

BST260 Final Project: Understanding COVID-19 Morality Rates of Nursing Homes in the US

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Introduction

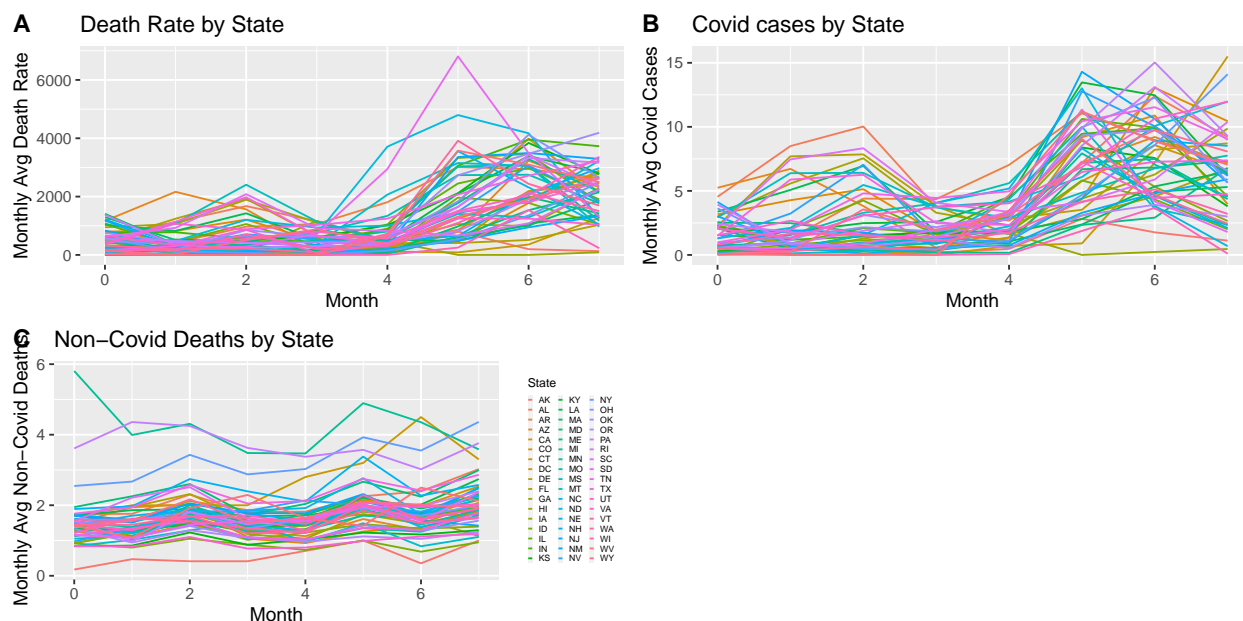
Over the past three years, the COVID-19 pandemic has affected the lives of millions worldwide. Although the global burden exists everywhere, the negative impact it has had on the senior population, especially those individuals residing in nursing homes, has been detrimental¹. It is critical to understand how and why so many senior residents in these homes lost their lives to the pandemic in order to implement prevention measures for this ongoing COVID-19 pandemic and for future outbreaks. This project investigated the effect of the quality of nursing homes on the number of COVID-19-related deaths in the US while controlling for geographic and socioeconomic factors. The quality of the residence was derived from the Centers for Medicare & Medicaid Services (CMS) 5-star quality rating system, a standardized measure created by the US federal agency².

The Nursing Home COVID-19 database in the US has been released on May 26, 2020. Since then, the database has been updated weekly by the CMS³. The data retained in this data set is from June 1, 2020 to January 31, 2021 (an 8-month period) with information on nursing homes from all states except Guam and Puerto Rico. Over the months of data collection, the data set has 99,314 observations of 24 variables related to the nursing home, the local COVID-19 situation, and geographic determinants.

The main outcome of the data set, mortality rate in nursing homes, as well as variables that are directly related to the main outcome (COVID-19 cases and non-COVID-related death cases in nursing home residents), were visualized to further understand the data set. The changes in COVID-19 cases per month seem to be following a trend proportional to the overall death rate in nursing homes. Additionally, different states reported varying levels of cases and deaths, but most states seem to be following the same trends over time (Fig. 1a, 1b). Therefore, it was not necessary to study a month-by-month difference in the death rates since most states appeared to follow the same trends. Rather, examining the overall difference during the entire 8-month study period to compare the state-by-state differences in nursing homes seems like a more appropriate approach for this data set. Additionally, the number of non-COVID-related deaths in nursing homes tend to stay relatively constant over the study period (Fig. 1c). Therefore, using the overall death rate in nursing homes was deemed as an accurate method for studying COVID-related mortality rates in nursing homes without further data reshaping for specifically the main outcome.

Since the original data set has information on each nursing home with each month being an entry, the data needs to be extensively reshaped to fit the research questions of this project. The month-by-month comparison needs to be averaged together as well as all the nursing home data by state. Moreover, certain predictors that do not align with the research question or cannot be properly analyzed using averaged data were omitted. After data wrangling, a Poisson regression model is employed to estimate the COVID-19 mortality rates in nursing homes from our data. To account for overdispersion, an extension of the Poisson model, the Negative Binomial regression, was used to prevent overconfident estimates. No further modifications were made to the data set to perform a Negative Binomial regression because the data was already in counts and rate form.

Figure 1:



Results (Route 1)

Data wrangling

The original data set was organized such that each row entry was for a nursing home in the US at each month of the study period. Therefore, there were 99,314 row entries of 12415 different senior homes across the US (Table 1). This data was not tidy. Additionally, it was not useful for studying state-by-state differences over the entire study period. Therefore, all location-related variables except the state variable was removed. All the data was grouped for all the data by each month and by state. Thus, there were 8 row entries for each state with each row representing a different month in the study period. Upon analysis of the variations between the study period (refer to Introduction), we decided to study patterns in mortality rates over the entire study period rather than at different time points. Hence, the data was further reshaped to display the overall averaged values for each state over the entire study period. All data from the Core Based Statistical Area (CBSA) were removed as they were not relevant for a state-by-state averaged study since CBSA data would be more useful for the individual, within-state research questions. Therefore, the final data set for our analysis contained 51 row entries (one for each state), 1 variable for the main outcome (mortality rate), and 10 potential predictors of the main outcome (Table 2).

Table 1: Original Data Set

```
## # A tibble: 6 x 24
##   providename   provi~1 provi~2 provi~3 provi~4 provz~5 RES_M~6 S_STA~7 S_PPE~8
##   <chr>         <chr>   <chr>   <chr>   <dbl> <chr>      <dbl>   <dbl>   <dbl>
## 1 EVENTIDE AT S~ 125 13~ WEST F~ ND       58078 58078      18      0      0
## 2 SUNNYVALE POS~ 1291 S~ SUNNYV~ CA       94087 94087      0      0      0
## 3 CENTINELA SKI~ 950 FL~ INGLEW~ CA       90301 90301      1      0      0
## 4 BAKER-KATZ SK~ 194 BO~ HAVERH~ MA        1830 01830      4      0      0
## 5 MONARCH MEADO~ 299 CO~ SEAMAN OH       45679 45679      0      0      0
## 6 CONSOLATA HOME 2319 E~ NEW IB~ LA       70560 70560      0      4      0
## # ... with 15 more variables: RES_Monthlyalldeaths_excptCOV <dbl>,
## #   overall_rating <dbl>, paymcaid_num <dbl>, pctwhite_2011pN <dbl>,
## #   vulnerabilityindex_county <dbl>, CBSACode <chr>, casesper100k_CBSA <dbl>,
## #   deathsper100k_CBSA <dbl>, NH_deathsper100k <dbl>, ownership_recode <dbl>,
## #   facility_size <dbl>, urban_rural <dbl>, month_final <dbl>,
## #   lnCBSAdeathRate <dbl>, lnCBSAcaseRate <dbl>, and abbreviated variable names
```

```
## # 1: provideraddress, 2: providercity, 3: providerstate, ...
```

