider next the vaccine-available period. Overall, CEMP is lower in this period, at 11;64% for women and 14.55% for men. The age pattern is very different, however – much higher for younger ages, yet much lower for the elderly. For children, CEMP is still low, but is much higher than in the pre-vaccine period. Children were not eligible for vaccination for much of this period,[5], and even when eligible had lower vaccination rates than adults.[6] Their higher CEMP rates suggest that COVID was more severe for the unvaccinated in the second, vaccine-available period, but CEMP was reduced because many people were vaccinated.

CEMP is also much higher in the vaccine-available period for persons aged 18-59, somewhat higher for those in their 60's, yet lower for those in their 70's, and much lower for ages 80+. In the vaccine-available period, CEMP, averaged across both genders, is highest for persons in their 40's, and nearly as high for persons aged 18-39 and persons in their 50's. We summarize the different age patterns for CEMP in the two periods in Figure 1.

A natural explanation for the different pattern in the vaccine-available period would reflect a combination of: (i) but for the vaccines, COVID would have been substantially more severe in this period; (ii) the vaccines reduced COVID mortality; and (iii) older people were more likely to be vaccinated and, when boosters became available in late 2021, more likely to get booster shots.[7] We explore this explanation below for Milwaukee by combining mortality and vaccination data. We confirm that for the unvaccinated, COVID mortality was indeed much higher in the vaccine-available period – especially in the fourth quarter of 2021, when the Delta variant was dominant.

The very different age patterns of COVID mortality in the pre-vaccine and vaccine-available periods have not, to our knowledge, been previously reported.

IV. Racial/Ethnic Disparities in CEMP by Age and Time Period

In Table 2, we report CEMP for the four major race/ethnicity groups in our data non-Hispanic Whites, Blacks, Hispanics, and Asian and other. We again report results separately for the pre-vaccine and vaccine-available periods, but average across both genders. For each group other than Whites, we also report a ratio of CEMP for the indicated group to Whites. In Figure 2, we display CEMP levels graphically, separately for men and women, in the pre-vaccine period (Panel A) and the vaccine-available period (Panel B).

A. CEMP and Disparities During the Pre-Vaccine Period

Consider first the pre-vaccine period (Panel A), and compare Hispanics to Whites. Overall COVID PFR for Hispanics is unremarkable – indeed lower than for Whites (0.11% versus 0.16%). However, this is misleading, because the Hispanic population is much younger and thus has a much lower non-COVID natural mortality rate (0.25% versus 0.98%). Within age bands, Hispanic

[5] The FDA approved vaccines for ages 16-17 at the same time as for adults; on May 10 2021 for ages 12-15; on October 29, 2021 for ages 6-11, with CDC approval coming a few days later, but only on June 18, 2022 for ages 6 months through 5 years.

[6] **[*support to come; asked Ruohao and Mariam for updated charts 2022.07.03, can go in text or appendix]**

[7] We show below that this is only a partial explanation for the different age pattern in the vaccine-available period.

CEMP is much higher than for Whites. The largest relative difference is for ages 50-59, for whom Hispanic CEMP of 65.3% is almost 9 times White CEMP of 7.3%. Hispanic/White ratios are also very large for ages 18-49. The ratios fall above age 60, but remain well above 1 at all age.

We provide related evidence in graphical form for CEMP in Figure 2, and for CEMP ratios in Figure 3, separately for women and men. Consider first Figure 2, Panel A (pre-vaccine period). CEMP values are consistently highest for Hispanics and lowest for Whites, and especially high for Hispanic men, who have CEMP levels in the 65-70% range for ages 50-79. Consider next the CEMP ratios in Figure 3. Hispanic/White ratios are very high for both genders, but higher for men than for women for ages 18-79. These are stunning ratios, especially for ages 18-59, and are far higher than we have seen reported before.

Racial/ethnic differences are also evident across Table 2 and Figures 2 and 3 for Blacks and (Asian and other), but smaller in magnitude than for Hispanics. Like those for Hispanics, these ratios are larger for the non-elderly, and shrink for the elderly.

The bottom rows of Table 2 provide a summary measure of racial/ethnic differences averaged across all ages. This summary measure essentially weights the sample by non-COVID natural mortality. The overall ratios are 2.76 for Hispanics/Whites; 1.65 for (Asian and other)/Whites, and 1.27 for Blacks/Whites. While well above 1, these summary measures obscure the much higher ratios for the non-elderly, which receive relatively low weight since the summary measures weight heavily the elderly, with their higher overall mortality rates.

B. A PFR-Based Disparity Measure

One concern with CEMP as a measure of COVID-19 disparities is that using natural deaths from other causes as the denominator bakes into the analysis any pre-existing disparities in mortality rates. One reason why Black CEMP is only moderately above that for Whites is that Blacks have substantially higher non-COVID natural mortality rates. For example, for ages 60-69 during the pre-vaccine period, the Black/White CEMP ratio is 1.60, but a corresponding ratio of PFRs would be (0.52%/0.14% = 3.71). This is not a concern for Hispanics, or for (Asian and Other), both of whom have PFRs comparable to and sometimes below those for Whites at similar ages. Nonetheless, the difference between CEMP and PFR-based ratios suggests that there can be value is reporting both.

In Figure 4, we accordingly provide PFR-based ratios of Hispanic/White, Black/White, and (Asian and Other)/White COVID-19 mortality. The Black/White ratio, computed this way, is around 5:0 in the pre-vaccine period for ages up to 59, and is well above 1 in the vaccine-available period, except for persons aged 90+.

C. Disparities During the Vaccine-Available Period

We turn next to analysis of CEMP and racial/ethnic disparities in the vaccine-available period. We present numerical results in Table 2, Panel B; graphical results for CEMP in Figure 2, Panel B, and CEMP ratios in Figure 3. For Hispanics, the very high Hispanic/White ratios seen for the non-elderly in the pre-vaccine period drop, but remain at around 2 to 2.5, with limited variation by age, except for the very old (90+). As Figure 2, Panel B, shows, CEMP levels for Hispanics are well above those for the other racial/ethnic groups. The Hispanic/White ratios are again generally higher for men than for women (figure 3).

For Blacks, CEMP levels, during the vaccine-available period, averaged across both genders, are somewhat higher than for Whites. The CEMP ratios are close to 1 for men through age 59, but increase with age above that (Figure 3, Panel B). For women, Black/White ratios are close to 1 through age 79 (Figure 3, Panel B).

For the Asian and Other group, male ratios are around 2 through age 49, but close to 1 at higher ages. Female ratios are close to 1 for ages 40-69 but somewhat higher for ages 70+.

These are complex patterns, that defy easy explanation. The very different patterns by race/ethnicity, by time period, and by age range within each racial/ethnic group have not, to our knowledge, been previously reported.

V. CEMP for Unvaccinated versus Vaccinated and Vaccine Effectiveness

A. Vaccination Rates

Table 3 provides summary information on vaccinated adults in Milwaukee, and which vaccine they received, Moderna, Pfizer or J&J. Overall, around 74% of the adult population received at least one dose, 70% were fully vaccinated (one J&J dose or two mRNA doses), and of those who received two doses, 56% received a third dose. These percentages are broadly in line with national averages.[8]

Figure 3, Panel A, provide information on "full vaccination" rates (two mRNA doses (Pfizer or Moderna), or one J&J dose) by age range over time. Vaccine uptake was more rapid among those aged 60+, and more gradual at younger ages. The ending percentage was highest for ages 60-79 and lower for ages 80+. Panel B provides information on receipt of a third dose, generally a booster dose following initial vaccination with an mRNA vaccine. Three-dose percentages (conditional on receiving two doses) rise with age, but similar for ages 60-79 and 80+.

B. CEMP Levels for the Unvaccinated

In Table 4, we report CEMP, and VE based on relative CEMP, by age range and number of doses for four periods: April-June 2021 (with Alpha as the dominant virus variant), July-September 2021 (Delta dominant, no boosters), October-December 2021 (Delta dominant, boosters available, initially for the elderly), and January-March 2022 (Omicron dominant, boosters available). Allowing for a two-week lag between vaccine administration and when we consider the vaccine to be effective, these time periods correspond fairly closely to the periods when the respective variants accounted for a majority of infections for which virus variant was sequenced.[9] We report results by age range and number of doses, and also provide summary rows for ages 18-59 and ages 60+. We chose to study these four periods separately, and not combined them, given evidence from other studies on waning efficacy of the primary series over time, and important

[8] *See* https://data.cdc.gov/Vaccinations/COVID-19-Vaccination-and-Case-Trends-by-Age-Group-/gxj9-t96f [visited 3 July 2022].

[9] Taking the two-week lag into account, the Alpha strain was dominant in the U.S. starting the week of March 14, 2021; the Delta variant was dominant beginning the week of July 4, 2021, and the Omicron variant has been dominant starting the week of Jan. 2, 2022. Source: https://www.gisaid.org/; see also https://covid.cdc.gov/covid-data-tracker/?utm_source=STAT+Newsletters&utm_campaign=059492f101-MR_COPY_01&utm_medium=email&utm_term=0_8cab1d7961-059492f101-153972538#variant-proportions

differences in severity for the unvaccinated and VE between the Delta and Omicron variants. Due in part to this choice, many death counts in individual cells are small, and VE estimates within a given time period and age range are necessarily rough.

Consider first the CEMP values for the unvaccinated. These were low in April-June 2021 -- a relatively low period for COVID infections and deaths -- but rose substantially in the third quarter of 2021 (Delta period) and rise further in the fourth quarter of 2021 (strong Delta infection wave). For persons aged 18-59, CEMP for the unvaccinated averaged 27% in 3Q 2021, 57% in 4Q 2021, and 24% in 1Q 2022.

