Technical Appendix

Notes for appendix

The Appendix contains all the code and plots in the IDMRD paper and some other important supplementary plots.

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Appendix 1: Map

This section contains all the types of map in our main paper.

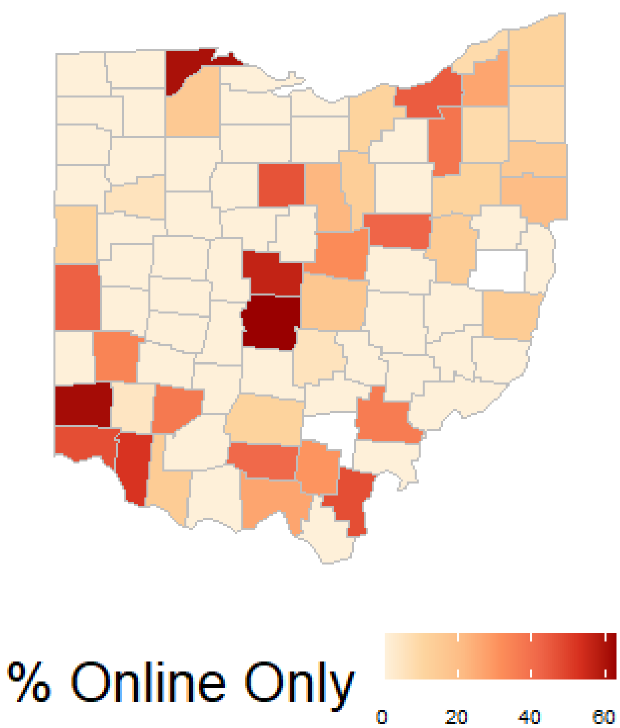
```
Sys.setlocale("LC_TIME", "English")

## [1] "English_United States.1252"

library(ggrepel)
library(cowplot)
library(sp)
source("step2_new.R")
# color blind friendly Palette
library(ggthemes)
col_theme <- c("Hybrid"="#009E73","On Premises"="#D55E00","Online Only"
="#0072B2")
## plot theme
grid_theme <- theme(axis.line = element_line(colour = "black"),
    panel.grid.major = element_blank(),
    panel.grid.minor = element_blank(),
    panel.border = element_blank(),
    legend.key = element_blank(),
    panel.background = element_blank(),
    legend.box="vertical", legend.margin=margin())
team_theme <- grid_theme+
```

```
  theme(legend.text = element_text(size=12),
        legend.title = element_text(size=12),
        axis.text = element_text(size=13),
        title=element_text(size=13),
        strip.text.x = element_text(size = 10, face = "bold.italic"))
```

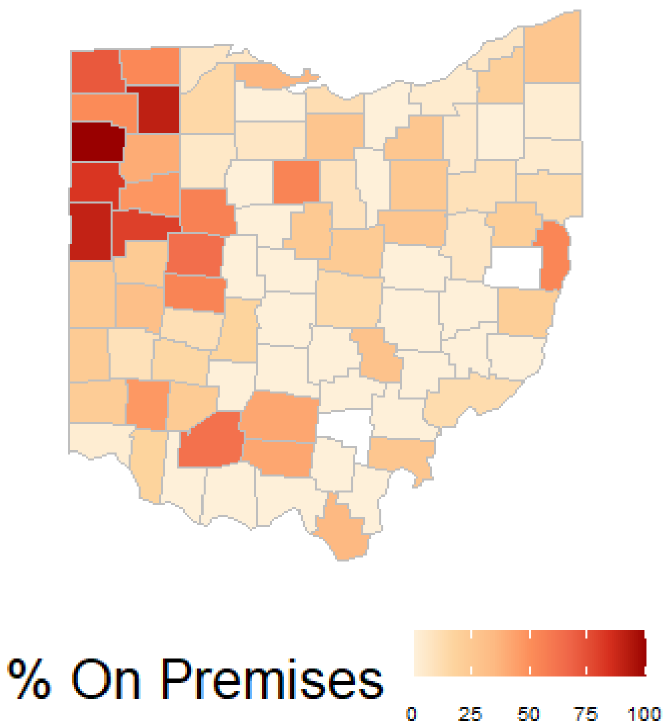
Teaching method, Population and Enrollment

This section contains the percentage of different teaching methods, the number of enrolled students and population profile in counties.

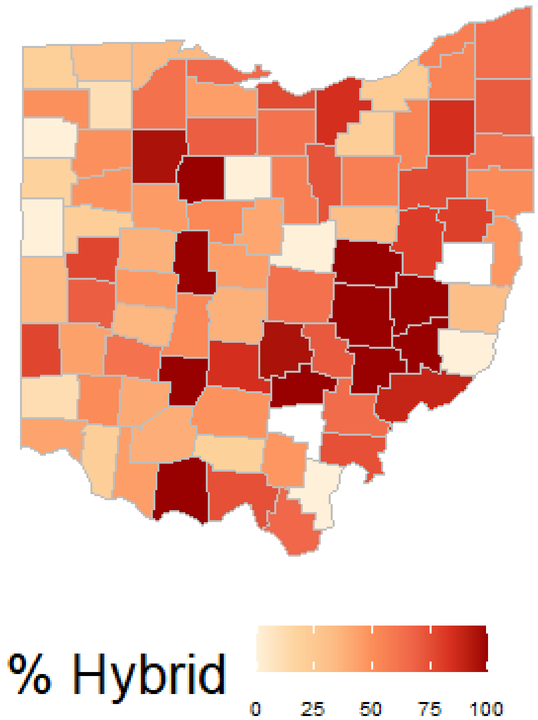
```
ohio_map <- map_data("county") %>%subset(region=="ohio")%>%
  mutate(county=toupper(subregion))%>%select(long,lat,county,group)
# create map plots
wide_teaching_enroll%>%
  left_join(ohio_map,by='county')%>%
  mutate(Online_Only= Online_Only*100)%>%
  ggplot() +
  geom_polygon(aes(x = long, y = lat, group = group, fill = Online_Onl
y), color = "gray") +
  coord_fixed(1.3) + theme_map() +
  scale_fill_distiller(palette = "OrRd",direction = 1)+
  labs(fill='% Online Only')+
  theme(legend.position = "bottom",legend.text = element_text(size=),le
gend.title = element_text(size=20))
```



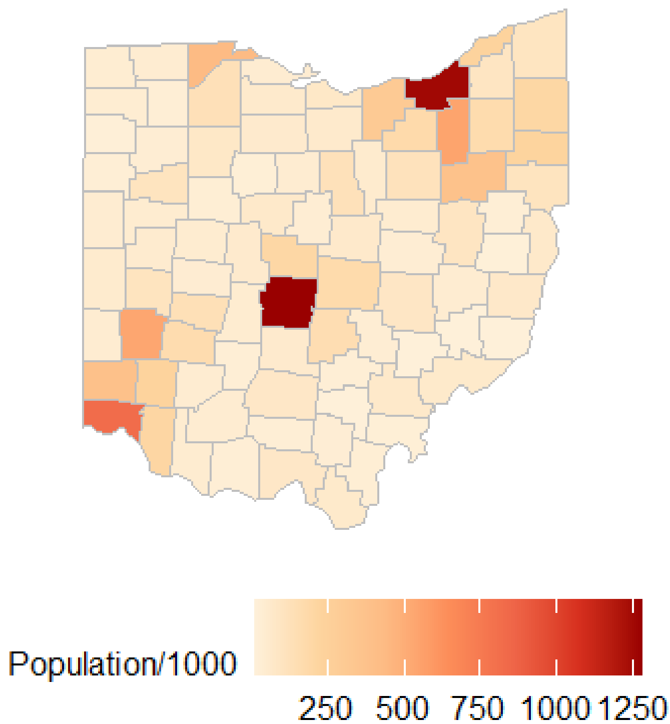
```
# create map plots
wide_teaching_enroll%>%
  left_join(ohio_map,by='county')%>%
  mutate(On_Premises= On_Premises*100)%>%
  ggplot() +
  geom_polygon(aes(x = long, y = lat, group = group, fill = On_Premise
s), color = "gray") +
  coord_fixed(1.3) + theme_map() +
  scale_fill_distiller(palette = "OrRd",direction = 1)+
  labs(fill='% On Premises')+
  theme(legend.position = "bottom",legend.text = element_text(size=),le
gend.title = element_text(size=20))
```