Table 2: Wrangled Data Set only including the first 6 variables

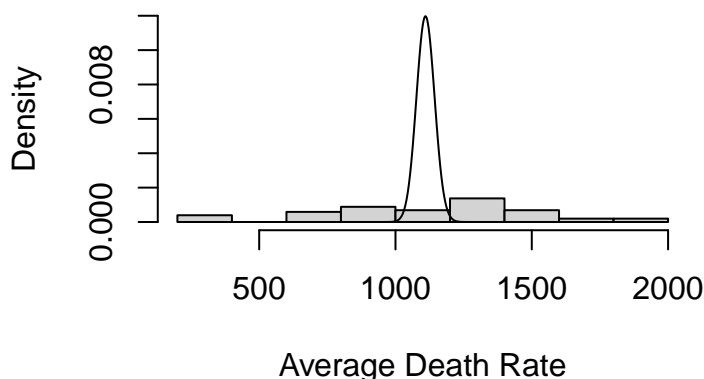
```
## # A tibble: 6 x 12
##   state NH_dea~1 RES_M~2 RES_M~3 S_STA~4 S_PPE~5 overa~6 paymc~7 pctwh~8 vulne~9
##   <chr>   <dbl>   <dbl>   <dbl>   <dbl>   <dbl>   <dbl>   <dbl>   <dbl>   <dbl>
## 1 AK      211.    0.868    0.566    1.54    0.662    3.69    NaN     NaN     0.499
## 2 AL     1336.    7.29     2.14     1.73    0.989    3.30    66.9    75.8    0.559
## 3 AR     1670.    5.81     1.50     0.797    0.303    2.99    66.0    83.6    0.602
## 4 AZ     1457.    5.22     1.58     0.802    0.704    3.59    52.8    74.3    0.504
## 5 CA     1096.    5.41     1.28     0.0957   0.517    3.35    59.4    59.5    0.557
## 6 CO     1142.    3.49     1.62     0.926    0.865    3.66    63.0    80.7    0.410
## # ... with 2 more variables: facility_size_mean <dbl>, urban_rural_mean <dbl>,
## # and abbreviated variable names 1: NH_deathsper100k_mean,
## # 2: RES_MonthlyconfC19cases_mean, 3: RES_Monthlyalldeaths_excptCOV_mean,
## # 4: S_STAFF_ANY_mean, 5: S_PPE_ANY_mean, 6: overall_rating_mean,
## # 7: paymcaid_num_mean, 8: pctwhite_2011pN_mean,
## # 9: vulnerabilityindex_county_mean
```

Analysis: Poisson Regression

Overdispersion:

As a model specialized for count data, we employed a Poisson regression. Although the Poisson density roughly fits each of our potential target variables, they are overdispersed because the variance is greater than the mean (nursing home death rate: mean of 1110.511 deaths/100,000 residents and variance of 160259.1 deaths²/100,000 residents² over the 8-month study period (Fig. 2). The presence of overdispersion suggest the use of a Poisson model extension, rather than the standard Poisson model itself. With a lack of zero-inflated data, we employ a Negative Binomial regression, which should account for overdispersion, to make sure we do not have overconfident estimates. For these data, we do not need to account for lag as they are all averaged over the same time period for each predictor and outcome variable, respectively.

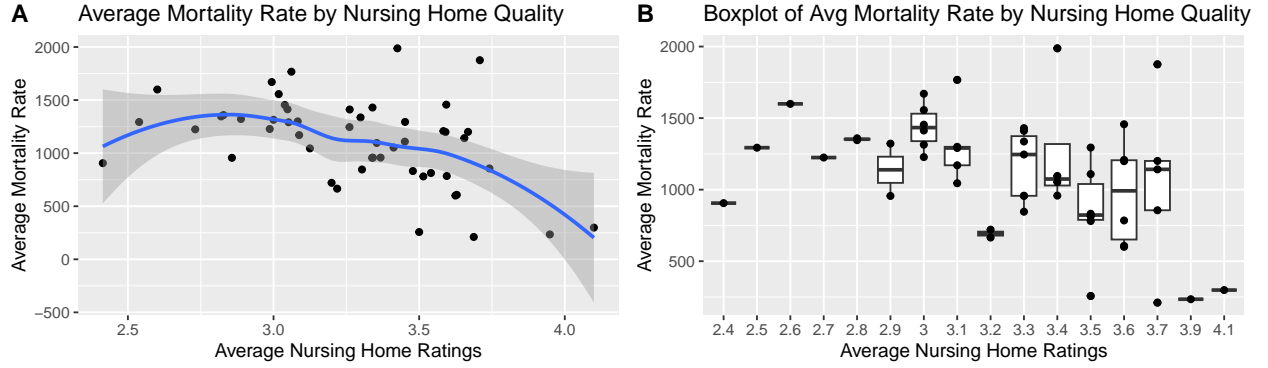
Figure 2: Average Covid-19 Death Rate Density Distribution



Correlation:

The main outcome is death rate (NH_deathsper100k_mean) and the main predictor is nursing home quality (overall_rating_mean). We want to understand how correlated the two variables are in order to get a better grasp of how nursing home quality is related to COVID-19 death rates.

Based on the plots below, there is a lot of variation between the main predictor and outcome from the large scatter (Fig. 3). However, there is a downward trend where the higher the nursing home rate, the lower the mortality rate among the residents. This is confirmed by the correlation coefficient ($R = -0.4471934$), which suggests that the variables are roughly negatively correlated. This implies that there is some relationship that should be further studied along with other potential predictors of mortality rate in these nursing homes.

Figure 3:

Model Fit:

The negative binomial model with just the main predictor (nursing home quality) with a mortality rate as the outcome had a relatively high AIC value of 763.81 despite the predictor being significant (p -value < 0.05). We then adjusted for the number of COVID-19 cases in the nursing home since there was some variability observed from the exploratory data analysis (refer to Introduction). Additionally, the COVID-19 cases in nursing home residents could be a potential confounder since it is could be associated with both the outcome (death rate) and main predictor (nursing home quality), but is not a downstream consequence of the main predictor. This decreased the AIC value to 756.01, thus suggesting an improved model fit for our data, however, the main predictor was no longer significant. Therefore, we checked for effect modification of COVID-19 cases on the main predictor effect on the main outcome. We observed effect modification with an improved model fit upon including the interaction term. Similarly, we controlled for nursing home size, staff shortages, and PPE shortages for the same reason of potential confounding while checking for effect modification. As a result, we had an improved model with an AIC value of 729.36.

Moreover, we controlled for socioeconomic factors like the percentage of white residents in the facility and the percentage of Medicaid residents in the facility since they can be determinants of the death rate. However, we did not control for whether the average nursing home was more urban or rural since the variable in the source data set was binary (0 for rural and 1 for urban). Our data were averaged over a large sample size for this binary operator and thus were not deemed to be effective at suggesting whether the homes were more rural or urban on average. Similarly, we did not adjust for the CDC social vulnerability index for the same reason of being a binary predictor averaged over a large sample size. (Note: detailed step-by-step analysis of the model fit can be found in the Appendix.)

Therefore, we derive our final model (Table 3).

$$\log(E[Y_i = mortalityrate|X_j]) = \beta_0 + \beta_1 X_1 + \dots + \beta_p X_p$$

Table 3: Fitted Negative Binomial regression model summary

| ## | Estimate | Std. Error |
|---|-------------|--------------|
| ## (Intercept) | 12.61231037 | 1.267100657 |
| ## overall_rating_mean | -1.51345882 | 0.370940292 |
| ## RES_MonthlyconfC19cases_mean | -0.79249801 | 0.299277799 |
| ## facility_size_mean | -0.48621313 | 0.124774616 |
| ## S_STAFF_ANY_mean | 0.17865175 | 0.077730591 |
| ## paymcaid_num_mean | -0.01319791 | 0.005816746 |
| ## overall_rating_mean:RES_MonthlyconfC19cases_mean | 0.29497492 | 0.088035770 |
| ## | z value | Pr(> z) |
| ## (Intercept) | 9.953677 | 2.430344e-23 |
| ## overall_rating_mean | -4.080060 | 4.502399e-05 |
| ## RES_MonthlyconfC19cases_mean | -2.648035 | 8.096121e-03 |

```
## facility_size_mean -3.896731 9.749976e-05
## S_STAFF_ANY_mean 2.298345 2.154213e-02
## paymcaid_num_mean -2.268950 2.327136e-02
## overall_rating_mean:RES_MonthlyconfC19cases_mean 3.350626 8.062920e-04
```

Note that “estimate” is equivalent to a β value.