It is instructive to compare the age pattern in CEMP for the unvaccinated during the 2H 2021 (including 3Q 2021 (moderately risky) and 4Q 2021 (high risk)) to that for the pre-vaccine period, when no one was vaccinated. In the pre-vaccine period, CEMP rose with age, although moderately. In 2H 2021, CEMP was higher for those under age 60, and generally fell with age for older persons. The different age patterns could reflect differences in age patters for the wild strain which dominated in 2020 versus the Delta variant, behavior differences between the two periods, and/or behavior differences between the two populations (all persons in 2020, only the unvaccinated in 2021). But whatever the causes, the Delta variant produced much higher CEMP for the unvaccinated non-elderly than one would have predicted from prior periods.

During the Omicron period (1Q 2022) CEMP levels fell substantially for persons under age 60 relative to 4Q 2021 (Delta period), but rose for older persons. Omicron was typically less severe than Delta, but much more infectious, including for persons who were previously infected. Lower severity but higher frequency led, on the whole, to lower but still substantial CEMP levels for younger unvaccinated persons, and higher levels among the unvaccinated elderly.

In each of the four periods, the unvaccinated numerically dominate the COVID death counts, despite being only about 25% of the population, and an even smaller percentage for the elderly, who face higher mortality risk.

C. VE for One Dose

One dose VE has been rarely studied, except for the initial period in early 2021 when many people had not yet received a second dose. The patterns are interesting. VE relative to the unvaccinated is limited, at 46%, 42%, 68% and 58% across our four time periods. Unlike the evidence for two doses, there is no evidence of apparent waning. A single dose does not provide great protection, but it does provide some protection, which appears to be long-lived.

D. VE for Two Doses

We find evidence of substantial waning of two-dose VE, from 84% to 81% to 77% to 64% across our four sample periods. We also find important differences in two-dose VE for younger versus older persons. For persons aged 60+, protection is always imperfect and waning is gradual, from 83% to 76% to 70% to 68%. For persons aged 18-59, VE is 100%, 100%, and 97%, before plummeting to 37% in the Omicron period, although some of this may be an artifact of small cell counts. Still VE against mortality is nearly 100% for ages 18-49, with only one death – a severely

comorbid 35-year-old Black woman, during the Omicron period,[10] among 213,000 two-dose recipients. Note that we cannot distinguish between declining VE due to waning, and lower VE against the Delta and Omicron variants, relative to prior variants.

The two-dose VE we find against mortality is well below those of other studies of the Delta period, summarized in Black and Thaw (2022). The reasons for these differences call for further investigation. Our use of CEMP to control for otherwise unobserved health differences could be one explanation; our data also includes relative recent data for

E. VE for Booster Dose

VE for a booster dose is 100% through age 59, and reasonably high for persons age 60+, at 85% for 4Q 2021 (Delta) and 90% for 1Q 2022 (Omicron). There is a stark difference between the substantial CEMP values for ages 18-59, especially in 4Q 2021, and the 0 values for those with a booster dose.

Our finding of *zero* deaths for people aged 18-59 with a booster dose will surely not last forever, and will likely not survive for a larger population than we were able to study. Still for 4Q 2021 and 1Q 2022 -- the two periods in which boosters were available -- there were 99 COVID deaths among the unvaccinated, and zero among a similar number of people with booster doses.

F. Age Differences in VE

We find important age differences in VE, with generally lower VE levels for ages 60+ versus ages 18-59. Our overall CEMP and VE estimates, presented in rows at the bottom of Table 4, are effectively weighted by the number of natural, non-COVID decedents in each cell. This weighting is unusual, since basing VE in CEMP is unusual. It feels appropriate to us, to weight VE toward the people who are most affected by COVID.

It is possible to also weight the VE estimates by population. We do so in the last row or Table 4. These estimates are generally, although not always, higher than our mortality-weighted estimates.

G. Robustness Checks

We conduct a number of robustness checks for the results reported above. First, in Table 5, we estimate a logit model on the sample of Indiana and Milwaukee decedents from natural causes. We predict the odds ratio for COVID-19 death for vaccinated persons, by quarter over the vaccine-available period, relative to baseline odds of 1.00 for the unvaccinated in the second quarter of 2021 (below, Q2 2021, and similarly for other quarters). The covariates included in the logit estimation are age, age^2, gender, race/ethnicity, education level, marital status, military veteran status, and quintile of socio-economic status, measured at the 5-digit zip code level using the Graham Social Deprivation Index, measured in 2019 ("zip-SES). We report three panels: For all decedents, for decedents age 18-59 and for decedents aged 60+. VE based on the logit estimation is consistent with the nonparametric estimation in Table 4. Note, however, the large differences in odds ratios across quarters. The unvaccinated were over 6 times as likely to die of

[10] 35-year-old Black woman with sickle cell anemia, hemochromatosis, and pulmonary hypertension; vaccinated with Pfizer April-May 2021; died Jan. 2022.

COVID-19 in 4Q 2021 and 1Q 2022 as in the quieter period of 2Q 2021. Persons who received two vaccine doses faced higher COVID mortality risk in 4Q 2021 and 1Q 2022 than *unvaccinated* persons faced in 2Q 2021.

As we show in the Appendix, our results for CEMP and racial/ethnic disparities during 2020 are similar if we include Cook County, Illinois, which has large Black and Hispanic populations . This makes it less likely that our results are specific to Indiana and Wisconsin. For Cook County, we can compute CEMP only for 2020.

As we show in the Appendix, CEMP is slightly higher, and VE estimates slightly lower, if we do not exclude the immune-compromised.

We provide in the Appendix estimates of $CMP_{natural}$ instead of CEMP, and VE estimates based on $CMP_{natural}$. The $CMP_{natural}$-based VE estimates are slightly lower than the CEMP-based measures reported the text.

In the Appendix, we report data on the percentage of the Milwaukee population that was fully vaccinated through March 31, 2022, and persons who received a third, booster dose, as a percentage of those who received two doses. The full vaccination percentages are broadly in line with national trends, with vaccination rates increasing strongly with age, but lower for the very old (age 80+) than for ages 60-79. Three dose rates, conditioned on receiving two doses, also increase with age, and are similar for those aged 60-79 and those aged 80+.

VI. Comparative COVID Mortality Rates and VE: Moderna versus Pfizer

We also compare VE for Pfizer and Moderna. We begin in Table 6 with nonparametric estimation. Due to small counts in individual cells, we: (i); compare the two vaccines only for two and three doses; (ii) collapse the age ranges to 18-59, 60-79 and 80+; and (iii) collapse the time periods to April-September 2021 (Alpha and Delta periods, booster not available) (Panel A) and October 2021-March 2022 (Delta and Omicron periods, booster available) (Panel B). In both time periods, two-dose VE for Moderna exceeds that for Pfizer. In the first period, VE levels are 84% for Moderna and 71% for Pfizer. These can be converted into remaining risk levels, which are 16% for Moderna, and 29% (nearly twice as high) for Pfizer. In the second period, Moderna shows slightly lower VE of 81%, which could be due to chance, to waning or to different virus variants being dominant. Pfizer shows a larger decline in VE to 59%. Remaining risk for Pfizer is roughly twice that for Moderna, at 41% versus 19%. In the final columns of Panel B, three dose efficacy is similar for both vaccines.

In Table 7, we switch to logit estimation of odds ratios for COVID mortality for persons who received Pfizer, relative to those who received Moderna. The sample is decedents in Indiana and Wisconsin from natural causes, during the vaccine-available period, who received two or three doses of either the Pfizer or Moderna vaccine. We use a logit model similar to Table 5, where the core predictor variable is Pfizer vaccination (Moderna is the omitted group). We exclude immune-compromised persons; persons who received the J&J vaccine; and persons who received both Pfizer and Moderna doses. In the first row of Table 7, the sample is persons who received exactly two doses of either Pfizer or Moderna. In the second row, we restrict the sample to 2Q and 3Q 2021 (before boosters were available). In the third row, we study the booster-available period (4Q 2021 and 1Q 2022). In the last row, we compare 3 Pfizer to 3 Moderna doses.

The Pfizer-versus-Moderna mortality odds ratios are large. For the full period, the odds ratio is 2.19 and strongly statistically significant (z = 4.43). The ratio is also large at 1.86, although not statistically significant, reflecting fewer COVID-19 deaths during this period -- only 33 COVID deaths among the two-dose vaccine recipients (see Table 6). It increases to 2.40 (z = 4.26) in the second period. The higher odds ratio in the second period is consistent with other evidence that indicates faster waning for Pfizer than for Moderna, including against hospitalization and death (Black and Thaw, 2022). However, very few prior studies evaluated VE for both vaccines in the same population.

For the VE comparisons above, there are likely to be important differences between the vaccinated and the unvaccinated, and also between one-dose, two-dose and three-dose recipients. In contrast, unobserved differences in health or behavior between Pfizer and Moderna recipients are likely to be small. When the Pfizer and Moderna vaccines were approved, they showed similar efficacy against infection, so there was no substantive basis for recipients to prefer one over the other. Evidence began to emerge in late 2021 suggesting faster waning of Pfizer than Moderna, but we consider it unlikely that many recipients were aware of this technical research.

Prior, large-sample research comparing Pfizer vs. Moderna VE for mortality is limited. Lin et. al (2022) study North Carolina for the period through early September 2021, find high VE against death for both vaccines, generally 90-95%, but their dataset was only 60% complete for mortality. Robles-Fontan et al. (2022) have essentially complete vaccination and mortality data for Puerto Rico, study mortality through mid-October 2021, and report estimated VE against death of 86% for Pfizer and 93% for Moderna, as of 130 days after second dose, based on modeling VE as a function of time since vaccination. Their time period is shorter than ours, and their VE percentages are higher, but the 2:1 ratio they find between RR for Pfizer versus Moderna is consistent with our study.