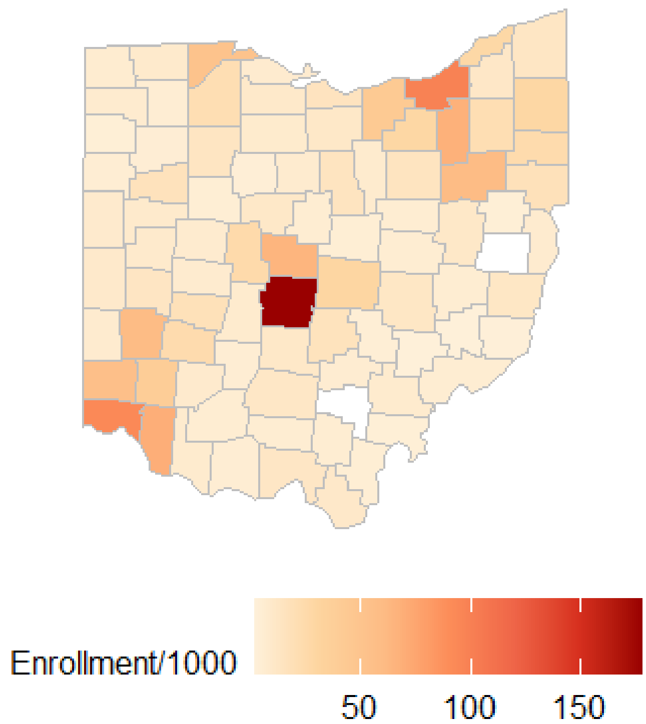

```
# create map plots for population
wide_teaching_enroll%>%
  left_join(ohio_map,by='county')%>%
  mutate(Hybrid= Hybrid*100)%>%
  ggplot() +
  geom_polygon(aes(x = long, y = lat, group = group, fill = Hybrid), co
lor = "gray") +
  coord_fixed(1.3) +
  theme_map() +
  scale_fill_distiller(palette = "OrRd",direction = 1)+
  labs(fill='% Hybrid')+
  theme(legend.position = "bottom",legend.text = element_text(size=),le
gend.title = element_text(size=20))
```




```r
# create map plots
cases%>%
  distinct(COUNTY,POPULATION)%>%
  left_join(ohio_map,by=c('COUNTY'='county'))%>%
  mutate(population = POPULATION/1000)%>%
  ggplot() +
  geom_polygon(aes(x = long, y = lat, group = group, fill = populatio
n), color = "gray") +
  coord_fixed(1.3) + theme_map() +
  scale_fill_distiller(palette = "OrRd",direction = 1)+
  labs(fill='Population/1000')+
  theme(legend.text = element_text(size=12),
        legend.title = element_text(size=12),
        legend.position = "bottom",
        legend.key.size = unit(2,"lines"))
```

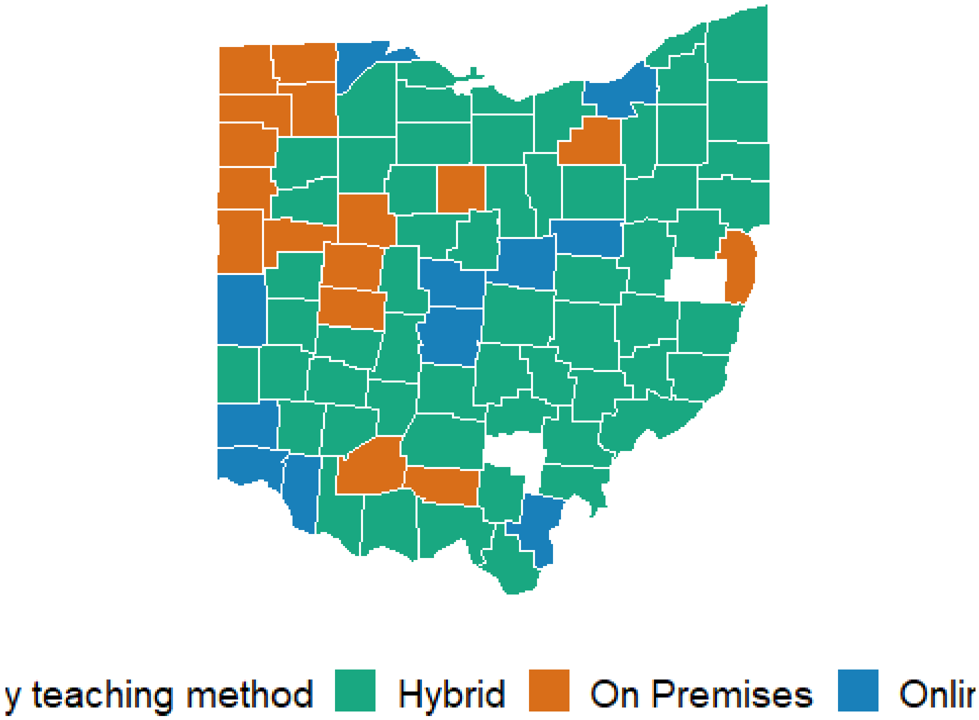



```r
# create map plots
teachingmethod_enroll%>%
  distinct(county,county_enroll)%>%
  left_join(ohio_map,by=c('county'))%>%
  mutate(county_enroll = county_enroll/1000)%>%
  ggplot() +
  geom_polygon(aes(x = long, y = lat, group = group, fill = county_enro
ll), color = "gray") +
  coord_fixed(1.3) + theme_map() +
  scale_fill_distiller(palette = "OrRd",direction = 1)+
  labs(fill='Enrollment/1000')+
  theme(legend.text = element_text(size=12),legend.title = element_text
(size=12),
        legend.position = "bottom",legend.key.size = unit(2,"lines"))
```



The following map shows the major teaching method in a certain county.

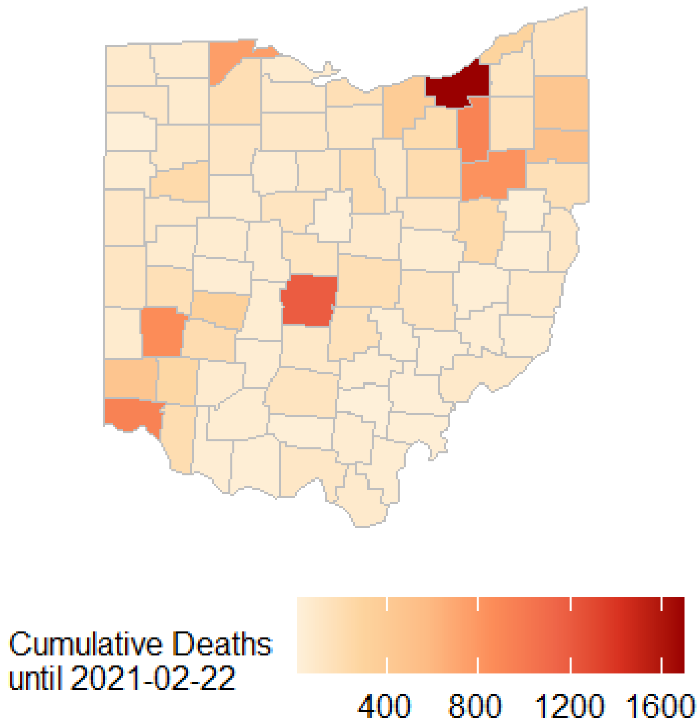
```
wide_teaching_enroll%>%
  left_join(ohio_map,by='county')%>%
  mutate(On_Premises= On_Premises*100)%>%
  ggplot() + geom_polygon(aes(x = long, y = lat, group = group, fill =
as.factor(major_teaching)), color = "white",alpha=0.9) +
  coord_fixed(1.3) + theme_map() +
  scale_fill_manual(values=col_theme)+
  labs(fill='Majority teaching method')+
  theme(legend.position = "bottom",legend.text = element_text(size=14),
legend.title = element_text(size=14))
```



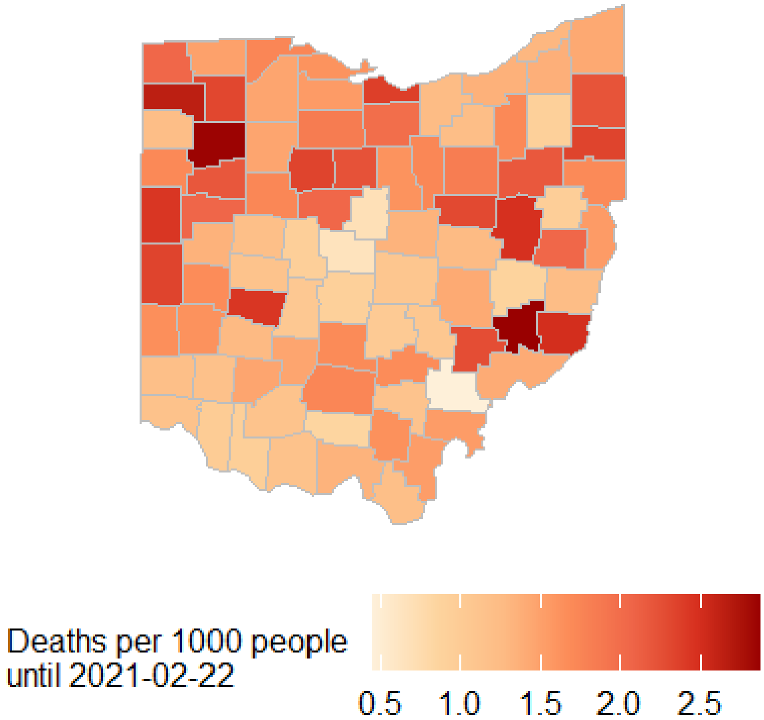
Covid deaths during fall semester and death proportion during fall semester