An AIC value of 685.11, the lowest value of all the other models we have explored, leads us to believe that it is the best-fit model of the models we have considered. Additionally, we find that the negative binomial regression has slightly higher standard errors and resulting test statistics compared to the standard Poisson regression. This is as we expected since it suggests that the standard Poisson regression may cause overconfidence in model evaluations, due to the property of $E[Y] = \text{Var}(Y)$ being unsatisfied.

Furthermore, we can interpret the Negative Binomial regression supposing nursing home quality is our covariate of interest. For a 1-star increase in nursing home quality rating, a state has an estimated $e^{-1.51345882} = 0.2201472$ times the incident rate of mortality rate in nursing home residents compared to if a state did not have a 1-star increase in nursing home quality rating, on average, holding all other covariates (monthly average COVID-19 cases among residents, average facility size, average staff storage, and average Medicaid resident percentage) fixed. This was a significant relationship as well, suggesting that nursing home quality may be negatively associated with the incidence rate of COVID-19 deaths according to these data.

Conclusion

Overall, our findings using the negative binomial regression model (an extension of the Poisson regression model) agree with previous literature and further elucidate the role of nursing home quality on COVID-19 mortality rates in nursing homes across the US. Additionally, other factors such as the severity of the COVID-19 pandemic in the state and socioeconomic status can influence the mortality rate in senior homes.

Throughout our model variations, we consistently observe a potential decrease in COVID-19 mortality rates on average following an increase in nursing home quality, according to these data. This, combined with the observation that an increase in staff shortages is associated with a potential increase in mortality rate suggests that the lack of access to care personnel such as nurses and clinicians could be potentially driving worse health outcomes. Interestingly, despite the racial composition of the nursing homes not significantly altering mortality rates, a potential decrease in mortality rate was observed as the percentage of Medicaid residents increased. This further confirms the impact of socioeconomic influences on the senior population in the US.

If given more time, I would have liked to explore differences in healthcare access and training of the staff in nursing homes. These factors could be important predictors for understanding mortality rates. Additionally, updating the data set to contain up-to-date data on the mortality rates would have been another future direction of interest given that the COVID-19 pandemic is still an ongoing outbreak. Understanding how vaccines and the differences in vaccine rollout in the different states affected the senior population, specifically those living in nursing homes, could have been interesting to investigate.

References

1. Cronin CJ, Evans WN. Nursing home quality, COVID-19 deaths, and excess mortality. *J Health Econ.* 2022;82:102592. doi:10.1016/j.jhealeco.2022.102592
2. Five-star quality rating system. CMS. <https://www.cms.gov/medicare/provider-enrollment-and-certification/certificationandcompliance/fsqrs>. Published December 6, 2022. Accessed December 16, 2022.
3. Gupta DD, Kelekar U, Turner SC, Sule AA, Jerman TG. Cov-19 deaths (monthly) among nursing home residents in the US: June-1, 2020 - January-31, 2021. openICPSR. <https://www.openicpsr.org/openicpsr/project/147921/version/V1/view?path=%2Fopenicpsr>. Published August 20, 2021. Accessed December 16, 2022.

Appendix

```
library(haven)
library(dplyr)
library(tidyr)
library(dslabs)
library(ggplot2)
library(ggpubr)
# the data set:
data <- read_dta('/Users/andy/Downloads/260projectfinal.dta')

##### START OF DATA WRANGLING #####

# remove all location variables except state
data2 <- data[ -c(1:3, 5:6) ]

# subset data into different months when data collected
month_0 = data2 |> filter(month_final == 0) |> rename("month_0" = "month_final")
month_1 = data2 |> filter(month_final == 1) |> rename("month_1" = "month_final")
month_2 = data2 |> filter(month_final == 2) |> rename("month_2" = "month_final")
month_3 = data2 |> filter(month_final == 3) |> rename("month_3" = "month_final")
month_4 = data2 |> filter(month_final == 4) |> rename("month_4" = "month_final")
month_5 = data2 |> filter(month_final == 5) |> rename("month_5" = "month_final")
month_6 = data2 |> filter(month_final == 6) |> rename("month_6" = "month_final")
month_7 = data2 |> filter(month_final == 7) |> rename("month_7" = "month_final")

# merge data for same states-- every variable represents the average value for the respective state
avg_state <- function(month_i) {
  month_i <- month_i[-c(17)]
  month_i |> group_by(providerstate) |>
    summarize(RES_MonthlyconfC19cases = mean(RES_MonthlyconfC19cases, na.rm = TRUE),
              S_STAFF_ANY = mean(S_STAFF_ANY, na.rm = TRUE),
              S_PPE_ANY = mean(S_PPE_ANY, na.rm = TRUE),
              RES_Monthlyalldeaths_excptCOV = mean(RES_Monthlyalldeaths_excptCOV, na.rm = TRUE),
              overall_rating = mean(overall_rating, na.rm = TRUE),
              paymcaid_num = mean(paymcaid_num, na.rm = TRUE),
              pctwhite_2011pN = mean(pctwhite_2011pN, na.rm = TRUE),
              vulnerabilityindex_county = mean(vulnerabilityindex_county, na.rm = TRUE),
              CBSACode = mean(as.numeric(CBSACode), na.rm = TRUE),
              casesper100k_CBSA = mean(casesper100k_CBSA, na.rm = TRUE),
              deathesper100k_CBSA = mean(deathesper100k_CBSA, na.rm = TRUE),
              NH_deathesper100k = mean(NH_deathesper100k, na.rm = TRUE),
              ownership_recode = mean(ownership_recode, na.rm = TRUE),
              facility_size = mean(facility_size, na.rm = TRUE),
              urban_rural = mean(urban_rural, na.rm = TRUE),
              lnCBSAdeathRate = mean(lnCBSAdeathRate, na.rm = TRUE),
              lnCBSAcaseRate = mean(lnCBSAcaseRate, na.rm = TRUE))
}

# apply function and wrangle these 3 variables (NH_deathesper100k, RES_MonthlyconfC19cases, RES_Monthlyalldeaths_excptCOV)
month_0 <- month_0 |> avg_state() |> mutate(month_0 = 0) |>
  rename("RES_MonthlyconfC19cases_m0" = "RES_MonthlyconfC19cases",
```

```

      "RES_Monthlyalldeaths_excptCOV_m0" = "RES_Monthlyalldeaths_excptCOV",
      "NH_deathsper100k_m0" = "NH_deathsper100k")
month_1 <- month_1 |> avg_state() |> mutate(month_0 = 1) |>
  rename("RES_MonthlyconfC19cases_m1" = "RES_MonthlyconfC19cases",
        "RES_Monthlyalldeaths_excptCOV_m1" = "RES_Monthlyalldeaths_excptCOV",
        "NH_deathsper100k_m1" = "NH_deathsper100k")
month_2 <- month_2 |> avg_state() |> mutate(month_0 = 2) |>
  rename("RES_MonthlyconfC19cases_m2" = "RES_MonthlyconfC19cases",
        "RES_Monthlyalldeaths_excptCOV_m2" = "RES_Monthlyalldeaths_excptCOV",
        "NH_deathsper100k_m2" = "NH_deathsper100k")
month_3 <- month_3 |> avg_state() |> mutate(month_0 = 3) |>
  rename("RES_MonthlyconfC19cases_m3" = "RES_MonthlyconfC19cases",
        "RES_Monthlyalldeaths_excptCOV_m3" = "RES_Monthlyalldeaths_excptCOV",
        "NH_deathsper100k_m3" = "NH_deathsper100k")
month_4 <- month_4 |> avg_state() |> mutate(month_0 = 4) |>
  rename("RES_MonthlyconfC19cases_m4" = "RES_MonthlyconfC19cases",
        "RES_Monthlyalldeaths_excptCOV_m4" = "RES_Monthlyalldeaths_excptCOV",
        "NH_deathsper100k_m4" = "NH_deathsper100k")
month_5 <- month_5 |> avg_state() |> mutate(month_0 = 5) |>
  rename("RES_MonthlyconfC19cases_m5" = "RES_MonthlyconfC19cases",
        "RES_Monthlyalldeaths_excptCOV_m5" = "RES_Monthlyalldeaths_excptCOV",
        "NH_deathsper100k_m5" = "NH_deathsper100k")
month_6 <- month_6 |> avg_state() |> mutate(month_0 = 6) |>
  rename("RES_MonthlyconfC19cases_m6" = "RES_MonthlyconfC19cases",
        "RES_Monthlyalldeaths_excptCOV_m6" = "RES_Monthlyalldeaths_excptCOV",
        "NH_deathsper100k_m6" = "NH_deathsper100k")
month_7 <- month_7 |> avg_state() |> mutate(month_0 = 7) |>
  rename("RES_MonthlyconfC19cases_m7" = "RES_MonthlyconfC19cases",
        "RES_Monthlyalldeaths_excptCOV_m7" = "RES_Monthlyalldeaths_excptCOV",
        "NH_deathsper100k_m7" = "NH_deathsper100k")

# -----START OF EDA-----
# for some EDA, lets see if there's any intra- or inter-state trends in the covid deaths or cases
##monthly death rate for senior home residents
month0 <- month_0 |> rename("0" = "NH_deathsper100k_m0") |>
  select(providerstate, "0")
month1 <- month_1 |> rename("1" = "NH_deathsper100k_m1") |>
  select(providerstate, "1")
month2 <- month_2 |> rename("2" = "NH_deathsper100k_m2") |>
  select(providerstate, "2")
month3 <- month_3 |> rename("3" = "NH_deathsper100k_m3") |>
  select(providerstate, "3")
month4 <- month_4 |> rename("4" = "NH_deathsper100k_m4") |>
  select(providerstate, "4")
month5 <- month_5 |> rename("5" = "NH_deathsper100k_m5") |>
  select(providerstate, "5")
month6 <- month_6 |> rename("6" = "NH_deathsper100k_m6") |>
  select(providerstate, "6")
month7 <- month_7 |> rename("7" = "NH_deathsper100k_m7") |>
  select(providerstate, "7")

total <- left_join(month0, month1, by="providerstate")