VII. Discussion

A. Overview of Results for CEMP

We report results for a new, population-based measure of COVID mortality risk – the COVID Excess Mortality Percentage (CEMP) which at least partly controls for otherwise unobserved health characteristics of the COVID decedents. We also report VE based on the CEMP measure. Our approach and dataset lead to a number of new results, discussed further below.

B. Some Attractive Features of the CEMP Measure

We believe that CEMP is an attractive measure of the impact of the COVID-19 pandemic on mortality. Any measure will have strengths and limitations. However, the CEMP measure that we rely on in the text, and the related $CMP_{natural}$ measure reported in the Appendix, have several attractive features, relative to other measures such as COVID PFR, or the all-cause excess mortality rate.

COVID PFR rises strongly with age, and raw PFR levels are low for the non-elderly. This can obscure the large impact – highlighted in this study -- that COVID had in increasing mortality risk for the non-elderly, relative to background risk from other natural causes. CEMP, in contrast, provide a measure of COVID risk, relative to risk of dying from other natural causes, for the sample population. All-cause excess mortality raises similar concerns, coupled with the need to

estimate expected mortality without COVID, based on extrapolation of mortality trends from the pre-COVID period.

CEMP also can be readily compared across different time periods, with different underlying COVID mortality rates. It lends itself to population-level analysis, because it requires only death certificate data, but can still be enriched by linking to vaccination data (as we do here), infection data (as we expect to be able to do in the near future), or both where available.

A key strength of the CEMP measure is that it controls, through the denominator, for background population health, as reflected in natural mortality rate from causes other than COVID. This control is crude and surely imperfect, but population health is otherwise often difficult to observe, and could vary substantially between the vaccinated and the unvaccinated, between high versus low SES areas (observable through decedents' residence zip codes, linked to American Community Survey data), and across racial/ethnic groups (directly observable in mortality data).

For racial/ethnic subgroups, a concern with PFR and excess mortality measures is the need to use American Community Survey or Census estimates of the population denominator to compute mortality rates. In contrast, the CEMP measure relies on a single source – death certificates. There is no reason to think that race/ethnicity is coded differently for COVID decedents than for persons who die of non-COVID natural causes.

As we discuss above, a concern with relative CEMP, as a measure of racial/ethnic disparities, is that the denominator reflects pre-existing disparities in mortality rates. This is a concern in our sample principally for Blacks, who have substantially higher non-COVID natural mortality rates than Whites. We address this concern above by also providing Hispanic/White, Black/White, and (Asian and Other)/White ratios based on COVID PFR.

Our CEMP and $CMP_{natural}$ measures are similar in spirit to Violanti et. al (2022), who report that in 2020, COVID (treated as duty-related) caused 62% of all duty-related police officer deaths in the U.S., thus far exceeding deaths due to gunshots (15%), traffic accidents (15%) and other causes (8%).

Our approach, in which we study population level VE against mortality, by age group and dominant virus variant, is similar to the Kiss et. al (2022) study of Hungary. Hungary, along with Israel was among the first countries to roll out boosters. Kiss et. al also find a strong age gradient in VE for full vaccination (without booster) during the Delta period, with lower VE for the elderly. They find that a first booster provides strong protection during 4Q 2021 (Delta period). Booster effectiveness is substantial, but far less complete than we find during the Omicron period, (perhaps reflecting the broader range of vaccines used in Hungary), but there is essentially zero mortality risk for those who receive a second booster, at any age.

C. Racial/ethnic Disparities

That COVID-19 had a disproportionate effect on some racial/ethnic groups is widely known. Our contribution is to show that these disparities, especially in 2020, were substantially higher than has been reported elsewhere. CEMP ratios, relative to Whites, are generally highest for middle-aged Hispanics, higher for men than for women, vary greatly by age, are much higher in the pre-vaccine period than the vaccine-available period, but remain substantial in the vaccine-available period.

These patterns, and the sheer magnitude of some of the disparities, call for close study of the underlying reasons for them, and for the variation with age, gender, and time period. It has become common to invoke "systemic racism" as a catch-phrase to explain all disparities. But this catch-phrase cannot explain the age pattern we find, nor the time pattern, nor the different patterns for men and women, nor, for example, the very different Hispanic versus Black CEMP rates, especially in the pre-vaccine period. Any explanation will surely be multifactorial, and will likely depend on factors we don't observe, including infection rates, variation across hospitals in in-hospital survival rates, and variation across racial/ethnic groups in how soon they seek treatment, and from which hospitals.

An advantage of measuring disparities using the CEMP measure, rather than population mortality rates, is that CEMP is less vulnerable to the miscounting of racial/ethnic groups that can occur in surveys. Undercounting the population denominator is a particular concern for younger Hispanics, who may be undocumented and avoid being included in ACS surveys or Census counts. In contrast, misattribution will affect CEMP only if it is different for deaths attributed to COVID than for deaths attributed to other natural causes. We know of no reason to expect that physicians or medical examiners report race/ethnicity on death certificates differently for COVID-attributable than for other natural deaths. The CEMP concept can also readily be extended to study natural mortality from specific diseases.

We lacked a large enough sample to study subgroups with the "Asian and Other" group, such as Native Americans. However, a 14-state study by Arrazola et. al (2020), although limited to January-June 2020, finds very high ratios of COVID PFR for Native Americans relative to Whites (combined Hispanic and non-Hispanic). A study of COVID infection rates over a similar time period (Hatcher et al., 2020) found higher Native American infection rates over roughly the same time period, but not at levels sufficient to explain the higher Native American mortality rates

D. CEMP and the Avoidable Tragedy of the Unvaccinated

Many younger persons chose to forego vaccination. Many surely believed that COVID was a disease mostly of the elderly. So it is, up to a point. The CEMP measure, however, highlights the large toll of COVID among the non-elderly. It is hard to know what would have persuaded more people to get vaccinated, sooner. But publicity for a measure such as CEMP might have brought home to some of them the substantial risk they faced, relative to other causes of death.

For racial/ethnic groups who faced especially high CEMP levels, especially Hispanics, publicity for a measure such as CEMP might have boosted vaccination rates. Younger Hispanics may have known that they faced higher COVID risk than non-Hispanic, but they almost surely did not know how much higher, as indicated by our data for the pre-vaccine period. That knowledge might have changed behavior, at least for some people.

The U.S. rolled out vaccination faster than almost any other major country, but the vaccination campaign faltered at coverage levels well below those of many other developed countries. Too many people, especially the middle-aged, remained vulnerable to the Delta wave that hit in 4Q 2021 and the early 2022 Omicron wave. As we write in mid-2022, the U.S. has won a competition that no one should want to win – it ranks highest among developed countries in

cumulative COVID PFR, of around 0.3%, including a number of European countries with older populations.[11]

E. The CEMP Measure and Vaccine Effectiveness

Our use of CEMP to measure VE, where the denominator controls for otherwise unobserved health characteristics, is novel, but is similar in spirit to Piernas et al. (2022), who study how VE against COVID-19 hospitalization and death in the UK population varies based on body-mass-index (BMI), which proxies in a different way for overall health and mortality risk. The main advantage of this measure, over more typical studies using different research designs (most often a test-negative design) is that the denominator of CEMP (natural, non-COVID deaths) partly controls for other, unobserved health characteristics of the decedents.

Using this measure of VE, we report lower two-dose VE estimates than in other studies, sometimes substantially lower. For example, we report two-dose VE of 77% during 4Q 2021 (Delta period) and 64% during 1Q 2022 (Omicron period).

F. Comparative Vaccine Effectiveness for Pfizer and Moderna

We find striking differences in two-dose RR for Pfizer versus Moderna, with a Pfizer-to-Moderna odds ratio over two (over twice the remaining mortality risk). Prior studies have tended to find somewhat greater VE for Moderna than for Pfizer, with Pfizer waning more quickly. However, most studies focused on VE against infection or symptomatic infection, or at most against hospitalization, which are easier to study with health records. We found only one study with access to population mortality records (Robles-Fontan et. al, 2022, study Puerto Rico). This study found higher VE than we do, but over a shorter time period. It also found RR for Pfizer twice that for Moderna.

G. The Avoidable Tragedy of the Unboosted

Evidence of vaccine waning first appeared in mid-2021, initially from Israel which used Pfizer almost exclusively. In response, Israel launched a booster campaign in late July 2021, initially for the elderly, but expanded to the whole population by the end of August. Israel encouraged receipt of a booster dose by generally limiting their "Green Pass," which allowed access to restaurants, theaters, etc, to persons who have received a booster shot within the last six months (or had recently recovered from COVID infection) (Tercatin, 2021). Other countries soon followed. The U.S., however, dithered. FDA scientists wrote publicly that the need for boosters was not sufficiently established (Krause et. al, 2021). Evidence of need, sufficient to persuade other countries, bolstered by evidence from the Israeli rollout, was not enough for them, nor for an expert committee convened to advise the Food and Drug Administration (FDA), which in September 2021 approved only a limited rollout to the elderly and persons at risk due to occupational exposure (Weiland and LaFraniere, 2021); nor for an advisory committee to the Centers for Disease Control and Prevention (CDC), which wanted boosters to be allowed only for the elderly, although the CDC committee's objections were overruled by the CDC director (Mandavilli and Mueller, 2021).

[11] **Source:** Authors' analysis of data from the Our World in Data website, which tracks reported COVID-19 deaths by country.

Only two months later did the FDA and the CDC approve boosters for all adults; only at the end of November, with the Omicron variant looming, did the CDC "recommend" boosters for all adults (CDC, 2021). Even when boosters were approved, public health messaging was muddled, with the value of boosters "lost in the sea of changing recommendations and guidance," leading to low takeup (Associated Press, 2022).