This section shows the death profile in the county(both cumulative death numbers and death per 1000 people).

```
getLabelPoint <- # Returns a county-named list of label points
function(county) {Polygon(county[c('long', 'lat')])@labpt}
centroids = by(ohio_map, ohio_map$county, getLabelPoint)# Returns list
centroids2 <- do.call("rbind.data.frame", centroids)# Convert to Data F
rame
centroids2$county = str_to_title(rownames(centroids))
names(centroids2) <- c('clong', 'clat', "county") # Appropriate Header

death_prop%>%
  left_join(ohio_map,by=c("COUNTY"='county'))%>%
  ggplot() +
  geom_polygon(aes(x = long, y = lat, group=group,fill = CUMDEATHS), co
lor = "gray")+
  coord_fixed(1.3) + theme_map() +
  scale_fill_distiller(palette = "OrRd",direction = 1)+
  labs(fill='Cumulative Deaths \nuntil 2021-02-22')+
  theme(legend.text = element_text(size=12),
        legend.title = element_text(size=12),legend.position = "bottom
",
        legend.key.size = unit(2,"lines"))
```



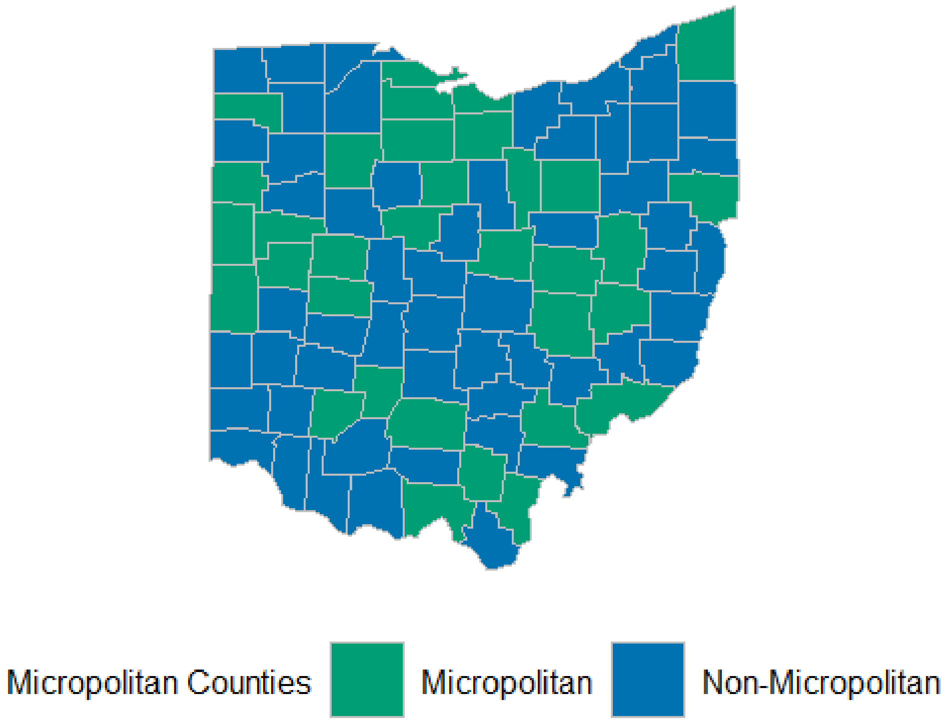

```
death_prop%>%
  left_join(ohio_map,by=c("COUNTY"='county'))%>%
  ggplot() +
  geom_polygon(aes(x = long, y = lat, group=group,fill = death_per_100
0),
                color = "gray") +
  coord_fixed(1.3) + theme_map() +
  scale_fill_distiller(palette = "OrRd",direction = 1)+
  labs(fill='Deaths per 1000 people \nuntil 2021-02-22')+
  theme(legend.text = element_text(size=12),
        legend.title = element_text(size=12),
        legend.position = "bottom",
        legend.key.size = unit(2,"lines"))
```



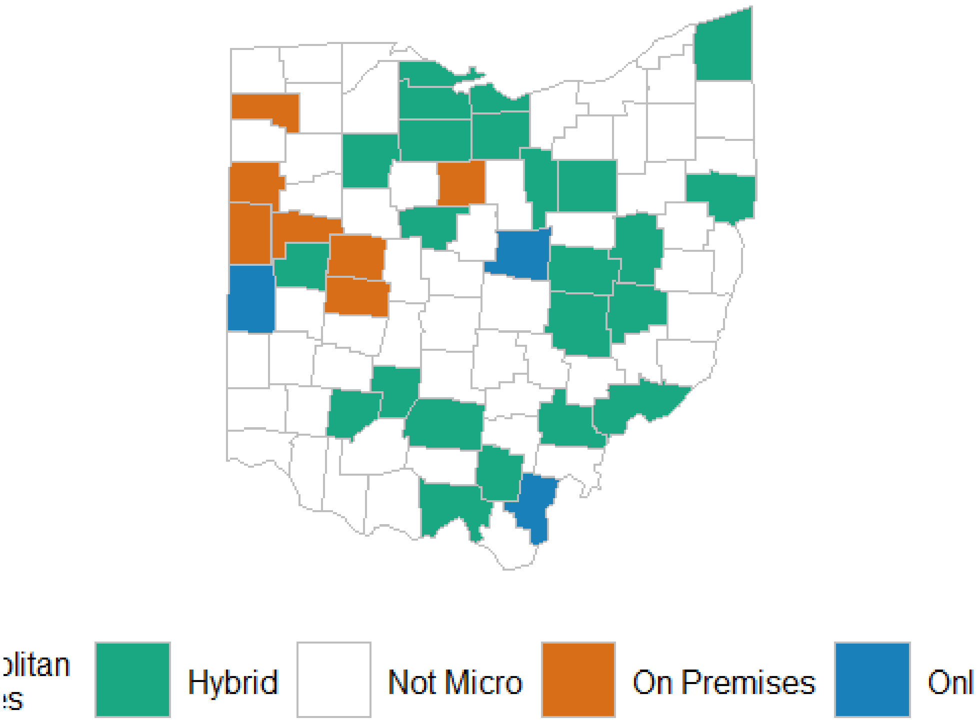
Micropolitan Map

Since we reduced our county samples to micropolitan counties, we also show how micropolitan county distribute in Ohio and which teaching method they used. We can find that micropolitan counties are well-spread.

```
# Micropolitan map plots
ohio_profile%>%
  distinct(County,NCHS.Urban.Rural.Status) %>%
  mutate(is_micro = factor(ifelse(NCHS.Urban.Rural.Status == "Micropoli
tan","Micropolitan","Non-Micropolitan")))%>%
  left_join(ohio_map,by=c('County'='county'))%>%
  ggplot() +
  geom_polygon(aes(x = long, y = lat, group = group, fill = is_micro),
               color = "gray") +
  coord_fixed(1.3) + theme_map() +
  scale_fill_manual(values = c("Non-Micropolitan" ="#0072B2",
                    "Micropolitan" ="#009E73"))+
  labs(fill='Micropolitan Counties')+
  theme(legend.text = element_text(size=12),
        legend.title = element_text(size=12),
        legend.position = "bottom",
        legend.key.size = unit(2,"lines"))
```




```
# Micropolitan map plots
ohio_profile%>%
  distinct(County,NCHS.Urban.Rural.Status) %>%
  left_join(wide_teaching_enroll[,c("county","major_teaching")],
            by = c("County" = "county"))%>%
  mutate(is_micro = factor(ifelse(NCHS.Urban.Rural.Status == "Micropoli
tan",1,0)),
         micro_teach = factor(ifelse(is_micro == 1, major_teaching, "No
t Micro")))%>%
  left_join(ohio_map,by=c('County'='county'))%>%
  ggplot() +
  geom_polygon(aes(x = long, y = lat, group = group, fill = micro_teac
h),
               color = "gray",alpha=0.9) +
  coord_fixed(1.3) + theme_map() +
  scale_fill_manual(values = c(col_theme, "Not Micro" = "white"))+
  labs(fill='Micropolitan \nCounties')+
  theme(legend.text = element_text(size=12),
        legend.title = element_text(size=12),
        legend.position = "bottom",
        legend.key.size = unit(2,"lines"))
```