```

```

total <- left_join(total, month2, by="providerstate")
total <- left_join(total, month3, by="providerstate")
total <- left_join(total, month4, by="providerstate")
total <- left_join(total, month5, by="providerstate")
total <- left_join(total, month6, by="providerstate")
total <- left_join(total, month7, by="providerstate")

new_total <- total |>
  pivot_longer("0":"7", names_to = "month", values_to = "res_death")
# graph cases of residents:
fig1a <- new_total |> ggplot(aes(x = month, y= res_death)) +
  geom_line(aes(x = as.numeric(month), y= res_death, color = factor(providerstate))) +
  labs(x = "Month", y = "Monthly Avg Death Rate",
        title = "Death Rate by State") +
  theme(legend.position = "none")
##monthly covid cases for senior home residents
month0 <- month_0 |> rename("0" = "RES_MonthlyconfC19cases_m0") |>
  select(providerstate, "0")
month1 <- month_1 |> rename("1" = "RES_MonthlyconfC19cases_m1") |>
  select(providerstate, "1")
month2 <- month_2 |> rename("2" = "RES_MonthlyconfC19cases_m2") |>
  select(providerstate, "2")
month3 <- month_3 |> rename("3" = "RES_MonthlyconfC19cases_m3") |>
  select(providerstate, "3")
month4 <- month_4 |> rename("4" = "RES_MonthlyconfC19cases_m4") |>
  select(providerstate, "4")
month5 <- month_5 |> rename("5" = "RES_MonthlyconfC19cases_m5") |>
  select(providerstate, "5")
month6 <- month_6 |> rename("6" = "RES_MonthlyconfC19cases_m6") |>
  select(providerstate, "6")
month7 <- month_7 |> rename("7" = "RES_MonthlyconfC19cases_m7") |>
  select(providerstate, "7")

total <- left_join(month0, month1, by="providerstate")
total <- left_join(total, month2, by="providerstate")
total <- left_join(total, month3, by="providerstate")
total <- left_join(total, month4, by="providerstate")
total <- left_join(total, month5, by="providerstate")
total <- left_join(total, month6, by="providerstate")
total <- left_join(total, month7, by="providerstate")

new_total <- total |>
  pivot_longer("0":"7", names_to = "month", values_to = "res_cases")

# graph cases of residents:
fig1b <- new_total |> ggplot(aes(x = month, y= res_cases)) +
  geom_line(aes(x = as.numeric(month), y= res_cases, color = factor(providerstate))) +
  labs(x = "Month", y = "Monthly Avg Covid Cases",
        title = "Covid cases by State") +
  theme(legend.position = "none")

##monthly non-covid-related death cases for senior home residents
month0 <- month_0 |> rename("0" = "RES_Monthlyalldeaths_excptCOV_m0") |>