The FDA scientists and the expert panels were wrong. Dead wrong. We should be thankful, at least, that in November 2021, when Pfizer reapplied for approval, the FDA and CDC acted without reconvening their misguided advisors. The VE evidence presented here implies that delay in authorizing boosters, and the low takeup resulting from muddled messaging, killed tens of thousands of Americans, who would have survived if the U.S. booster rollout had matched Israel's or Hungary's – although a more precise estimate is beyond the scope of this paper.

H. The Role of Behavioral Differences

For the VE comparisons above, there are likely to be important differences between the vaccinated and the unvaccinated, and also between one-dose, two-dose and three-dose recipients. They may have different health, which we seek to control for using the CEMP measure. They may behave differently, in when they get tested for possible infection, when they seek care if infected, which hospitals they go to.

Persons with different vaccination trajectories may also behave differently in the COVID infection risks they are willing to accept, versus those they seek to avoid. One the one hand, the unvaccinated, and to a lesser extent the one-dose vaccinated, maybe believe COVID is less severe than those who receive two or three doses. On the other hand, the vaccinated will generally understand that they are less likely to become seriously ill if infected, and may be willing to take greater risk of becoming infected – going to restaurants; forgoing masks; traveling, etc.

Behavioral differences are a major confounder both for this and for any other VE study. Only the initial randomized trials can avoid this concern, and even then only partly. But they were sized to study only risk of infection, were far too small to study mortality, and studied principally the original wild strain.

I. Limitations

This study has important limitations. We study only mortality, not less-extreme outcomes such as hospitalization or admission to an intensive care unit. For CEMP, we have data for Indiana and Wisconsin, but for VE, we are limited to Milwaukee. Milwaukee is racially, ethnically, and economically diverse, with an adult population of around 720,000. However, especially for younger persons, mortality from COVID or other natural causes is relatively rare, which limits statistical power. Milwaukee's COVID experience may also not be representative of other areas.

We do not observe individual health characteristics, except through the limited lens of death certificates. There could be health differences between the vaccinated and unvaccinated, that would affect COVID mortality rates, yet not be captured in rates of natural non-COVID deaths. However, VE estimates using this partial control are still useful; many studies have even weaker controls. Our VE measure does not control for behavior differences between the vaccinated and unvaccinated. However, neither do other VE studies, other than the initial randomized trials. For behavioral differences, our CEMP-based measure is population-based and

thus avoids the selection issues that cannot be avoided for studies that begin with, say, persons with electronic health records or COVID hospitalizations.

Our CEMP measure is a downward-biased measure of the excess mortality due to COVID, because it ignores the effect of COVID infection on natural deaths, not directly attributable to COVID. Our VE measure may be biased if the downward bias in CEMP differs across groups with different vaccination status.

COVID deaths could be underreported, but we coded COVID-19 as the likely cause of death based on reading death certificates; this produced significantly larger counts than the ICD-10 codes prepared by the NCHS.[12] Any remaining undercount would bias CEMP values downward, but there is no reason to expect this to cause bias in VE, which is based on *relative* CEMP levels across different vaccination groups.

We lacked data on COVID-19 infection rates, which may differ across vaccination groups and affect mortality. We thus cannot study whether or how VE differs for the previously infected versus the uninfected. We lacked sufficient sample size to study VE for the J&J vaccine, or to further decompose the broad "Asian and other" racial/ethnic group. That group includes two very different broad groups: Asians, whom in other studies had higher vaccination rates and lower COVID mortality rates than Whites; and the "other" group (Native American, mixed race, etc.) which faced higher COVID mortality rates, and possibly lower vaccination rates.

VIII. Conclusion

We develop a new measure of COVID mortality risk, which we call COVID Excess Mortality Risk (CEMP) (COVID-19 deaths for a group of persons, divided by non-COVID deaths from natural causes for the same group. We then derive a number of novel results using this measure. First, we find very different patterns for how CEMP varies with age during the pre-vaccine period (April-December, 2020, and the vaccine-available period (April 2021-March 2022). CEMP rises with age, although moderately, in the pre-vaccine period, but peaks at middle ages in the vaccine-available period. The very different pattern in the vaccine-available period is partly, but only partly, explained by higher vaccination rates for the elderly.

Second, we report very large racial/ethnic disparities in CEMP levels, especially in 2020 (pre-vaccine period), especially for Hispanics relative to Whites, and even more so for Hispanic men relative to White men. Male Hispanic/White ratios in 2020 range from 7:1 to almost 10:1 across ages 18-59. Prior research has reported higher Black and Hispanic COVID-mortality rates, but none of this magnitude. Black/White ratios based on CEMP are lower, but ratios for COVID population fatality rates average around 5:1 for both genders for this age range. CEMP ratios varied by age, gender, and time period, and defy easy explanation. They deserve a full exploration, with richer data than we had available.

Third, we use the CEMP measure to study vaccine effectiveness against mortality. Our VE estimates are often well below those reported in other studies. For example, we estimate two-dose VE at 79% in 2H 2021, when the Delta variant was dominant, and only 64% in 1Q 2022

[12] The ICD-10 codes are created by personnel at the National Center for Health Statistics, based on the text fields. We found that the ICD-10 codes contained a meaningful number of false negatives (likely COVID deaths not recorded as such), but many fewer false positives (deaths recorded using the ICD-10 code for COVID-19 without meaningful support from the text fields.

(Omicron variant). Three-dose VE is substantially higher at around 90% in both periods. The combination of low two-dose efficacy and much higher three-dose efficacy implies that many lives were lost, almost surely in the tens of thousands, that could have been saved with a faster, more forceful rollout of booster doses. At the same time, we find a strong protective vaccination effect for younger persons, with only one death among two-dose recipients aged 49 or less, and no deaths among three-dose recipients aged 59 or less.

Finally, we report that for two-dose recipients, the remaining mortality risk for those vaccinated with Pfizer is more than double that for persons vaccinated with Moderna. Our data on vaccine effectiveness, especially the stark difference between two Pfizer and two Moderna doses, should support a strong public push for all adults, certainly all age 50+, and especially Pfizer recipients, to receive a booster dose.

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Table 1. COVID-19 Related Statistics by Age and Gender for Wisconsin and Indiana

Population, COVID-19 deaths, Non-COVID natural deaths, COVID-19 PFR, Non-COVID natural mortality rate, and CEMP for Wisconsin and Indiana during pre-vaccination period (April 1, 2020 – December 31, 2020) and vaccine-available period (April 1, 2021-March 31, 2022). **Panel A**. Pre-vaccination period. **Panel B**. Vaccine-available period. In Panel A, PFR and Natural Mortality Rate are annualized by multiplying by 12/9, because the time period has only nine months. The time period in Panel B is 12 months so no annualization was necessary. We drop the initial vaccine rollout period (January-March 2021).

$$\text{PFR} = \frac{COVID\ deaths}{Population} \times \frac{\mathbf{12}}{\#\boldsymbol{Months}}\ ;\ \text{Non-COVID Natural Mortality Rate} = \frac{Non{-}Covid\ natural\ deaths}{Population} \times \frac{\mathbf{12}}{\#\boldsymbol{Months}}\ ;\ \text{CEMP} = \frac{COVID\ deaths}{Non{-}COVID\ natural\ deaths}$$

Panel A. Pre-Vaccination Period (April – December 2020)

	Female						Male					
Age Group	Covid Deaths	Non-COVID Natural Deaths	Population	COVID PFR	Non-COVID Natural Mort. Rate	CEMP	Covid Deaths	Non-COVID Natural Deaths	Population	COVID PFR	Non-COVID Natural Mort Rate	CEMP
0-17	1	309	1,388,231	0.00%	0.03%	0.32%	3	330	1,457,103	0.00%	0.03%	0.91%
18-39	50	553	1,782,774	0.00%	0.04%	9.04%	63	713	1,838,115	0.00%	0.05%	8.84%
40-49	88	968	748,861	0.02%	0.17%	9.09%	144	1,311	750,514	0.03%	0.23%	10.98%
50-59	273	2,709	856,307	0.04%	0.42%	10.08%	418	4,058	836,769	0.07%	0.65%	10.30%
60-69	754	5,849	768,508	0.13%	1.01%	12.89%	1,253	8,626	726,147	0.23%	1.58%	14.53%
70-79	1,500	8,984	456,663	0.44%	2.62%	16.70%	2,153	10,852	390,426	0.74%	3.71%	19.84%
80-89	2,300	12,103	237,453	1.29%	6.80%	19.00%	2,338	10,648	157,223	1.98%	9.03%	21.96%
90+	2,016	10,450	74,938	3.59%	18.59%	19.29%	1,175	5,242	33,836	4.63%	20.66%	22.42%
Total	**6,982**	**41,925**	**6,313,735**	**0.15%**	**0.89%**	**16.65%**	**7,547**	**41,780**	**6,190,133**	**0.16%**	**0.90%**	**18.06%**

Panel B. Vaccine-Available Period (April 2021 – March 2022)

	Female						Male					
Age Group	Covid Deaths	Non-COVID Natural Deaths	Population	COVID PFR	Non-COVID Natural Mort. Rate	CEMP	Covid Deaths	Non-COVID Natural Deaths	Population	COVID PFR	Non-COVID Natural Mort. Rate	CEMP
0-17	14	345	1,388,231	0.00%	0.02%	4.06%	9	419	1,457,103	0.00%	0.03%	2.15%
18-39	158	680	1,782,774	0.01%	0.04%	23.24%	223	932	1,838,115	0.01%	0.05%	23.93%
40-49	271	1,185	748,861	0.04%	0.16%	22.87%	476	1,645	750,514	0.06%	0.22%	28.94%
50-59	679	3,316	856,307	0.08%	0.39%	20.48%	1,056	4,883	836,769	0.13%	0.58%	21.63%
60-69	1,293	7,796	768,508	0.17%	1.01%	16.59%	1,858	11,284	726,147	0.26%	1.55%	16.47%
70-79	1,592	12,521	456,663	0.35%	2.74%	12.71%	2,076	14,737	390,426	0.53%	3.77%	14.09%
80-89	1,468	15,690	237,453	0.62%	6.61%	9.36%	1,645	14,057	157,223	1.05%	8.94%	11.70%
90+	865	12,955	74,938	1.15%	17.29%	6.68%	612	6,713	33,836	1.81%	19.84%	9.12%
Total	**6,340**	**54,488**	**6,313,735**	**0.10%**	**0.86%**	**11.64%**	**7,955**	**54,670**	**6,190,133**	**0.13%**	**0.88%**	**14.55%**

Table 2. COVID-19 Related Statistics by Age and Race/Ethnicity for Wisconsin and Indiana

Table shows separate results for non-Hispanic White, Black, non-Black Hispanic, and Asian and other, pooled across genders, for same time periods and overall sample as Table 1.