Appendix 2: Death Incidence

Data Process

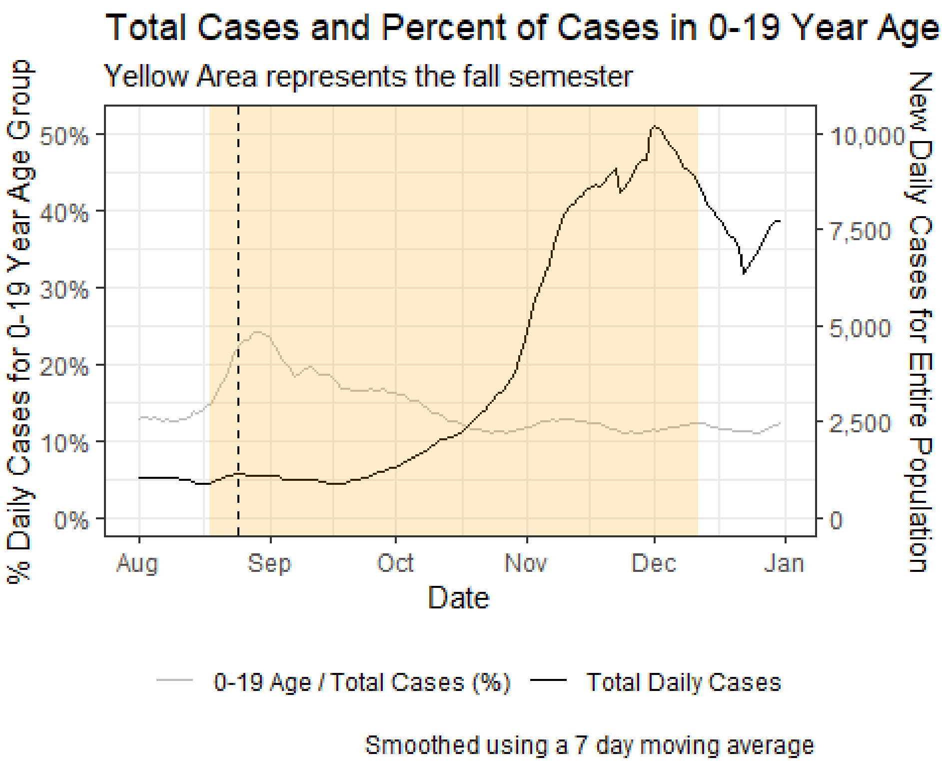
```
library(tidyverse)
library(lubridate)
require(scales)
library(readxl)
cases_by_age <- read_excel("OhiobyAge.xlsx")
rolling_age_cases <- cases_by_age %>%
  mutate(youth_prop_roll = zoo::rollmean(`00_19/total(%)`, k = 7, fill
= NA),
         all_roll = zoo::rollmean(`00_80+`, k = 7, fill = NA))
colors <- c("Total Daily Cases" = "black",
            "0-19 Age / Total Cases (%)" = "gray")
coeff <- 200
cases_by_age_long <- cases_by_age %>%
  gather(age_group, percent_cases,
         `00_19/total(%)`:`80+/total(%)`,
         factor_key=TRUE) %>%
  group_by(age_group) %>%
  mutate(roll_percent_cases= zoo::rollmean(percent_cases, k = 7, fill =
 NA))
county_policy_wide$major_teaching <- factor(county_policy_wide$major_te
aching,
                                            levels = c("On Premises","H
```

```r
ybrid","Online Only"))
# see when the intesection happens
date.intercept <- as.Date("2020-11-24")
# add 95% confidence bans
confidence_level <- .95
z_cl <- qnorm(confidence_level)
# case_policy_wide
case_policy_wide <- cases %>%
  left_join(county_policy_wide[,c("county","major_teaching","Online_Onl
y","Hybrid","On_Premises")],
            by = c("COUNTY" = "county")) %>%
  mutate(death_prop = CUMDEATHS/POPULATION)
opendate_cases <- case_policy_wide%>%
  inner_join(major_reopening%>%select(COUNTY,major_opendate),by=c('COUN
TY'))
# Box Plots in Fall semester
library(PMCMRplus)
require(DescTools)
fall_cases <- opendate_cases %>%
  filter(DATE >= major_opendate & DATE <= as.Date("2020/12/15")) %>%
  group_by(COUNTY) %>%
  arrange(DATE) %>%
  filter(row_number()==1 | row_number()==n()) %>%
  mutate(death_incidence = diff(CUMDEATHS),
         death_incidence_per_1000 = death_incidence*1000/POPULATION)
 %>%
  distinct(COUNTY,POPULATION,major_teaching,
           death_incidence,death_incidence_per_1000)
fall_major_teaching.aov <- aov(death_incidence_per_1000 ~ major_teachin
g,
                               data = fall_cases)
summary(fall_major_teaching.aov) # p-value of .012

##                 Df Sum Sq Mean Sq F value  Pr(>F)
## major_teaching  2  1.653  0.8264   5.205 0.00761 **
## Residuals      76 12.067  0.1588
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

stat.test <- PostHocTest(fall_major_teaching.aov, method = "duncan")$ma
jor_teaching%>%
  as.data.frame()%>%
  rownames_to_column("group") %>%
  separate(group,"-", into = c("group1","group2")) %>%
  mutate(pval = round(pval,3),
         p = case_when(pval <= .01~ "**",
                       pval <= .05 ~ "*",
                       TRUE ~ "NS"))%>%
  select(group1, group2, pval, p)
library(ggpubr)
```

Daily Cases for 0-19 Year Age Group

This plot shows total cases and percent of cases in 0-19 Year Age group, this special figure is one reason why we would like investigate schooling effect.

```
colors <- c("Total Daily Cases" = "black",
            "0-19 Age / Total Cases (%)" = "gray")
coeff <- 200
ggplot(rolling_age_cases, aes(x=Date)) +
  geom_line( aes(y=youth_prop_roll,
                 color = "0-19 Age / Total Cases (%)"),
             na.rm = T)+
  geom_line( aes(y=all_roll/coeff,
                 color = "Total Daily Cases"),
             na.rm = T) +
  scale_y_continuous(
    # Features of the first axis
    name = "% Daily Cases for 0-19 Year Age Group",
    labels = function(x){paste0(x, "%")},
    # Add a second axis and specify its features
    sec.axis = sec_axis(~.*coeff, name="New Daily Cases for Entire Popu
lation",
                        label=comma)
  ) +
  geom_rect(data=rolling_age_cases[1,],
            aes(xmin=as.POSIXct ("2020/08/18"), xmax=as.POSIXct ("2020/
12/12"),
                ymin=-Inf,ymax=Inf),
            color = NA,alpha=0.2, show.legend = F, fill = "orange") +
  geom_vline(xintercept = as.POSIXct ("2020/08/18") + days(7),lty = 2)+

  xlim(c(as.POSIXct ("2020/08/01"),as.POSIXct ("2021/01/01"))) +
  labs(title = "Total Cases and Percent of Cases in 0-19 Year Age Group
",
       subtitle = "Yellow Area represents the fall semester",
       caption = "Smoothed using a 7 day moving average",
       color = "")+
  scale_color_manual(values = colors)+
  theme_bw() +
  theme(legend.position='bottom')
```

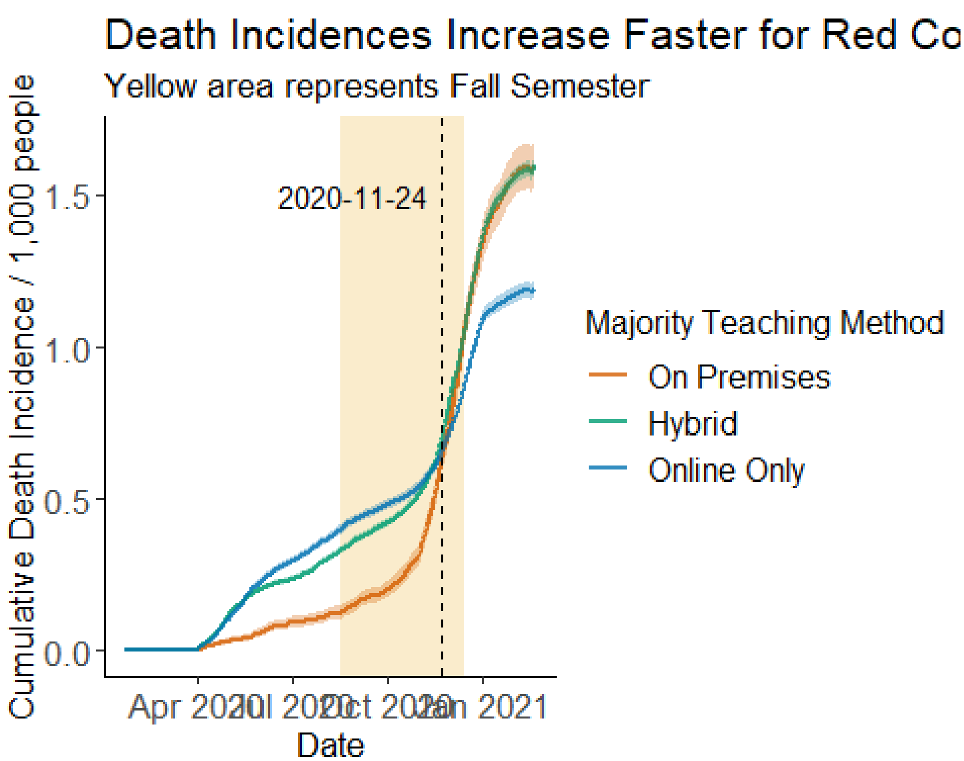


Death Prop Over Time by the Majority Teaching Method

This section shows a special death incidence plot over time, which is the reason we want to investigate the change of death incidence.

```
case_policy_wide%>%
  group_by(DATE, major_teaching) %>%
  drop_na(major_teaching)%>%
  summarise(total_deaths = sum(CUMDEATHS),
            total_pop = sum(POPULATION),
            death_prop = total_deaths/total_pop,
            death_prop_upper = death_prop + z_cl*sqrt(death_prop*(1 - d
eath_prop)/total_pop),
            death_prop_lower = death_prop - z_cl*sqrt(death_prop*(1 - d
eath_prop)/total_pop),
            .groups = "drop") %>%
  ggplot(aes(x = DATE, y = death_prop*1000, group = major_teaching))+
  geom_rect(data=case_policy_wide[1,],
            aes(xmin=as.Date("2020/08/18"), xmax=as.Date("2020/12/15"),
                ymin=-Inf,ymax=Inf),
            color = NA,alpha=0.2, show.legend = F, fill = "#E69F00") +
  geom_line(aes(color = major_teaching),size = 1, alpha = .8) +
  geom_ribbon(aes(ymin = 1000*death_prop_lower, ymax = 1000*death_prop_
upper,
                  fill= major_teaching),
              alpha = .3, show.legend = F)+
  geom_vline(xintercept = date.intercept, linetype = "dashed") +
```

```
  annotate("text",x = date.intercept,y = 1.5,
           label = date.intercept,
           hjust = 1.1) +
  theme_bw() +
  ggtitle("Death Incidences Increase Faster for Red Counties ")+
  labs(x = "Date", y = "Cumulative Death Incidence / 1,000 people",
       subtitle = "Yellow area represents Fall Semester",
       color = "Majority Teaching Method") +team_theme+ scale_colour_ma
nual(values=col_theme)+scale_fill_manual(values=col_theme)
```