```



```

  select(providerstate, "0")
month1 <- month_1 |> rename("1" = "RES_Monthlyalldeaths_excptCOV_m1") |>
  select(providerstate, "1")
month2 <- month_2 |> rename("2" = "RES_Monthlyalldeaths_excptCOV_m2") |>
  select(providerstate, "2")
month3 <- month_3 |> rename("3" = "RES_Monthlyalldeaths_excptCOV_m3") |>
  select(providerstate, "3")
month4 <- month_4 |> rename("4" = "RES_Monthlyalldeaths_excptCOV_m4") |>
  select(providerstate, "4")
month5 <- month_5 |> rename("5" = "RES_Monthlyalldeaths_excptCOV_m5") |>
  select(providerstate, "5")
month6 <- month_6 |> rename("6" = "RES_Monthlyalldeaths_excptCOV_m6") |>
  select(providerstate, "6")
month7 <- month_7 |> rename("7" = "RES_Monthlyalldeaths_excptCOV_m7") |>
  select(providerstate, "7")

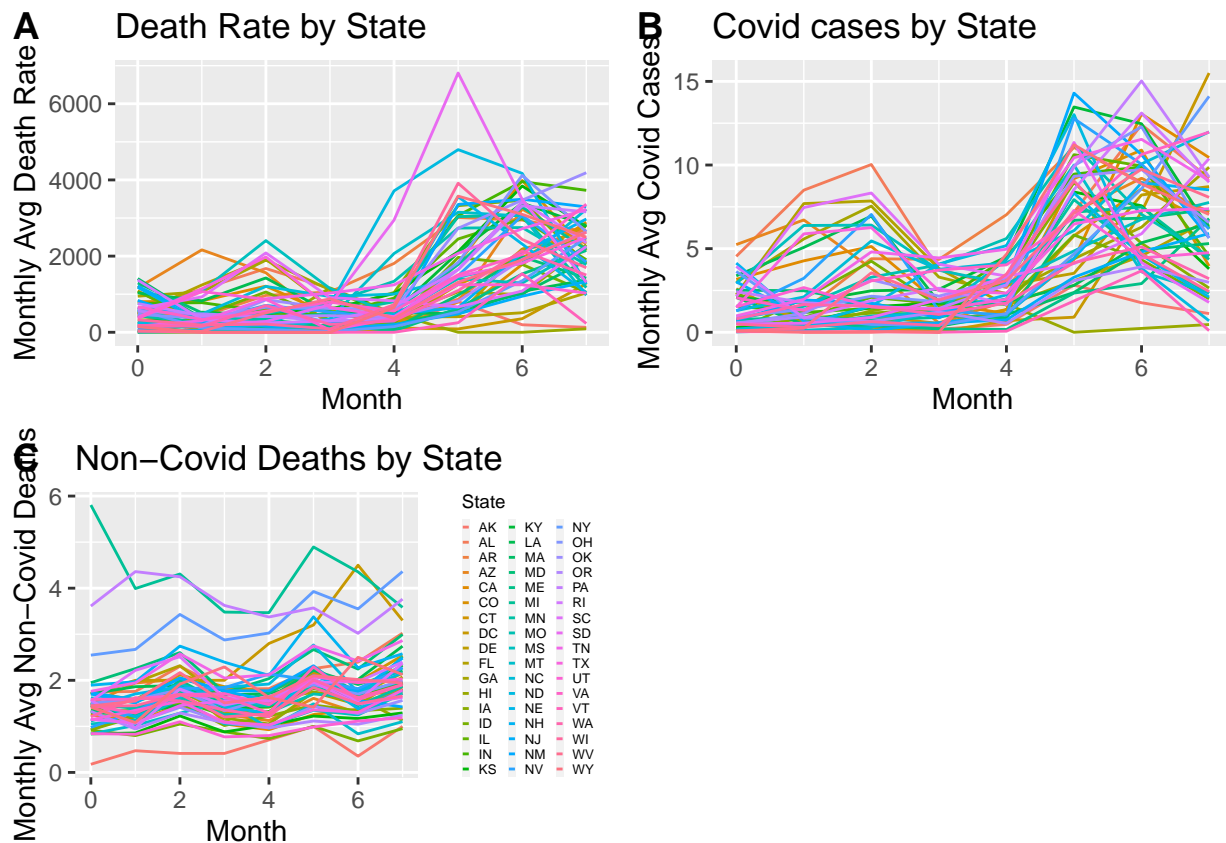
total <- left_join(month0, month1, by="providerstate")
total <- left_join(total, month2, by="providerstate")
total <- left_join(total, month3, by="providerstate")
total <- left_join(total, month4, by="providerstate")
total <- left_join(total, month5, by="providerstate")
total <- left_join(total, month6, by="providerstate")
total <- left_join(total, month7, by="providerstate")

new_total <- total |>
  pivot_longer("0":"7", names_to = "month", values_to = "res_nonCovidDeath")

# graph cases of residents:
fig1c <- new_total |> ggplot(aes(x = month, y= res_nonCovidDeath)) +
  geom_line(aes(x = as.numeric(month), y= res_nonCovidDeath, color = factor(providerstate))) +
  labs(x = "Month", y = "Monthly Avg Non-Covid Deaths",
       title = "Non-Covid Deaths by State", color = "State") +
  theme(legend.key.size = unit(.1, 'cm'), #change legend key size
        legend.key.height = unit(.2, 'cm'), #change legend key height
        legend.key.width = unit(.1, 'cm'), #change legend key width
        legend.title = element_text(size=7), #change legend title font size
        legend.text = element_text(size=5))

ggarrange(fig1a, fig1b, fig1c,
          labels = c("A", "B", "C"),
          ncol = 2, nrow = 2)