Panel A. Pre-Vaccination Period (April – December 2020)

	Non-Hispanic White							Black						
Age Group	Covid Deaths	Non-COVID Natural Deaths	Population	COVID PFR	Non-COVID Natural Mort. Rate	CEMP		Covid Deaths	Non-COVID Natural Deaths	Population	COVID PFR	Non-COVID Natural Mort. Rate	CEMP	CEMP Ratio to White
0-17	2	377	2,060,767	0.00%	0.02%	0.53%		1	168	285,134	0.00%	0.08%	0.60%	**1.12**
18-39	47	916	2,806,284	0.00%	0.04%	5.13%		28	229	325,854	0.01%	0.09%	12.23%	**2.38**
40-49	116	1,691	1,243,778	0.01%	0.18%	6.86%		50	414	113,974	0.06%	0.48%	12.08%	**1.76**
50-59	411	5,641	1,488,293	0.04%	0.51%	7.29%		145	826	110,166	0.18%	1.00%	17.55%	**2.41**
60-69	1,452	12,336	1,353,808	0.14%	1.21%	11.77%		303	1,605	77,178	0.52%	2.77%	18.88%	**1.60**
70-79	3,076	17,944	781,643	0.52%	3.06%	17.14%		352	1,383	38,909	1.21%	4.74%	25.45%	**1.48**
80-89	4,179	21,113	370,487	1.50%	7.60%	19.79%		307	1,132	14,258	2.87%	10.59%	27.12%	**1.37**
90+	2,989	14,863	102,380	3.89%	19.36%	20.11%		129	555	3,947	4.36%	18.75%	23.24%	**1.16**
Total (all ages)	**12,272**	**74,881**	**10,207,440**	**0.16%**	**0.98%**	**16.39%**		**1,315**	**6,312**	**969,418**	**0.18%**	**0.87%**	**20.83%**	**1.27**
Ratio to White											**1.13**	**0.89**	**1.27**	

	Non-Black Hispanic							Asian and Other						
Age Group	Covid Deaths	Non-COVID Natural Deaths	Population	COVID PFR	Non-COVID Natural Mort. Rate	CEMP	CEMP Ratio to White	Covid Deaths	Non-COVID Natural Deaths	Population	COVID PFR	Non-COVID Natural Mort. Rate	CEMP	CEMP Ratio to White
0-17	1	62	295,273	0.00%	0.03%	1.61%	**3.04**	0	32	204,160	0.00%	0.02%	0.00%	**0.00**
18-39	24	64	284,337	0.01%	0.03%	37.50%	**7.31**	14	57	204,414	0.01%	0.04%	24.56%	**4.79**
40-49	54	117	85,519	0.08%	0.18%	46.15%	**6.73**	12	57	56,105	0.03%	0.14%	21.05%	**3.07**
50-59	111	170	51,906	0.29%	0.44%	65.29%	**8.96**	24	130	42,712	0.07%	0.41%	18.46%	**2.53**
60-69	185	315	32,669	0.76%	1.29%	58.73%	**4.99**	67	219	31,001	0.29%	0.94%	30.59%	**2.60**
70-79	138	287	12,355	1.49%	3.10%	48.08%	**2.80**	87	222	14,182	0.82%	2.09%	39.19%	**2.29**
80-89	92	278	5,349	2.29%	6.93%	33.09%	**1.67**	60	228	4,583	1.75%	6.63%	26.32%	**1.33**
90+	49	152	1,481	4.41%	13.68%	32.24%	**1.60**	24	122	966	3.31%	16.84%	19.67%	**0.98**
Total (all ages)	**654**	**1,445**	**768,888**	**0.11%**	**0.25%**	**45.26%**	**2.76**	**288**	**1,067**	**558,123**	**0.07%**	**0.25%**	**26.99%**	**1.65**
Ratio to White				**0.71**	**0.26**	**2.76**					**0.43**	**0.26**	**1.65**	

Panel B. Vaccine-Available Period (April 2021 – March 2022)

	White							Black						
Age Group	Covid Deaths	Non-COVID Natural Deaths	Population	COVID PFR	Natural Mortality Rate	CEMP		Covid Deaths	Non-COVID Natural Deaths	Population	COVID PFR	Natural Mortality Rate	CEMP	CEMP Ratio to White
0-17	16	458	2,060,767	0.00%	0.02%	3.49%		2	151	285,134	0.00%	0.05%	1.32%	**0.38**
18-39	249	1,141	2,806,284	0.01%	0.04%	21.82%		59	278	325,854	0.02%	0.09%	21.22%	**0.97**
40-49	529	2,154	1,243,778	0.04%	0.17%	24.56%		107	436	113,974	0.09%	0.38%	24.54%	**1.00**
50-59	1,422	6,806	1,488,293	0.10%	0.46%	20.89%		171	946	110,166	0.16%	0.86%	18.08%	**0.87**
60-69	2,638	16,579	1,353,808	0.19%	1.22%	15.91%		320	1,839	77,178	0.41%	2.38%	17.40%	**1.09**
70-79	3,253	24,878	781,643	0.42%	3.18%	13.08%		244	1,659	38,909	0.63%	4.26%	14.71%	**1.12**
80-89	2,828	27,814	370,487	0.76%	7.51%	10.17%		178	1,230	14,258	1.25%	8.63%	14.47%	**1.42**
90+	1,377	18,667	102,380	1.34%	18.23%	7.38%		69	634	3,947	1.75%	16.06%	10.88%	**1.48**
Total (all ages)	**12,312**	**98,497**	**10,207,440**	**0.12%**	**0.96%**	**12.50%**		**1,150**	**7,173**	**969,418**	**0.12%**	**0.74%**	**16.03%**	**1.28**
Ratio to White											**0.98**	**0.77**	**1.28**	

	Hispanic							Asian and Other						
Age Group	Covid Deaths	Non-COVID Natural Deaths	Population	COVID PFR	Natural Mortality Rate	CEMP	CEMP Ratio to White	Covid Deaths	Non-COVID Natural Deaths	Population	COVID PFR	Natural Mortality Rate	CEMP	CEMP Ratio to White
0-17	3	101	295,273	0.00%	0.03%	2.97%	**0.85**	2	54	204,160	0.00%	0.03%	3.70%	**1.06**
18-39	45	120	284,337	0.02%	0.04%	37.50%	**1.72**	28	73	204,414	0.01%	0.04%	38.36%	**1.76**
40-49	83	144	85,519	0.10%	0.17%	57.64%	**2.35**	28	96	56,105	0.05%	0.17%	29.17%	**1.19**
50-59	107	249	51,906	0.21%	0.48%	42.97%	**2.06**	35	198	42,712	0.08%	0.46%	17.68%	**0.85**
60-69	142	342	32,669	0.43%	1.05%	41.52%	**2.61**	51	320	31,001	0.16%	1.03%	15.94%	**1.00**
70-79	110	376	12,355	0.89%	3.04%	29.26%	**2.24**	61	345	14,182	0.43%	2.43%	17.68%	**1.35**
80-89	75	387	5,349	1.40%	7.24%	19.38%	**1.91**	32	316	4,583	0.70%	6.90%	10.13%	**1.00**
90+	19	234	1,481	1.28%	15.80%	8.12%	**1.10**	12	133	966	1.24%	13.77%	9.02%	**1.22**
Total (all ages)	**584**	**1,953**	**768,888**	**0.08%**	**0.25%**	**29.90%**	**2.39**	**249**	**1,535**	**558,123**	**0.04%**	**0.28%**	**16.22%**	**1.30**
Ratio to White				**0.63**	**0.26**	**2.39**					**0.37**	**0.29**	**1.30**	

Table 3. Summary Statistics for Milwaukee County Vaccination Status

Table provides summary information on vaccine doses for adults vaccinated in Milwaukee County, through March 31, 2022. Vaccine type for fully vaccinated persons is based on first two doses. Includes immune-compromised persons. For fully vaccinated persons, breakdown by vaccine type is based on the first dose (for the J&J vaccine; includes 2 people who received one mRNA dose followed by a J&J dose) or the first two doses (for the mRNA vaccines).