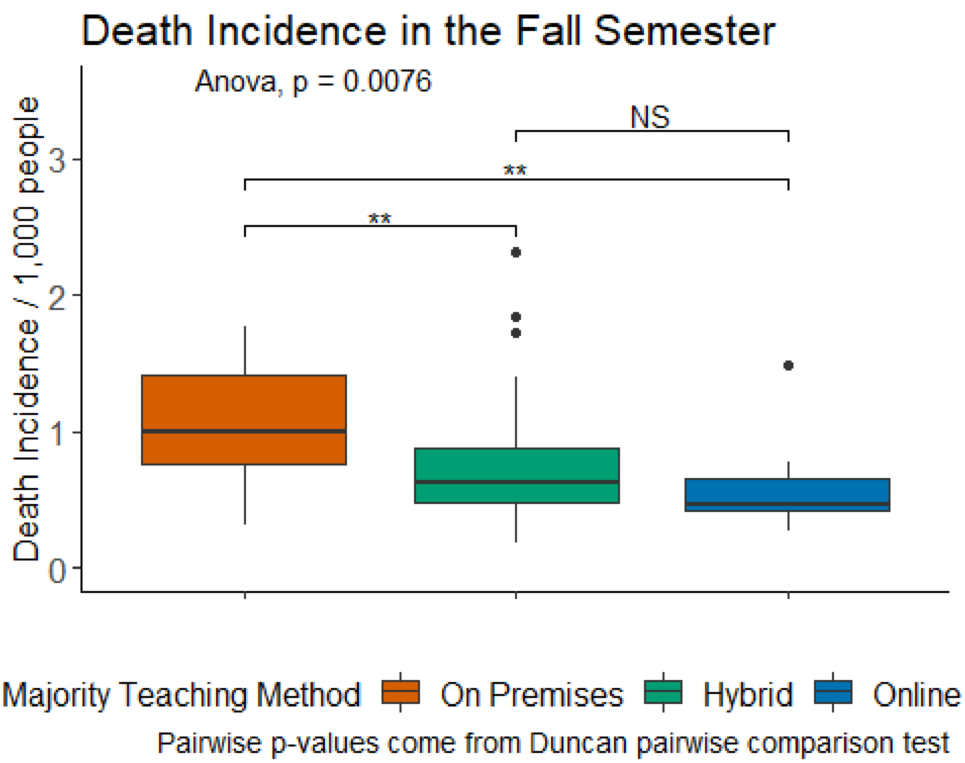


Pairwise of Death Incidence

We find that death incidence during the fall semester for different teaching methods show obvious significant difference.

```
ggplot(fall_cases,aes(y = death_incidence_per_1000, x = major_teachin
g)) +
  geom_boxplot(aes(fill = major_teaching))+
  stat_compare_means(method = "anova")+
  stat_pvalue_manual(stat.test, label = "p",y.position = 2.5, step.incr
ease = 0.15)+
  ylim(c(0,3.5))+
  theme_bw()+
  labs(y = "Death Incidence / 1,000 people",x = "",
       fill = "Majority Teaching Method",
       title = "Death Incidence in the Fall Semester",
       caption = "Pairwise p-values come from Duncan pairwise compariso
```

```
n test") +
  theme(legend.position = "bottom",
        axis.text.x=element_blank())+team_theme+ scale_colour_manual(va
lues=col_theme)+scale_fill_manual(values=col_theme)
```



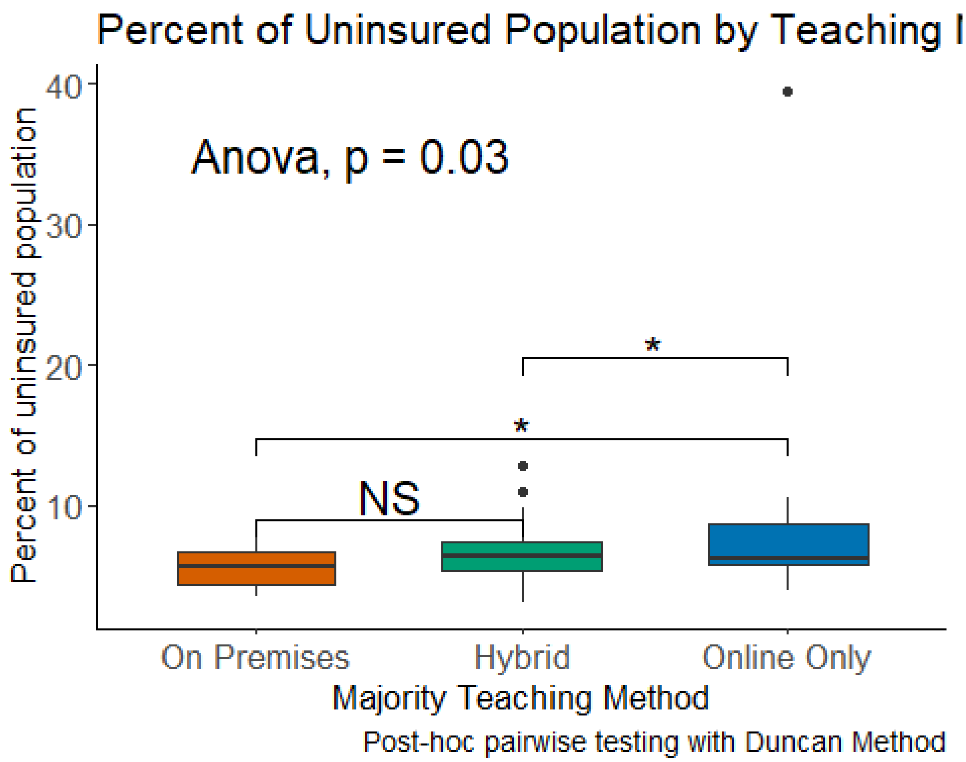
Appendix 3: Confounding Variables

There are also some other variables which may affect death incidence. We do some pairwise analysis based on teaching methods for these variables.

Uninsured Population

```
library(ggpubr)
library(PMCMRplus)
require(DescTools)

teaching_profile <- ohio_profile%>%
  inner_join(wide_teaching_enroll,by=c("County"="county"))
teaching_profile$major_teaching <- factor(teaching_profile$major_teachi
ng,levels = c("On Premises","Hybrid","Online Only"))

profile_major_teaching.aov <- aov(Percent.uninsured ~ major_teaching,da
ta = teaching_profile)
summary(profile_major_teaching.aov)
```

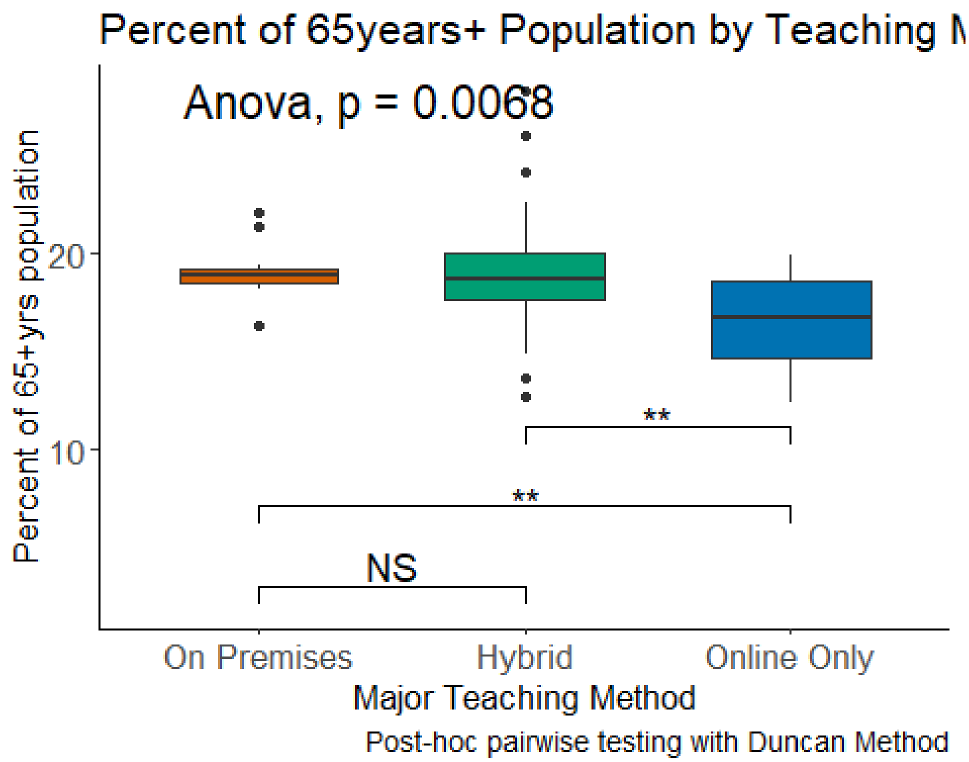
```
##                Df Sum Sq Mean Sq F value Pr(>F)
## major_teaching  2  108.8   54.38   3.645 0.0304 *
## Residuals      83 1238.2   14.92
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

# p-value of .012
stat.test <- PostHocTest(profile_major_teaching.aov, method = "duncan")
$major_teaching %>%
  as.data.frame()%>%
  rownames_to_column("group") %>%
  separate(group,"-", into = c("group1","group2")) %>%
  mutate(pval = round(pval,3),
         p = case_when(pval <= .01~ "**",
                       pval <= .05 ~ "*",
                       TRUE ~ "NS"))%>%
  select(group1, group2, pval, p)



teaching_profile%>%
  ggplot(aes(x=major_teaching,y=Percent.uninsured))+geom_boxplot(aes(fi
ll=major_teaching),width=0.6)+
  stat_compare_means(method = "anova",size=6,label.y.npc=0.85)+
  stat_pvalue_manual(stat.test, label = "p",y.position = 1, step.increa
se = 0.15,size = 6,bracket.nudge.y = 8)+
  labs(title="Percent of Uninsured Population by Teaching Method",x="Ma
jority Teaching Method",y="Percent of uninsured population",caption = "
Post-hoc pairwise testing with Duncan Method")+
  team_theme+theme(legend.position = "")+scale_fill_manual(values=col_t
heme)
```