```



```
# -----END OF EDA-----
##### DATA WRANGLING CONTINUED #####

# now finish wrangling the data
# find mean of all variables -- since we are doing overall study period approach
NH_deathsper100k <- data.frame(month_0$NH_deathsper100k_m0, month_1$NH_deathsper100k_m1, month_2$NH_deathsper100k_m2, month_3$NH_deathsper100k_m3, month_4$NH_deathsper100k_m4, month_5$NH_deathsper100k_m5, month_6$NH_deathsper100k_m6, month_7$NH_deathsper100k_m7)
NH_deathsper100k_mean <- rowMeans(NH_deathsper100k)

RES_MonthlyconfC19cases <- data.frame(month_0$RES_MonthlyconfC19cases_m0, month_1$RES_MonthlyconfC19cases_m1, month_2$RES_MonthlyconfC19cases_m2, month_3$RES_MonthlyconfC19cases_m3, month_4$RES_MonthlyconfC19cases_m4, month_5$RES_MonthlyconfC19cases_m5, month_6$RES_MonthlyconfC19cases_m6, month_7$RES_MonthlyconfC19cases_m7)
RES_MonthlyconfC19cases_mean <- rowMeans(RES_MonthlyconfC19cases)

RES_Monthlyalldeaths_excptCOV <- data.frame(month_0$RES_Monthlyalldeaths_excptCOV_m0, month_1$RES_Monthlyalldeaths_excptCOV_m1, month_2$RES_Monthlyalldeaths_excptCOV_m2, month_3$RES_Monthlyalldeaths_excptCOV_m3, month_4$RES_Monthlyalldeaths_excptCOV_m4, month_5$RES_Monthlyalldeaths_excptCOV_m5, month_6$RES_Monthlyalldeaths_excptCOV_m6, month_7$RES_Monthlyalldeaths_excptCOV_m7)
RES_Monthlyalldeaths_excptCOV_mean <- rowMeans(RES_Monthlyalldeaths_excptCOV)

S_STAFF_ANY <- data.frame(month_0$S_STAFF_ANY, month_1$S_STAFF_ANY, month_2$S_STAFF_ANY, month_3$S_STAFF_ANY, month_4$S_STAFF_ANY, month_5$S_STAFF_ANY, month_6$S_STAFF_ANY, month_7$S_STAFF_ANY)
S_STAFF_ANY_mean <- rowMeans(S_STAFF_ANY)

S_PPE_ANY <- data.frame(month_0$S_PPE_ANY, month_1$S_PPE_ANY, month_2$S_PPE_ANY, month_3$S_PPE_ANY, month_4$S_PPE_ANY, month_5$S_PPE_ANY, month_6$S_PPE_ANY, month_7$S_PPE_ANY)
S_PPE_ANY_mean <- rowMeans(S_PPE_ANY)

overall_rating <- data.frame(month_0$overall_rating, month_1$overall_rating, month_2$overall_rating, month_3$overall_rating, month_4$overall_rating, month_5$overall_rating, month_6$overall_rating, month_7$overall_rating)
overall_rating_mean <- rowMeans(overall_rating)

paymcaid_num <- data.frame(month_0$paymcaid_num, month_1$paymcaid_num, month_2$paymcaid_num, month_3$paymcaid_num, month_4$paymcaid_num, month_5$paymcaid_num, month_6$paymcaid_num, month_7$paymcaid_num)
paymcaid_num_mean <- rowMeans(paymcaid_num)

pctwhite_2011pN <- data.frame(month_0$pctwhite_2011pN, month_1$pctwhite_2011pN, month_2$pctwhite_2011pN, month_3$pctwhite_2011pN, month_4$pctwhite_2011pN, month_5$pctwhite_2011pN, month_6$pctwhite_2011pN, month_7$pctwhite_2011pN)
```

```

pctwhite_2011pN_mean <- rowMeans(pctwhite_2011pN)

vulnerabilityindex_county <- data.frame(month_0$vulnerabilityindex_county, month_1$vulnerabilityindex_county,
vulnerabilityindex_county_mean <- rowMeans(vulnerabilityindex_county)

CBSACode <- data.frame(month_0$CBSACode, month_1$CBSACode, month_2$CBSACode, month_3$CBSACode, month_4$
CBSACode_mean <- rowMeans(CBSACode)

casesper100k_CBSA <- data.frame(month_0$casesper100k_CBSA, month_1$casesper100k_CBSA, month_2$casesper100k_CBSA,
casesper100k_CBSA_mean <- rowMeans(casesper100k_CBSA)

deathesper100k_CBSA <- data.frame(month_0$deathesper100k_CBSA, month_1$deathesper100k_CBSA, month_2$deathesper100k_CBSA,
deathesper100k_CBSA_mean <- rowMeans(deathesper100k_CBSA)

ownership_recode <- data.frame(month_0$ownership_recode, month_1$ownership_recode, month_2$ownership_recode,
ownership_recode_mean <- rowMeans(ownership_recode)

facility_size <- data.frame(month_0$facility_size, month_1$facility_size, month_2$facility_size, month_3$facility_size,
facility_size_mean <- rowMeans(facility_size)

urban_rural <- data.frame(month_0$urban_rural, month_1$urban_rural, month_2$urban_rural, month_3$urban_rural,
urban_rural_mean <- rowMeans(urban_rural)

lnCBSAdeathRate <- data.frame(month_0$lnCBSAdeathRate, month_1$lnCBSAdeathRate, month_2$lnCBSAdeathRate, month_3$lnCBSAdeathRate,
lnCBSAdeathRate_mean <- rowMeans(lnCBSAdeathRate)

lnCBSAcaseRate <- data.frame(month_0$lnCBSAcaseRate, month_1$lnCBSAcaseRate, month_2$lnCBSAcaseRate, month_3$lnCBSAcaseRate,
lnCBSAcaseRate_mean <- rowMeans(lnCBSAcaseRate)

# now, merge all the averaged data together
# exclude CBSA rate data -- not necessary for research questions
data_final <- data.frame("state" = month_0$providerstate, NH_deathesper100k_mean, RES_MonthlyconfC19casesper100k_mean,
head(data))

## # A tibble: 6 x 24
##   providername   provi~1 provi~2 provi~3 provi~4 provz~5 RES_M~6 S_STA~7 S_PPE~8
##   <chr>         <chr>   <chr>   <chr>   <dbl> <chr>   <dbl>   <dbl>   <dbl>
## 1 EVENTIDE AT S~ 125 13~ WEST F~ ND      58078 58078      18      0      0
## 2 SUNNYVALE POS~ 1291 S~ SUNNYV~ CA      94087 94087      0      0      0
## 3 CENTINELA SKI~ 950 FL~ INGLEW~ CA      90301 90301      1      0      0
## 4 BAKER-KATZ SK~ 194 BO~ HAVERH~ MA      1830 01830      4      0      0
## 5 MONARCH MEADO~ 299 CO~ SEAMAN OH      45679 45679      0      0      0
## 6 CONSOLATA HOME 2319 E~ NEW IB~ LA      70560 70560      0      4      0
## # ... with 15 more variables: RES_Monthlyalldeaths_excptCOV <dbl>,
## #   overall_rating <dbl>, paymcaid_num <dbl>, pctwhite_2011pN <dbl>,
## #   vulnerabilityindex_county <dbl>, CBSACode <chr>, casesper100k_CBSA <dbl>,
## #   deathesper100k_CBSA <dbl>, NH_deathesper100k <dbl>, ownership_recode <dbl>,
## #   facility_size <dbl>, urban_rural <dbl>, month_final <dbl>,
## #   lnCBSAdeathRate <dbl>, lnCBSAcaseRate <dbl>, and abbreviated variable names
## #   1: provideraddress, 2: providercity, 3: providerstate, ...

head(as_tibble(data_final))

## # A tibble: 6 x 12
##   state NH_dea~1 RES_M~2 RES_M~3 S_STA~4 S_PPE~5 overa~6 paymc~7 pctwh~8 vulne~9

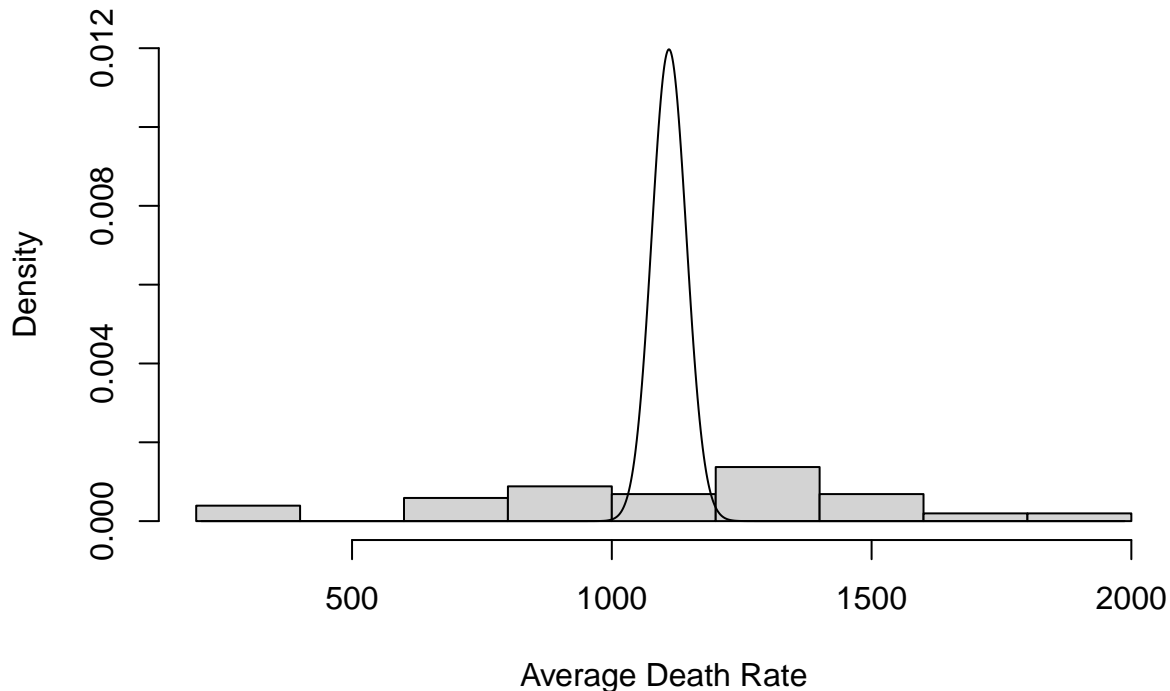
```

```
##   <chr>      <dbl>   <dbl>   <dbl>   <dbl>   <dbl>   <dbl>   <dbl>   <dbl>   <dbl>
## 1 AK         211.    0.868    0.566    1.54     0.662    3.69    NaN     NaN     0.499
## 2 AL        1336.    7.29     2.14     1.73     0.989    3.30    66.9    75.8    0.559
## 3 AR        1670.    5.81     1.50     0.797    0.303    2.99    66.0    83.6    0.602
## 4 AZ        1457.    5.22     1.58     0.802    0.704    3.59    52.8    74.3    0.504
## 5 CA        1096.    5.41     1.28     0.0957   0.517    3.35    59.4    59.5    0.557
## 6 CO        1142.    3.49     1.62     0.926    0.865    3.66    63.0    80.7    0.410
## # ... with 2 more variables: facility_size_mean <dbl>, urban_rural_mean <dbl>,
## #   and abbreviated variable names 1: NH_deathsper100k_mean,
## #   2: RES_MonthlyconfC19cases_mean, 3: RES_Monthlyalldeaths_excptCOV_mean,
## #   4: S_STAFF_ANY_mean, 5: S_PPE_ANY_mean, 6: overall_rating_mean,
## #   7: paymcaid_num_mean, 8: pctwhite_2011pN_mean,
## #   9: vulnerabilityindex_county_mean
```

```
##### DATA ANALYSIS - POISSON DISTRIBUTION #####
##### CHECK OVER DISPERSION
```

```
# death rate in nursing homes study period
```

```
hist(data_final$NH_deathsper100k_mean, freq = F, ylim = c(0, 0.012), main = NULL, xlab = "Average Death Rate",
lines(as.integer(min(data_final$NH_deathsper100k_mean)):as.integer(max(data_final$NH_deathsper100k_mean)),
```



```
# mean and variance calculations to check for overdispersion
print(mean(data_final$NH_deathsper100k_mean))
```

```
## [1] 1110.511
```

```
print(var(data_final$NH_deathsper100k_mean))
```

```
## [1] 160259.1
```

```
##### VARIABLE SELECTION AND MODEL FITS
```

```
# CHECK CORRELATIONS
```