Number of Doses	Vaccine Type	No. of People	% of pop.	All in dose category	% of pop.
Exactly 1	All			53,439	7.41
	Moderna	11,801	1.64		
	Pfizer	21,963	3.04		
	J&J	19,675	2.73		
Exactly 2	All			212,977	29.52
	Moderna Only	67,724	9.39		
	Pfizer Only	129,938	18.01		
	J&J Only	2,461	0.34		
	Mixed mRNA	829	0.11		
	Mixed J&J and mRNA	12,027	1.67		
Fully Vax (one J&J or two mRNA), or more	All			503,317	69.76
	Moderna	172,638	23.93		
	Pfizer	295,464	40.95		
	J&J	34,163	4.73		
	Mixed mRNA	1,050	3.45		
Exactly 3	All			270,597	37.50
	Moderna Only	93,542	12.96		
	Pfizer Only	152,839	21.18		
	Mixed mRNA	23,841	3.31		
	Mixed J&J and mRNA	375	0.05		
4+ (max 7)	All			68	0.01
Total		**537,081**	**74.44**	**537,081**	**74.44**
Milwaukee Adult Pop.		**721,518**		**721,519**	

Table 4. Vaccine Effectiveness (VE) by Time Period

Table shows COVID deaths, natural non-COVID deaths, CEMP, and VE based on CEMP for indicated age ranges and time periods. Sample excludes immune-compromised persons. Last row shows population-weighted VE.

Age		April-Jun 2021 (Alpha)			Jul-Sep 2021 (Delta no Booster)			Oct-Dec 2021 (Delta, With Booster)				Jan-Mar 2022 (Omicron)			
Group	Measure	0 doses	1 dose	2 doses	0 doses	1 dose	2 doses	0 doses	1 dose	2 doses	3 doses	0 doses	1 dose	2 doses	3 doses
18-39	Covid deaths	2	0	0	7	0	0	16	0	0	0	3	0	1	0
	Other natural deaths	33	4	1	40	6	10	42	3	11	0	18	2	10	4
	CEMP	6.5%	0.0%	0.0%	21.2%	0.0%	0.0%	61.5%	0.0%	0.0%	NA	20.0%	0.0%	11.1%	0.0%
	VE		100%	100%		100%	100%		100%	100%	NA		100%	44%	100%
40-49	Covid deaths	2	1	0	11	1	0	20	1	0	0	8	0	0	0
	Other natural deaths	41	10	11	59	8	10	55	12	18	7	40	10	14	4
	CEMP	5.1%	11.1%	0.0%	22.9%	14.3%	0.0%	57.1%	9.1%	0.0%	0.0%	25.0%	0.0%	0.0%	0.0%
	VE		-117%	100%		38%	100%		84%	100%	100%		100%	100%	100%
50-59	Covid deaths	6	2	0	21	4	0	37	6	2	0	15	2	8	0
	Other natural deaths	115	24	25	87	27	47	105	36	77	6	76	25	44	32
	CEMP	5.5%	9.1%	0.0%	31.8%	17.4%	0.0%	54.4%	20.0%	2.7%	0.0%	24.6%	8.7%	22.2%	0.0%
	VE		-65%	100%		45%	100%		63%	95%	100%		65%	10%	100%
60-69	Covid deaths	15	1	2	23	3	3	51	5	15	1	46	6	8	4
	Other natural deaths	197	44	109	181	46	156	182	44	163	32	166	31	116	98
	CEMP	8.2%	2.3%	1.9%	14.6%	7.0%	2.0%	38.9%	12.8%	10.1%	3.2%	38.3%	24.0%	7.4%	4.3%
	VE		72%	77%		52%	87%		67%	74%	92%		37%	81%	89%
70-79	Covid deaths	12	0	1	25	4	11	45	2	18	2	44	1	16	7
	Other natural deaths	204	43	144	167	37	202	184	34	229	59	164	24	153	195
	CEMP	6.3%	0.0%	0.7%	17.6%	12.1%	5.8%	32.4%	6.3%	8.5%	3.5%	36.7%	4.3%	11.7%	3.7%
	VE		100%	89%		31%	67%		81%	74%	89%		88%	68%	90%
80-89	Covid deaths	3	1	1	18	4	5	34	5	25	3	34	5	21	10
	Other natural deaths	169	35	172	139	41	247	163	48	267	67	147	27	141	197
	CEMP	1.8%	2.9%	0.6%	14.9%	10.8%	2.1%	26.4%	11.6%	10.3%	4.7%	30.1%	22.7%	17.5%	5.3%
	VE		-63%	68%		27%	86%		56%	61%	82%		24%	42%	82%
90+	Covid deaths	3	0	1	9	1	9	15	1	11	2	19	2	5	2
	Other natural deaths	117	25	167	93	21	199	113	21	198	39	90	17	97	196
	CEMP	2.6%	0.0%	0.6%	10.7%	5.0%	4.7%	15.3%	5.0%	5.9%	5.4%	26.8%	13.3%	5.4%	1.0%
	VE		100%	77%		53%	56%		67%	62%	65%		50%	80%	96%
Total	**Covid deaths**	**10**	**3**	**0**	**39**	**5**	**0**	**73**	**7**	**2**	**0**	**26**	**2**	**9**	**0**
18-59	**Other natural deaths**	**189**	**38**	**37**	**186**	**41**	**67**	**202**	**51**	**106**	**13**	**134**	**37**	**68**	**40**
	CEMP	**5.6%**	**8.6%**	**0.0%**	**26.5%**	**13.9%**	**0.0%**	**56.6%**	**15.9%**	**1.9%**	**0.0%**	**24.1%**	**5.7%**	**15.3%**	**0.0%**
	VE		**-53%**	**100%**		**48%**	**100%**		**72%**	**97%**	**100%**		**76%**	**37%**	**100%**
Total	**Covid deaths**	**33**	**2**	**5**	**75**	**12**	**28**	**145**	**13**	**69**	**8**	**143**	**14**	**50**	**23**
60+	**Other natural deaths**	**687**	**147**	**592**	**580**	**145**	**804**	**642**	**147**	**857**	**197**	**567**	**99**	**507**	**686**
	CEMP	**5.0%**	**1.4%**	**0.9%**	**14.9%**	**9.0%**	**3.6%**	**29.2%**	**9.7%**	**8.8%**	**4.2%**	**33.7%**	**16.5%**	**10.9%**	**3.5%**
	VE		**73%**	**83%**		**39%**	**76%**		**67%**	**70%**	**85%**		**51%**	**68%**	**90%**
Total	**Covid deaths**	**43**	**5**	**5**	**114**	**17**	**28**	**218**	**20**	**71**	**8**	**169**	**16**	**59**	**23**
18+	**Other natural deaths**	**876**	**185**	**629**	**766**	**186**	**871**	**844**	**198**	**963**	**210**	**701**	**136**	**575**	**726**
	CEMP	**5.2%**	**2.8%**	**0.8%**	**17.5%**	**10.1%**	**3.3%**	**34.8%**	**11.2%**	**8.0%**	**4.0%**	**31.8%**	**13.3%**	**11.4%**	**3.3%**
	VE		**46%**	**84%**		**42%**	**81%**		**68%**	**77%**	**89%**		**58%**	**64%**	**90%**
	VE (pop. weighted)		**26%**	**94%**		**64%**	**94%**		**82%**	**91%**	**95%**		**79%**	**55%**	**97%**

Table 5. Vaccination Effectiveness (VE) Calculated Using a Multivariate Logit Model

Table shows the odds ratios from logit regressions for sample of persons in Indiana and Wisconsin who died of natural causes, for different numbers of vaccine doses by quarter over April 2021 – March 2022, and VE computed based on the odds ratios. Odds ratios are from logit model of Prob(Covid-19 Death) = f(doses received, baseline is 0 doses), by quarter (baseline period is Q2 2021), with controls for age, age^2, zip-SES quintile, gender, race/ethnicity, education level, marital status, and military veteran status. 95% Confidence intervals are in parentheses (not available for 3 doses for 2Q and 3Q 2021, or for cells with 0 deaths). Sample excludes immune-compromised persons. Coefficients on covariates are suppressed. **Panel A.** All persons. **Panel B**. Persons aged 18-59, from logit model for sample limited to decedents aged 18-59. **Panel C**. Persons aged 60+, from logit model for sample limited to decedents aged 60+. VE is computed as:

$$\text{VE}_{\text{q,dose}} = \frac{(OddsRatio_{q,0} - OddsRatio_{q,dose})}{OddsRatio_{q,0}}$$

Panel A. Sample is All Natural Deaths

	Odds Ratios				Implied Vaccine Effectiveness		
Quarter	0 Doses	1 Dose	2 Doses	3 Doses	1 Dose	2 Doses	3 Doses
2021-Q2	1.00	0.52 (0.20-1.32)	0.17 (0.07-0.42)	NA	48.2%	83.3%	NA
2021-Q3	3.42 (2.37-4.92)	1.94 (1.08-3.49)	0.68 (0.42-1.11)	NA	43.1%	80.0%	NA
2021-Q4	6.85 (4.85-9.67)	2.08 (1.19-3.63)	1.63 (1.10-2.41)	0.83 (.38-1.79)	69.6%	76.2%	87.9%
2022-Q1	6.27 (4.40-8.93)	2.52 (1.36-4.67)	2.29 (1.52-3.45)	0.69 (0.41-1.15)	59.7%	63.5%	89.1%

Panel B. Sample is Natural Deaths for People Aged 18-59

	Odds Ratios				Implied Vaccine Effectiveness		
Quarter	0 Doses	1 Dose	2 Doses	3 Doses	1 Dose	2 Doses	3 Doses
2021-Q2	1.00	1.40 (0.35-5.62)	NA	NA	-39.6%	100.0%	NA
2021-Q3	5.26 (2.51-11.05)	2.42 (0.81-7.21)	NA	NA	53.9%	100.0%	NA
2021-Q4	11.68 (5.72-23.85)	2.60 (0.91-7.42)	0.30 (0.07-1.37)	0 deaths	77.8%	97.4%	100.0%
2022-Q1	4.34 (2.02-9.33)	1.09 (0.24-5.04)	2.71 (1.01-7.25)	0 deaths	74.9%	37.6%	100.0%

Panel C. Sample is Natural Deaths for People Aged 60+

	Odds Ratios				Implied Vaccine Effectiveness		
Quarter	0 Doses	1 Dose	2 Doses	3 Doses	1 Dose	2 Doses	3 Doses
2021-Q2	1.00	0.27 (0.06-1.13)	0.18 (0.07-0.47)	NA	73.4%	81.7%	NA
2021-Q3	3.00 (1.96-4.59)	1.78 (0.89-3.58)	0.76 (0.45-1.27)	NA	40.5%	74.7%	NA
2021-Q4	5.84 (3.93-8.70)	1.84 (0.94-3.61)	1.84 (1.20-2.82)	0.90 (0.41-1.99)	68.5%	68.6%	84.5%
2022-Q1	6.91 (4.63-10.30)	3.21 (1.62-6.36)	2.20 (1.40-3.48)	0.74 (0.43-1.28)	53.5%	68.1%	89.3%

Table 6. Vaccine Effectiveness and CEMP by Age, Time Period, and Vaccine Type

Sample is Milwaukee residents who received only Moderna or only Pfizer. Sample size was insufficient to study separately persons who received two doses with different vaccine types. Sample size for persons receiving one dose was insufficient to compare Pfizer to Moderna.