Percentage of Senior

```
senior_major_teaching.aov <- aov(Percent.Population.65..yrs~ major_teac
hing,data = teaching_profile)

summary(senior_major_teaching.aov)

##                 Df Sum Sq Mean Sq F value  Pr(>F)
## major_teaching  2   61.8   30.88   5.297 0.00684 **
## Residuals      83  483.9    5.83
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

# p-value of .012
stat.test <- PostHocTest(senior_major_teaching.aov, method = "duncan")
$major_teaching %>%
  as.data.frame()%>%
  rownames_to_column("group") %>%
  separate(group,"-", into = c("group1","group2")) %>%
  mutate(pval = round(pval,3),
         p = case_when(pval <= .01~ "**",
                       pval <= .05 ~ "*",
                       TRUE ~ "NS"))%>%
  select(group1, group2, pval, p)

teaching_profile%>%
  ggplot(aes(x=major_teaching,y=Percent.Population.65..yrs))+geom_boxpl
```

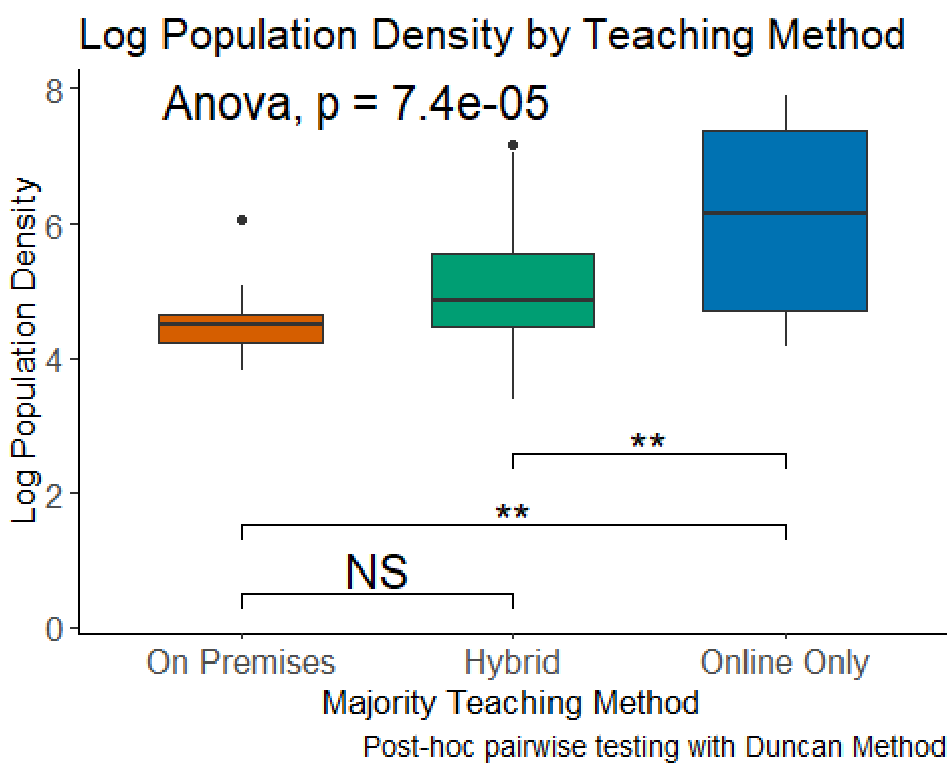
```
ot(aes(fill=major_teaching),width=0.6)+
  stat_compare_means(method = "anova",size=6,label.y.npc=0.95)+
  stat_pvalue_manual(stat.test, label = "p",y.position = 1, step.increa
se = 0.15,size = 5,bracket.nudge.y = 2)+
  labs(title="Percent of 65years+ Population by Teaching Method",x="Maj
or Teaching Method",y="Percent of 65+yrs population",fill="Majority Tea
ching Method",caption = "Post-hoc pairwise testing with Duncan Method")
+team_theme+theme(legend.position = "")+scale_fill_manual(values=col_th
eme)
```



Log Population Density

```
pop_den_major_teaching.aov <- aov(log(Population.density)~ major_teachi
ng,data = teaching_profile)

summary(pop_den_major_teaching.aov)

##                 Df Sum Sq Mean Sq F value   Pr(>F)
## major_teaching  2  17.04   8.520   10.69 7.41e-05 ***
## Residuals      83  66.16   0.797
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

# p-value of .012
stat.test <- PostHocTest(pop_den_major_teaching.aov, method = "duncan")
$major_teaching %>%
  as.data.frame()%>%
  rownames_to_column("group") %>%
```

```
  separate(group,"-", into = c("group1","group2")) %>%
  mutate(pval = round(pval,3),
         p = case_when(pval <= .01~ "**",
                       pval <= .05 ~ "*",
                       TRUE ~ "NS"))%>%
  select(group1, group2, pval, p)


teaching_profile%>%
  ggplot(aes(x=major_teaching,y=log(Population.density)))+geom_boxplot
(aes(fill=major_teaching),width=0.6)+
  stat_compare_means(method = "anova",size=6,label.y.npc=0.95)+
  stat_pvalue_manual(stat.test, label = "p",y.position = 1, step.increa
se = 0.15,size = 6,bracket.nudge.y = -0.5)+
  labs(title="Log Population Density by Teaching Method",x="Majority Te
aching Method",y="Log Population Density",caption = "Post-hoc pairwise
testing with Duncan Method")+
  team_theme+theme(legend.position = "")+scale_fill_manual(values=col_t
heme)
```



These confounding variables show significant difference for different teahcing methods.

Appendix 4: Exponential growth model

We construct the exponential growth in order to better measure the state of pandemic.

Data process

```
cases_slope <- read.csv("county_splines.csv", header = T)%>%
  select(COUNTY,DATE,POPULATION,CUMDEATHS,log_tot_deaths,tot.slope,NEWD
EATHS,rev_NEWDEATHS,log_new_deaths,new.slope)
# SHIFT THE DATE!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
cases_slope$DATE <- as.Date(cases_slope$DATE)-24
# get majority teaching method wide_teaching_enroll
cases_slope_teach <-death_teaching%>%
  select(-DATE,-POPULATION,-CUMDEATHS,-NEWDEATHS)%>%
  distinct()%>%
  right_join(cases_slope,by=c("COUNTY"))%>%
  filter(DATE>as.Date("2020-01-23"))
write.csv(cases_slope_teach,"cases_slope_teach.csv",row.names = F)
## ordering the teaching method factor to ensure the color order
cases_slope_teach$major_teaching <- factor(cases_slope_teach$major_teac
hing,levels = c("On Premises","Hybrid","Online Only"))
cases_slope_teach$DATE <- as.Date(cases_slope_teach$DATE)
```

Select Max B

Max B during the fall semester is used to meaure how severe the pandemic is in the county.

```
maxB1 <- cases_slope_teach%>%
  group_by(COUNTY)%>%
  filter(DATE >= as.Date("2020-08-18") & DATE<=as.Date("2020-12-15
"))%>%
  summarise(max_B1 = max(new.slope), .groups = 'drop')
avgB1 <- cases_slope_teach%>%
  group_by(COUNTY)%>%
  filter(DATE >= as.Date("2020-08-18") & DATE<=as.Date("2020-12-15
"))%>%
  summarise(avg_B1 = mean(new.slope), .groups = 'drop')
## avg3w_B0 ## average B0 of the first 3 weeks of school reopening
## avg1w_2w_B0 ## OR average B0s between  2020-08-18 -7days and +14days
 [before the rate bounce back around the dashed line]
## avg3w_bf_B0 ## OR average B0s between  2020-08-18 -21days and 2020-0
8-18 [before the rate bounce back around the dashed line]
avgB0 <- cases_slope_teach%>%
  group_by(COUNTY)%>%
  filter(DATE > as.Date("2020-08-18") & DATE<as.Date(major_opendate)+2
1)%>%
  summarise(avg3w_B0 = mean(new.slope), .groups = 'drop')%>%
  left_join(cases_slope_teach%>%
  group_by(COUNTY)%>%
```