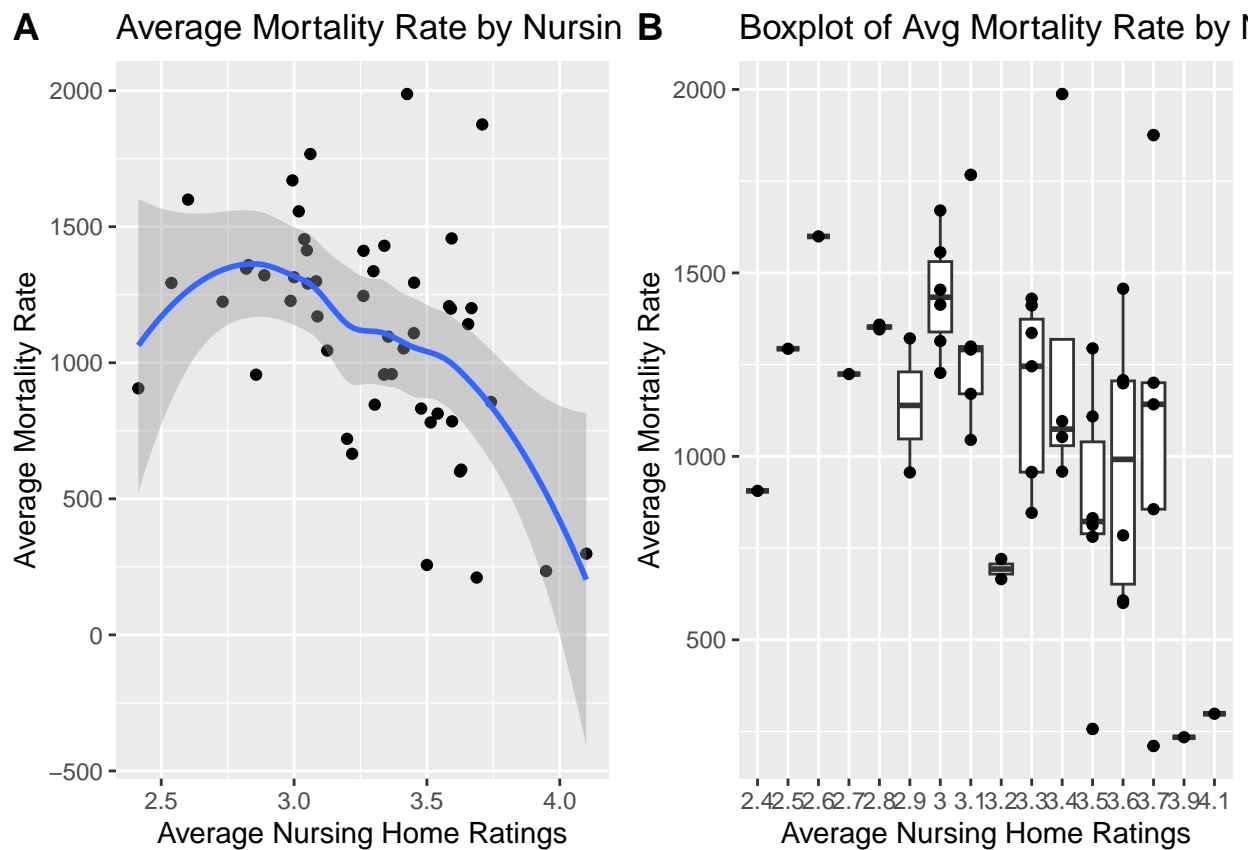
```
# how correlated are death rate and nursing home ratings?
```

```
fig3a <- data_final |>
  ggplot(aes(overall_rating_mean, NH_deathsper100k_mean)) +
  geom_point() +
  geom_smooth() +
  labs(x = "Average Nursing Home Ratings", y = "Average Mortality Rate", title = "Average Mortality Rate")

fig3b <- data_final |> mutate(rating_strata = factor(round(overall_rating_mean, digits = 0.5))) |>
  ggplot(aes(rating_strata, NH_deathsper100k_mean)) +
  geom_boxplot() +
  geom_point() +
  labs(x = "Average Nursing Home Ratings", y = "Average Mortality Rate", title = "Boxplot of Avg Mortality Rate")

ggarrange(fig3a, fig3b,
  labels = c("A", "B"),
  ncol = 2, nrow = 1)
```

```
## `geom_smooth()` using method = 'loess' and formula = 'y ~ x'
```



```
data_final |> summarize(r = cor(NH_deathsper100k_mean, overall_rating_mean)) |> pull(r)
```

```
## [1] -0.4471934
```

```
# -0.4471934 -- variables are negatively correlated, but not extremely strong relationship. Will contro
# MODELING
```

```
# poisson fit general only with main predictor
```

```
pois_general <- data_final %>% glm(formula = NH_deathsper100k_mean ~ overall_rating_mean, family=poisson)
summary(pois_general)$coefficients
```

```

##              Estimate Std. Error   z value Pr(>|z|)
## (Intercept)      8.4537905 0.03787053 223.22871      0
## overall_rating_mean -0.4429845 0.01167019 -37.95862      0

summary(pois_general)$aic

## [1] Inf

# neg bin fit general only with main predictor
neg_bin <- data_final %>% MASS::glm.nb(formula = NH_deathspers100k_mean ~ overall_rating_mean, data=.)
summary(neg_bin)$coefficients

##              Estimate Std. Error   z value   Pr(>|z|)
## (Intercept)      8.7167876  0.5128064 16.998203 8.467591e-65
## overall_rating_mean -0.5238084  0.1553911 -3.370903 7.492232e-04

summary(neg_bin)$aic # AIC = 763.81

## [1] 763.8066

#-----#

# include monthly covid cases of residents in facility
neg_bin_2 <- data_final %>% MASS::glm.nb(formula = NH_deathspers100k_mean ~ overall_rating_mean + RES_Mo
summary(neg_bin_2)$coefficients

##              Estimate Std. Error   z value   Pr(>|z|)
## (Intercept)      6.9115399 0.69465994  9.9495300 2.533770e-23
## overall_rating_mean      -0.1602646 0.17682486 -0.9063465 3.647525e-01
## RES_MonthlyconfC19cases_mean  0.1536474 0.04274731  3.5943183 3.252420e-04

summary(neg_bin_2)$aic

## [1] 756.0149

# AIC = 756.01 (decreases), but main predictor no longer significant

neg_bin_2_EM <- data_final %>% MASS::glm.nb(formula = NH_deathspers100k_mean ~ overall_rating_mean + RES
summary(neg_bin_2_EM)$coefficients

##              Estimate Std. Error   z value
## (Intercept)      13.547836  1.8646318  7.265690
## overall_rating_mean      -2.094628  0.5310092 -3.944618
## RES_MonthlyconfC19cases_mean      -1.396737  0.4172822 -3.347224
## overall_rating_mean:RES_MonthlyconfC19cases_mean  0.460075  0.1222114  3.764584
##              Pr(>|z|)
## (Intercept)      3.711394e-13
## overall_rating_mean      7.992733e-05
## RES_MonthlyconfC19cases_mean      8.162531e-04
## overall_rating_mean:RES_MonthlyconfC19cases_mean 1.668269e-04

summary(neg_bin_2_EM)$aic

## [1] 747.35

# There is effect modification since p-value of interaction term <0.05
# AIC = 747.35 (decreases), AND main predictor NOW significant again

# include facility size