Panel A. April 2021- September 2021, when boosters are not available

Age Group	Measure	0 doses	1 dose	2 doses Moderna	2 doses Pfizer
18-59	Covid deaths	49	8	0	0
	Natural deaths	375	79	37	67
	CEMP	15.0%	11.3%	0.0%	0.0%
	VE		25%	100%	100%
60-79	Covid deaths	75	8	6	11
	Natural deaths	749	170	305	303
	CEMP	11.1%	4.9%	2.0%	3.8%
	VE		56%	82%	66%
80+	Covid deaths	33	6	9	7
	Natural deaths	518	122	552	231
	CEMP	6.8%	5.2%	1.7%	3.1%
	VE		24%	76%	54%
Total	**Covid deaths**	**157**	**22**	**15**	**18**
	Natural deaths	**1,642**	**371**	**894**	**601**
	CEMP	**10.6%**	**6.3%**	**1.7%**	**3.1%**
	VE		**40%**	**84%**	**71%**
	VE (pop. weighted)		**32%**	**94%**	**89%**

Panel B. October 2021- March 2022, when boosters become available

Age Group	Measure	0 doses	1 dose	2 doses Moderna	2 doses Pfizer	3 doses Moderna	3 doses Pfizer
18-59	Covid deaths	99	9	6	5	0	0
	Natural deaths	336	88	65	105	24	24
	CEMP	41.8%	11.4%	10.2%	5.0%	0.0%	0.0%
	VE		73%	76%	88%	100%	100%
60-79	Covid deaths	186	14	20	36	5	7
	Natural deaths	696	133	332	309	158	199
	CEMP	36.5%	11.8%	6.4%	13.2%	3.3%	3.6%
	VE		68%	82%	64%	91%	90%
80+	Covid deaths	102	13	24	38	7	8
	Natural deaths	513	113	454	238	304	167
	CEMP	24.8%	13.0%	5.6%	19.0%	2.4%	5.0%
	VE		48%	78%	23%	91%	80%
Total	**Covid deaths**	**387**	**36**	**50**	**79**	**12**	**15**
	Natural deaths	**1,545**	**334**	**851**	**652**	**486**	**390**
	CEMP	**33.4%**	**12.1%**	**6.2%**	**13.8%**	**2.5%**	**4.0%**
	VE		**64%**	**81%**	**59%**	**92%**	**88%**
	VE (pop. weighted)		**70%**	**77%**	**79%**	**97%**	**97%**

Table 7. Comparative VE of Pfizer vs. Moderna from Multivariate Logit Model

Table shows relative odds ratio from logit estimation of COVID mortality for sample of persons in Indiana and Wisconsin who died of natural causes and received 2 (or 3, including booster) doses of Pfizer relative to Moderna over indicated periods. **First row:** 2 Pfizer vs. 2 Moderna doses for full vaccine-available period (April 2021 – March 2022). **Second row:** 2 Pfizer vs. 2 Moderna for April-September 2021 (booster not yet available). T**hird row:** 2 Pfizer vs. 2 Moderna for October 2021-March 2022 (booster available). **Last row:** 3 Pfizer vs. 3 Moderna for October 2021-March 2022 (booster available). Odds ratios are from logit model of Prob(Covid-19 Death) = f(received Pfizer (Moderna is baseline), with controls for age, age^2, zip-SES, gender, race/ethnicity, education level, marital status, and military veteran status. Coefficients on covariates are suppressed. Sample excludes immune-compromised persons and small number of persons who received mixed Moderna and Pfizer doses. Statistically significant odds ratios (at 5% level or better) in **boldface**.

Doses	Period	Odds Ratio	z-stat	95% CI
2	Full (Apr 2021 – Mar 2022)	**2.19**	**4.43**	1.55 - 3.11
2	No Booster (Apr– Sep 2021)	1.86	1.64	0.88 - 3.90
2	Booster Avail (Oct 2021 – Mar 2022)	**2.40**	**4.26**	1.60 - 3.58
3 (incl booster)	Booster Avail (Oct 2021 – Mar 2022)	1.25	0.50	0.54 - 2.96

Figure 1: CEMP: Pre- versus Post-Vaccination (Wisconsin + Indiana)

Figure shows COVID Excess Mortality Percentage (CEMP) for all decedents in Indiana and Wisconsin, separately for men and women, and separately for the pre-vaccination period (April 2020 - December 2020) (dashed lines), and the vaccine-available period (April 2021 - March 2022) (solid lines). We drop the initial vaccine rollout period of January-March 2021.

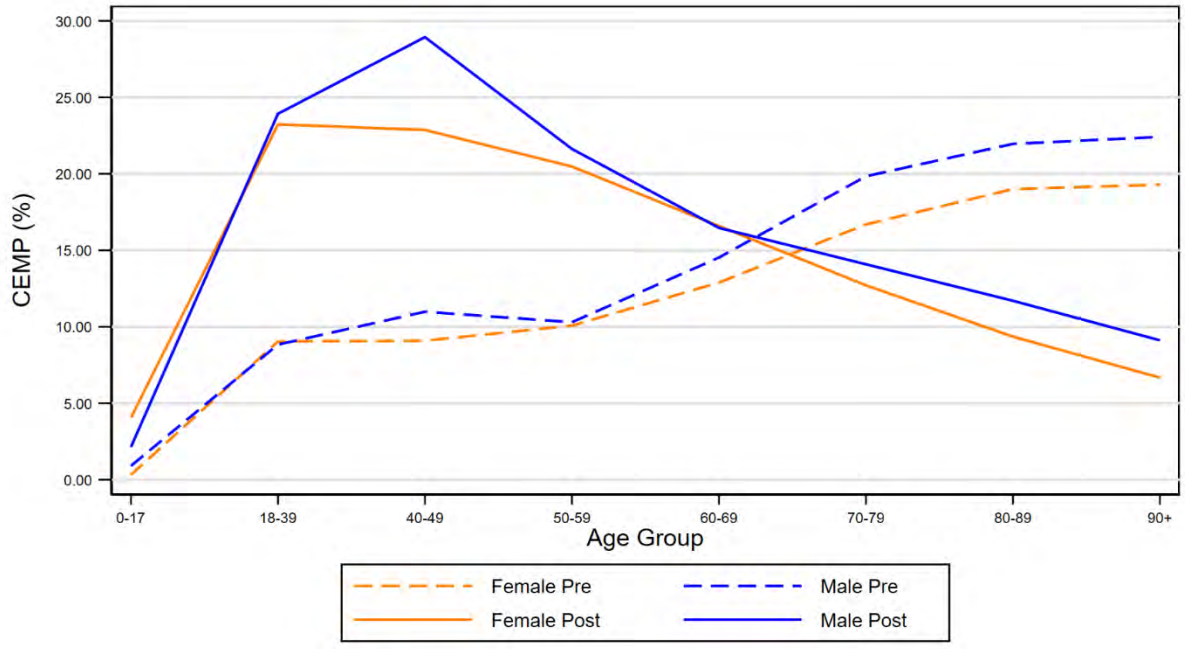
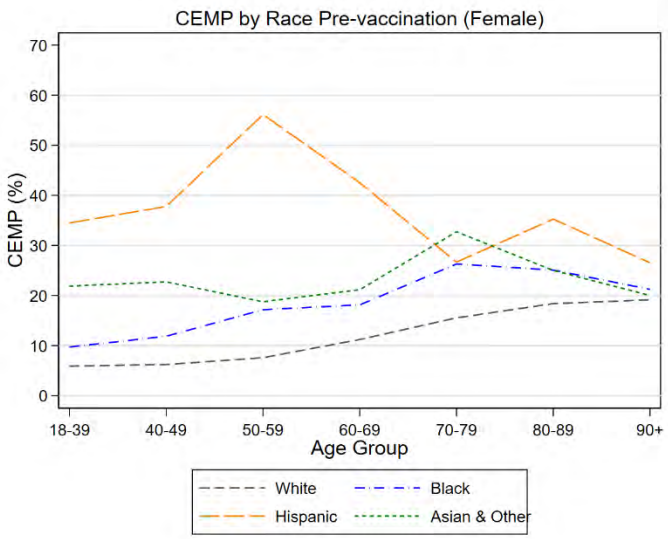
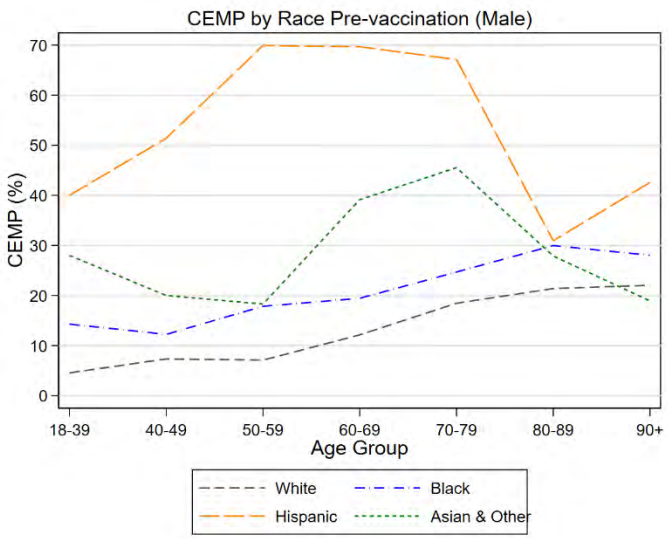