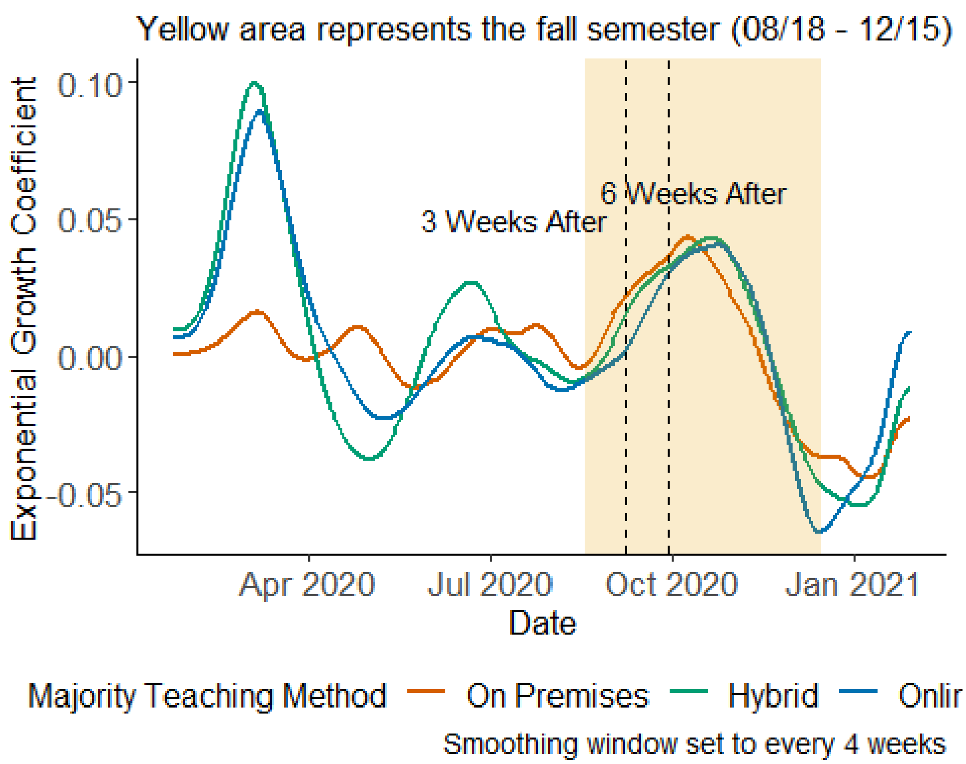
```
  filter(DATE > as.Date("2020-08-18")-7 & DATE<as.Date("2020-08-18")+1
4)%>%
  summarise(avg1w_2w_B0 = mean(new.slope)),by="COUNTY", .groups = 'drop
')%>%
  left_join(cases_slope_teach%>%
  group_by(COUNTY)%>%
  filter(DATE < as.Date("2020-08-18") & DATE>=as.Date("2020-08-18")-2
1)%>%
  summarise(avg3w_bf_B0 = mean(new.slope)),by="COUNTY", .groups = 'drop
')
#  B0 and B1
B0B1 <- death_teaching%>%
  distinct(COUNTY,POPULATION,NCHS.Urban.Rural.Status,Population.densit
y)%>%
  left_join(maxB1,by="COUNTY")%>%
  left_join(wide_teaching_enroll, by = c("COUNTY" = "county"))%>%
  left_join(avgB1,by="COUNTY")%>%
  left_join(avgB0,by="COUNTY") %>%
  left_join(avg_mobility,by="COUNTY")
## ordering the teaching method factor to ensure the color order
B0B1$major_teaching <- factor(B0B1$major_teaching,levels = c("On Premis
es","Hybrid","Online Only"))
```

Aggregate counties by teaching method

We aggregate the growth coefficient based on the major teaching method used, and draw a time series plot for different teahcing methods.

```
cases_slope_teach_agg <- cases_slope_teach %>%
  drop_na(major_teaching)%>%
  group_by(DATE, major_teaching) %>%
  summarise(total_new_deaths = sum(rev_NEWDEATHS), .groups = "drop")
 %>%
  mutate(log_new_deaths = log(total_new_deaths + 1)) %>%
  group_by(major_teaching) %>%
  mutate(smooth.spline = smooth.spline(DATE,log_new_deaths,df = 398/28)
$y,
         B = predict(smooth.spline(DATE,log_new_deaths,df = 398/28),der
iv = 1)$y,B2 = predict(smooth.spline(DATE,log_new_deaths,df = 398/28),d
eriv = 2)$y)
week3_after_start <- as.Date("2020/08/18") + 21

####
ggplot(cases_slope_teach_agg, aes(x = DATE, color = major_teaching)) +
  geom_line(aes(y = B), size = 1) +
  geom_rect(data = cases_slope_teach_agg[1,],
            aes(xmin=as.Date("2020/08/18"), xmax=as.Date("2020/12/15"),
                ymin=-Inf,ymax=Inf),
            color = NA,alpha=0.2, show.legend = F, fill = "#E69F00") +
  geom_vline(xintercept = week3_after_start, lty = 2) +
```

```
  annotate("text",label = "3 Weeks After",
           x = week3_after_start, y = .05, hjust = 1.1)+
  geom_vline(xintercept = as.Date("2020/08/18")+42, lty = 2) +
  annotate("text",label = "6 Weeks After",
           x = as.Date("2020/08/18")+130, y = .06, hjust = 1.3)+
  labs(x = "Date", y = "Exponential Growth Coefficient",
       color = "Majority Teaching Method",
       caption = "Smoothing window set to every 4 weeks",
       subtitle = "Yellow area represents the fall semester (08/18 - 12
/15)") +
  theme(legend.position = "bottom")+team_theme+scale_color_manual(value
s=col_theme)
```



Difference in B's

We capture the B values in some specific time point.

```
B0w <- cases_slope_teach%>%
  filter(DATE==as.Date("2020-08-18"))%>%
  drop_na(major_teaching)%>%
  rename(new.slope0w=new.slope)
B3w <- cases_slope_teach%>%
  filter(DATE==as.Date("2020-08-18")+21)%>%
  drop_na(major_teaching)%>%
  rename(new.slope3w=new.slope)
B6w <- cases_slope_teach%>%
  filter(DATE==as.Date("2020-08-18")+42)%>%
```

```
  drop_na(major_teaching)%>%
  rename(new.slope6w=new.slope)
B1w <- cases_slope_teach%>%
  filter(DATE==as.Date("2020-08-18")+7)%>%
  drop_na(major_teaching)%>%
  rename(new.slope1w=new.slope)
B2w <- cases_slope_teach%>%
  filter(DATE==as.Date("2020-08-18")+14)%>%
  drop_na(major_teaching)%>%
  rename(new.slope2w=new.slope)
B4w <- cases_slope_teach%>%
  filter(DATE==as.Date("2020-08-18")+28)%>%
  drop_na(major_teaching)%>%
  rename(new.slope4w=new.slope)
B5w <- cases_slope_teach%>%
  filter(DATE==as.Date("2020-08-18")+35)%>%
  drop_na(major_teaching)%>%
  rename(new.slope5w=new.slope)
B7w <- cases_slope_teach%>%
  filter(DATE==as.Date("2020-08-18")+49)%>%
  drop_na(major_teaching)%>%
  rename(new.slope7w=new.slope)

Bm1w <- cases_slope_teach%>%
  filter(DATE==as.Date("2020-08-18")-7)%>%
  drop_na(major_teaching)%>%
  rename(new.slopem1w=new.slope)
Bm2w <- cases_slope_teach%>%
  filter(DATE==as.Date("2020-08-18")-14)%>%
  drop_na(major_teaching)%>%
  rename(new.slopem2w=new.slope)
Bm3w <- cases_slope_teach%>%
  filter(DATE==as.Date("2020-08-18")-21)%>%
  drop_na(major_teaching)%>%
  rename(new.slopem3w=new.slope)

avg_mobi_0w3w <- case_mobility%>%
  left_join(major_reopening,by=c("COUNTY"))%>%
  group_by(COUNTY)%>%
  filter(DATE >= as.Date("2020-08-18")& DATE <as.Date("2020-08-18") + 2
1)%>%
  summarise(avg_full_work_prob = mean(full_work_prop_7d))
avg_mobi_3w6w <- case_mobility%>%
  left_join(major_reopening,by=c("COUNTY"))%>%
  group_by(COUNTY)%>%
  filter(DATE >= as.Date("2020-08-18")+ 21 & DATE <=as.Date("2020-08-18
") + 42)%>%
  summarise(avg2_full_work_prob = mean(full_work_prop_7d))

# Before slope mobility
```