```

```
neg_bin_3 <- data_final %>% MASS::glm.nb(formula = NH_deathsper100k_mean ~ overall_rating_mean + RES_Mo
summary(neg_bin_3)$coefficients
```

```
##                                Estimate Std. Error
## (Intercept)                   14.0613004  1.5882253
## overall_rating_mean           -2.0780966  0.4490949
## RES_MonthlyconfC19cases_mean  -1.2378624  0.3521561
## facility_size_mean            -0.6394713  0.1349910
## overall_rating_mean:RES_MonthlyconfC19cases_mean  0.4328719  0.1032069
##                                z value      Pr(>|z|)
## (Intercept)                   8.853467 8.484193e-19
## overall_rating_mean           -4.627299 3.704655e-06
## RES_MonthlyconfC19cases_mean  -3.515096 4.395950e-04
## facility_size_mean            -4.737142 2.167534e-06
## overall_rating_mean:RES_MonthlyconfC19cases_mean  4.194214 2.738199e-05
```

```
summary(neg_bin_3)$aic
```

```
## [1] 731.3994
```

```
# AIC = 731.4 (decreases) and all significant co-variates
```

```
neg_bin_3_EM <- data_final %>% MASS::glm.nb(formula = NH_deathsper100k_mean ~ overall_rating_mean + RES_M
summary(neg_bin_3_EM)$coefficients
```

```
##                                Estimate Std. Error
## (Intercept)                   13.26286108  2.4881929
## overall_rating_mean           -1.84827887  0.7101336
## RES_MonthlyconfC19cases_mean  -1.28616573  0.3720690
## facility_size_mean            0.02723134  1.5934641
## overall_rating_mean:RES_MonthlyconfC19cases_mean  0.44776992  0.1100366
## overall_rating_mean:facility_size_mean  -0.19469034  0.4654272
##                                z value      Pr(>|z|)
## (Intercept)                   5.3303186 9.804063e-08
## overall_rating_mean           -2.6027198 9.248750e-03
## RES_MonthlyconfC19cases_mean  -3.4567932 5.466441e-04
## facility_size_mean            0.0170894 9.863653e-01
## overall_rating_mean:RES_MonthlyconfC19cases_mean  4.0692832 4.715801e-05
## overall_rating_mean:facility_size_mean  -0.4183046 6.757244e-01
```

```
# No effect modification of facility size on overall rating
# thus, keep neg_bin_3
```

```
# include shortages
```

```
neg_bin_4a <- data_final %>% MASS::glm.nb(formula = NH_deathsper100k_mean ~ overall_rating_mean + RES_M
summary(neg_bin_4a)$coefficients
```

```
##                                Estimate Std. Error
## (Intercept)                   14.0917590  1.5291260
## overall_rating_mean           -2.2083085  0.4365471
## RES_MonthlyconfC19cases_mean  -1.3666253  0.3444533
## facility_size_mean            -0.4552096  0.1493042
## S_STAFF_ANY_mean              0.2174068  0.1024211
## S_PPE_ANY_mean                -0.0166623  0.1079262
## overall_rating_mean:RES_MonthlyconfC19cases_mean  0.4672648  0.1007131
##                                z value      Pr(>|z|)
```



```
## (Intercept) 9.215565 3.096444e-20
## overall_rating_mean -5.058580 4.223898e-07
## RES_MonthlyconfC19cases_mean -3.967520 7.262440e-05
## facility_size_mean -3.048873 2.297016e-03
## S_STAFF_ANY_mean 2.122676 3.378105e-02
## S_PPE_ANY_mean -0.154386 8.773054e-01
## overall_rating_mean:RES_MonthlyconfC19cases_mean 4.639563 3.491466e-06
```

```
summary(neg_bin_4a)$aic
```

```
## [1] 731.3332
```

```
# AIC = 731.33 (almost same) and S_PPE_ANY_mean not significant
```

```
neg_bin_4b <- data_final %>% MASS::glm.nb(formula = NH_deathsper100k_mean ~ overall_rating_mean + RES_M
summary(neg_bin_4b)$coefficients
```

```
## Estimate Std. Error
## (Intercept) 14.0952927 1.52902614
## overall_rating_mean -2.2124359 0.43654447
## RES_MonthlyconfC19cases_mean -1.3686909 0.34452946
## facility_size_mean -0.4555477 0.14933356
## S_STAFF_ANY_mean 0.2132906 0.09842543
## overall_rating_mean:RES_MonthlyconfC19cases_mean 0.4680620 0.10072303
## z value Pr(>|z|)
## (Intercept) 9.218477 3.013490e-20
## overall_rating_mean -5.068065 4.018796e-07
## RES_MonthlyconfC19cases_mean -3.972638 7.108097e-05
## facility_size_mean -3.050538 2.284316e-03
## S_STAFF_ANY_mean 2.167028 3.023273e-02
## overall_rating_mean:RES_MonthlyconfC19cases_mean 4.647021 3.367632e-06
```

```
summary(neg_bin_4b)$aic
```

```
## [1] 729.3563
```

```
# AIC = 729.36 (decreases)
```

```
# include SES factors
```

```
neg_bin_5a <- data_final %>% MASS::glm.nb(formula = NH_deathsper100k_mean ~ overall_rating_mean + RES_M
summary(neg_bin_5a)$coefficients
```

```
## Estimate Std. Error
## (Intercept) 11.199347025 1.616183387
## overall_rating_mean -1.213679200 0.426975967
## RES_MonthlyconfC19cases_mean -0.550515102 0.344237570
## facility_size_mean -0.425592421 0.129548829
## S_STAFF_ANY_mean 0.157526543 0.077876015
## pctwhite_2011pN_mean 0.004259116 0.002964769
## paymcaid_num_mean -0.013746136 0.005718261
## overall_rating_mean:RES_MonthlyconfC19cases_mean 0.223774792 0.101073514
## z value Pr(>|z|)
## (Intercept) 6.929503 4.223228e-12
## overall_rating_mean -2.842500 4.476123e-03
## RES_MonthlyconfC19cases_mean -1.599230 1.097695e-01
## facility_size_mean -3.285189 1.019139e-03
## S_STAFF_ANY_mean 2.022786 4.309518e-02
```



```
## pctwhite_2011pN_mean          1.436576 1.508385e-01
## paymcaid_num_mean             -2.403902 1.622114e-02
## overall_rating_mean:RES_MonthlyconfC19cases_mean 2.213981 2.683012e-02
```

```
summary(neg_bin_5a)$aic
```

```
## [1] 685.1363
```

```
# AIC = 685.14 (decreases) and pctwhite_2011pN_mean not significant
```

```
neg_bin_5b <- data_final %>% MASS::glm.nb(formula = NH_deathspers100k_mean ~ overall_rating_mean + RES_M
summary(neg_bin_5b)$coefficients
```

```
##              Estimate Std. Error
## (Intercept)  12.61231037 1.267100657
## overall_rating_mean -1.51345882 0.370940292
## RES_MonthlyconfC19cases_mean -0.79249801 0.299277799
## facility_size_mean -0.48621313 0.124774616
## S_STAFF_ANY_mean 0.17865175 0.077730591
## paymcaid_num_mean -0.01319791 0.005816746
## overall_rating_mean:RES_MonthlyconfC19cases_mean 0.29497492 0.088035770
##              z value Pr(>|z|)
## (Intercept) 9.953677 2.430344e-23
## overall_rating_mean -4.080060 4.502399e-05
## RES_MonthlyconfC19cases_mean -2.648035 8.096121e-03
## facility_size_mean -3.896731 9.749976e-05
## S_STAFF_ANY_mean 2.298345 2.154213e-02
## paymcaid_num_mean -2.268950 2.327136e-02
## overall_rating_mean:RES_MonthlyconfC19cases_mean 3.350626 8.062920e-04
```

```
summary(neg_bin_5b)$aic
```

```
## [1] 685.1088
```

```
# AIC = 685.11 (decreases slightly) and all covariates significant (p-value <0.05) # final model!!
```

```
neg_bin_5b <- data_final %>% MASS::glm.nb(formula = NH_deathspers100k_mean ~ overall_rating_mean + RES_M
summary(neg_bin_5b)$coefficients
```

```
##              Estimate Std. Error
## (Intercept)  12.61231037 1.267100657
## overall_rating_mean -1.51345882 0.370940292
## RES_MonthlyconfC19cases_mean -0.79249801 0.299277799
## facility_size_mean -0.48621313 0.124774616
## S_STAFF_ANY_mean 0.17865175 0.077730591
## paymcaid_num_mean -0.01319791 0.005816746
## overall_rating_mean:RES_MonthlyconfC19cases_mean 0.29497492 0.088035770
##              z value Pr(>|z|)
## (Intercept) 9.953677 2.430344e-23
## overall_rating_mean -4.080060 4.502399e-05
## RES_MonthlyconfC19cases_mean -2.648035 8.096121e-03
## facility_size_mean -3.896731 9.749976e-05
## S_STAFF_ANY_mean 2.298345 2.154213e-02
## paymcaid_num_mean -2.268950 2.327136e-02
## overall_rating_mean:RES_MonthlyconfC19cases_mean 3.350626 8.062920e-04
```