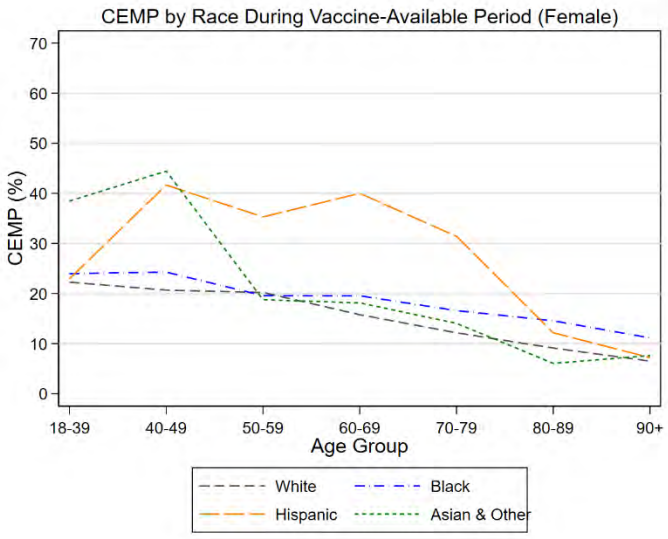
Figure 2. CEMP Levels by Gender and Race/Ethnicity

Panel A. Pre-Vaccine Period





Panel B. Vaccine-Available Period



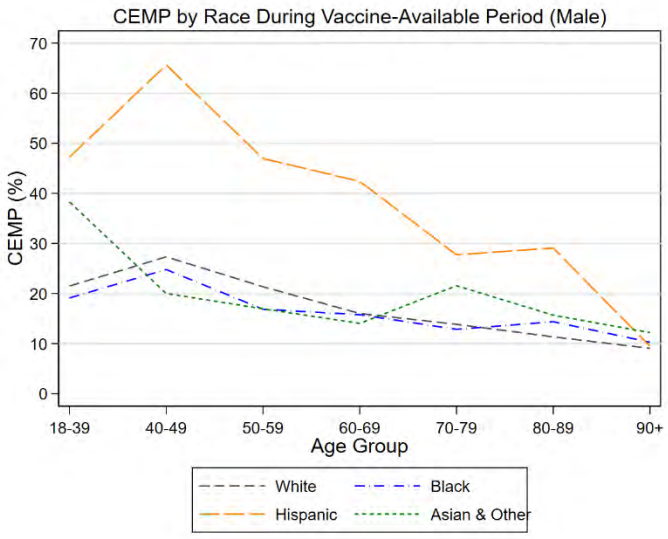
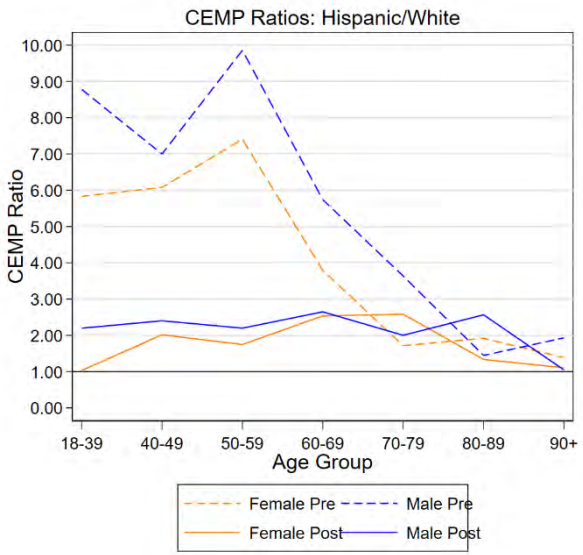


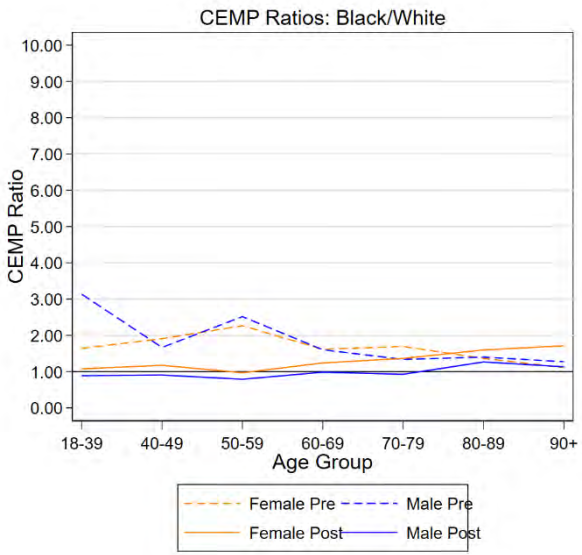
Figure 3. CEMP Ratios by Race/Ethnicity and Age Group

Figure shows CEMP ratios for Hispanic, Black, and Other to White, by age range for adults (age 18+), separately for pre-vaccine period (April-December 2020) and vaccine-available period (April 2021-March 2022), separately for men and women. **Panel A**. Hispanic/White. **Panel B.** Black/White. **Panel C.** (Asian and Other)/White.

Panel A. Hispanic/White CEMP Ratios



Panel B. Black/White CEMP Ratios



Panel C. (Asian and other)/White Ratios

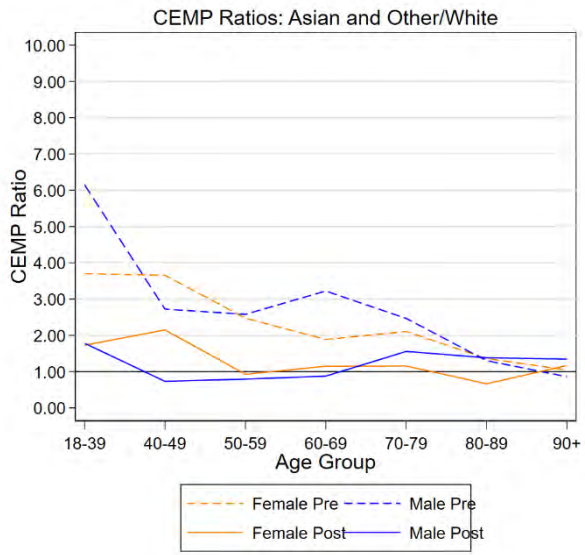
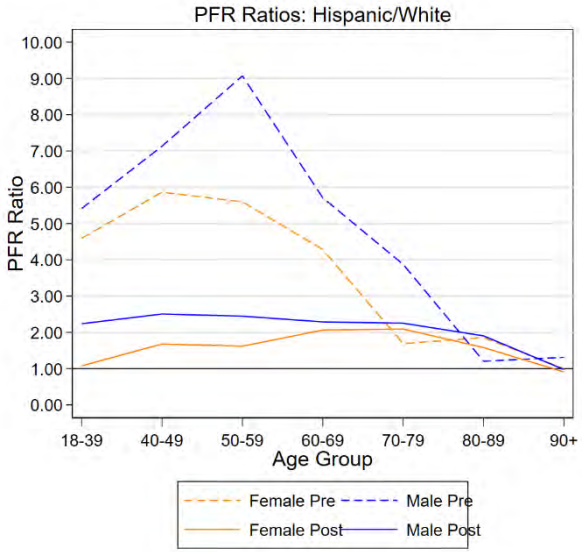


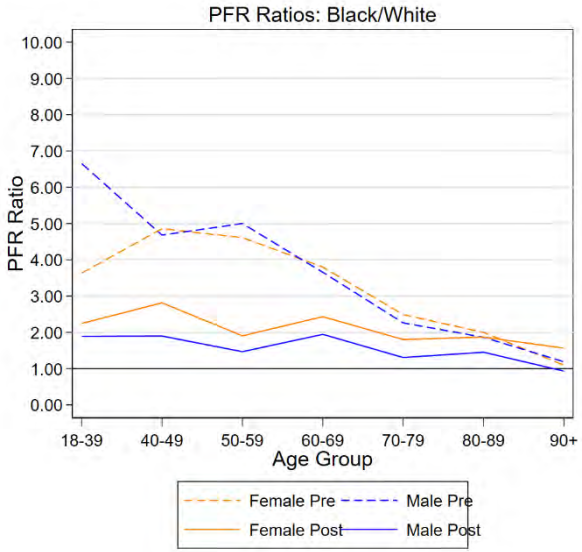
Figure 4. PFR Ratios by Race/Ethnicity and Age Group

Figure shows PFR ratios for Hispanic, Black, and Other to White, by age range for adults (age 18+), separately for pre-vaccine period (April-December 2020) and vaccine-available period (April 2021-March 2022), separately for men and women. **Panel A**. Hispanic/White. **Panel B.** Black/White. **Panel C.** (Asian and Other)/White.

Panel A. Hispanic/White PFR Ratios



Panel B. Black/White PFR Ratios



Panel C. (Asian and other)/White PFR Ratios