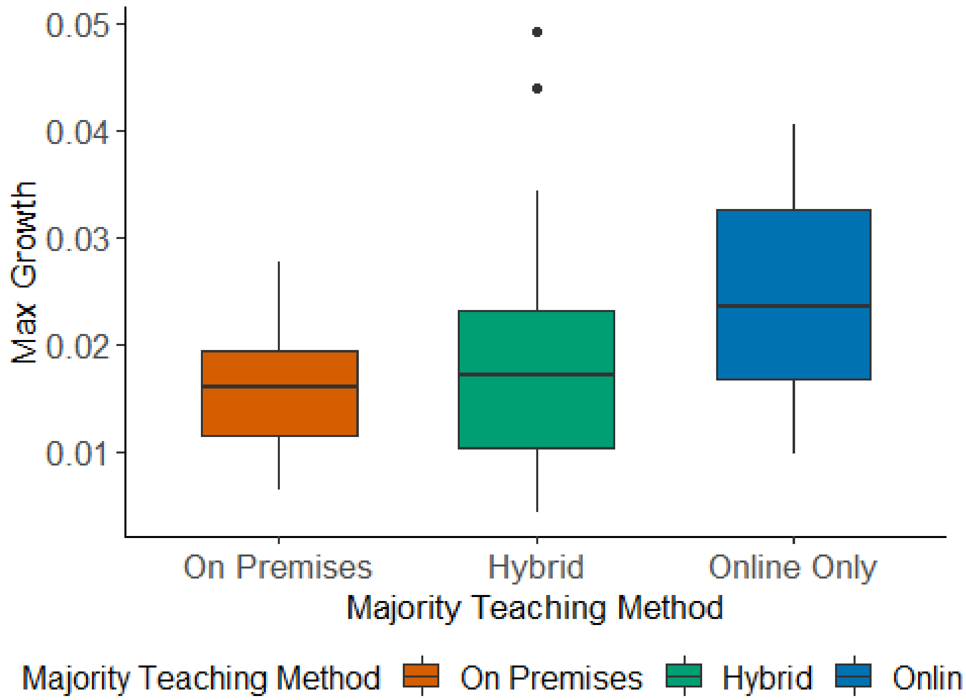
```r
avg_mobi_m1w2w <- case_mobility%>%
  left_join(major_reopening,by=c("COUNTY"))%>%
  group_by(COUNTY)%>%
  filter(DATE >= as.Date("2020-08-18")-7 & DATE <=as.Date("2020-08-18")
 + 14)%>%
  summarise(avg_full_work_prob_m1w2w = mean(full_work_prop_7d))

avg_mobi_m2w1w <- case_mobility%>%
  left_join(major_reopening,by=c("COUNTY"))%>%
  group_by(COUNTY)%>%
  filter(DATE >= as.Date("2020-08-18")-14 & DATE <=as.Date("2020-08-18
") + 7)%>%
  summarise(avg_full_work_prob_m2w1w = mean(full_work_prop_7d))

avg_mobi_m3w0w <- case_mobility%>%
  left_join(major_reopening,by=c("COUNTY"))%>%
  group_by(COUNTY)%>%
  filter(DATE >= as.Date("2020-08-18")-21 & DATE <=as.Date("2020-08-18
"))%>%
  summarise(avg_full_work_prob_m3w0w = mean(full_work_prop_7d))

# After slope mobility
avg_mobi_1w4w <- case_mobility%>%
  left_join(major_reopening,by=c("COUNTY"))%>%
  group_by(COUNTY)%>%
  filter(DATE >= as.Date("2020-08-18")+7 & DATE <=as.Date("2020-08-18")
+28)%>%
  summarise(avg_full_work_prob_1w4w = mean(full_work_prop_7d))

avg_mobi_2w5w <- case_mobility%>%
  left_join(major_reopening,by=c("COUNTY"))%>%
  group_by(COUNTY)%>%
  filter(DATE >= as.Date("2020-08-18")+14 & DATE <=as.Date("2020-08-18
")+35)%>%
  summarise(avg_full_work_prob_2w5w = mean(full_work_prop_7d))

avg_mobi_4w7w <- case_mobility%>%
  left_join(major_reopening,by=c("COUNTY"))%>%
  group_by(COUNTY)%>%
  filter(DATE >= as.Date("2020-08-18")+28 & DATE <=as.Date("2020-08-18
")+49)%>%
  summarise(avg_full_work_prob_4w7w = mean(full_work_prop_7d))

# Construct B_diff
B_diff <- B6w[,c(1:9,13,20)]%>%
  left_join(B3w%>%select(COUNTY,new.slope3w),by="COUNTY")%>%
  left_join(B0w%>%select(COUNTY,new.slope0w),by="COUNTY")%>%
  left_join(B1w%>%select(COUNTY,new.slope1w),by="COUNTY")%>%
  left_join(B2w%>%select(COUNTY,new.slope2w),by="COUNTY")%>%
```

```
  left_join(B4w%>%select(COUNTY,new.slope4w),by="COUNTY")%>%
  left_join(B5w%>%select(COUNTY,new.slope5w),by="COUNTY")%>%
  left_join(B7w%>%select(COUNTY,new.slope7w),by="COUNTY")%>%
  left_join(Bm1w%>%select(COUNTY,new.slopem1w),by="COUNTY")%>%
  left_join(Bm2w%>%select(COUNTY,new.slopem2w),by="COUNTY")%>%
  left_join(Bm3w%>%select(COUNTY,new.slopem3w),by="COUNTY")%>%
  mutate(new.slope.diff = new.slope3w-new.slope0w,
         new.slope.diff2 = new.slope6w-new.slope3w,
         new.slope.diff2m1 = new.slope2w-new.slopem1w,
         new.slope.diff1m2 = new.slope1w-new.slopem2w,
         new.slope.diff0m3 = new.slope0w-new.slopem3w,
         new.slope.diff52 = new.slope5w-new.slope2w,
         new.slope.diff41 = new.slope4w-new.slope1w,
         new.slope.diff74 = new.slope7w-new.slope4w)%>%
  left_join(avg_mobi_0w3w,by="COUNTY")%>%
  left_join(avg_mobi_3w6w,by="COUNTY")%>%
  left_join(avg_mobi_m1w2w,by="COUNTY")%>%
  left_join(avg_mobi_m2w1w,by="COUNTY")%>%
  left_join(avg_mobi_m3w0w,by="COUNTY")%>%
  left_join(avg_mobi_1w4w,by="COUNTY")%>%
  left_join(avg_mobi_2w5w,by="COUNTY")%>%
  left_join(avg_mobi_4w7w,by="COUNTY")
B_diff$major_teaching <- factor(B_diff$major_teaching,levels = c("On Pr
emises","Hybrid","Online Only"))
```

Distribution of Maximum Growth Coefficient for All Counties by Majority Teaching posture

Online Only counties have highest max B value, which is not what we expected.

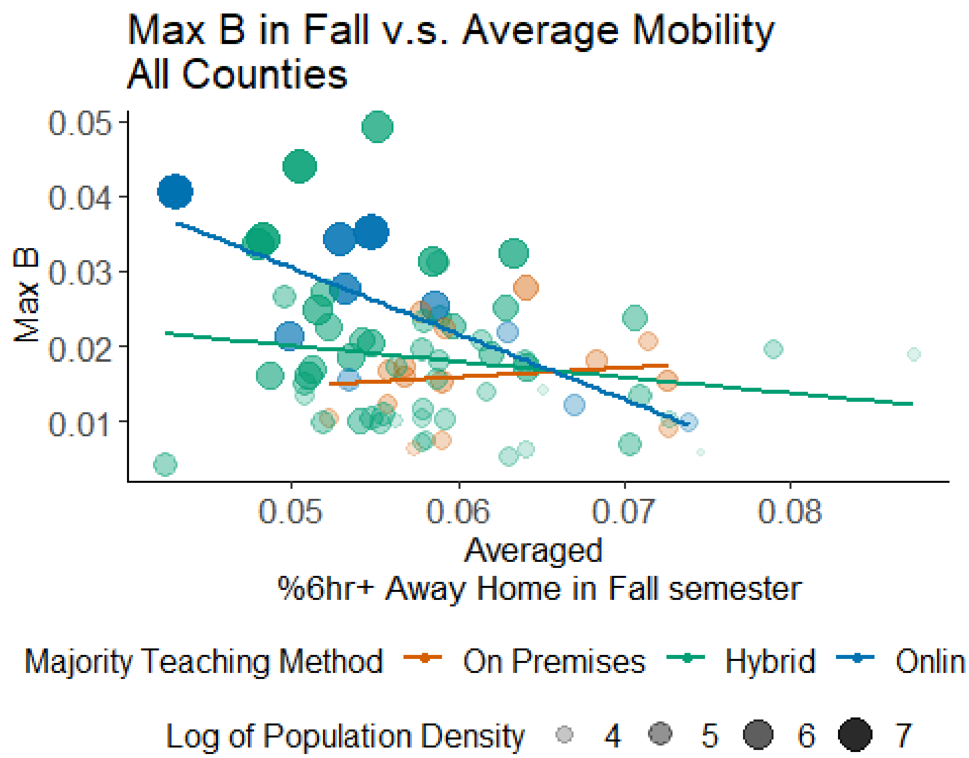
```
na.omit(B0B1)%>%
  ggplot(aes(x=major_teaching,y=max_B1))+geom_boxplot(aes(fill=major_te
aching),width=0.6)+
  labs(title="",x="Majority Teaching Method",y="Max Growth",fill="Major
ity Teaching Method")+
  team_theme+theme(legend.position = "bottom")+scale_fill_manual(values
=col_theme)
```



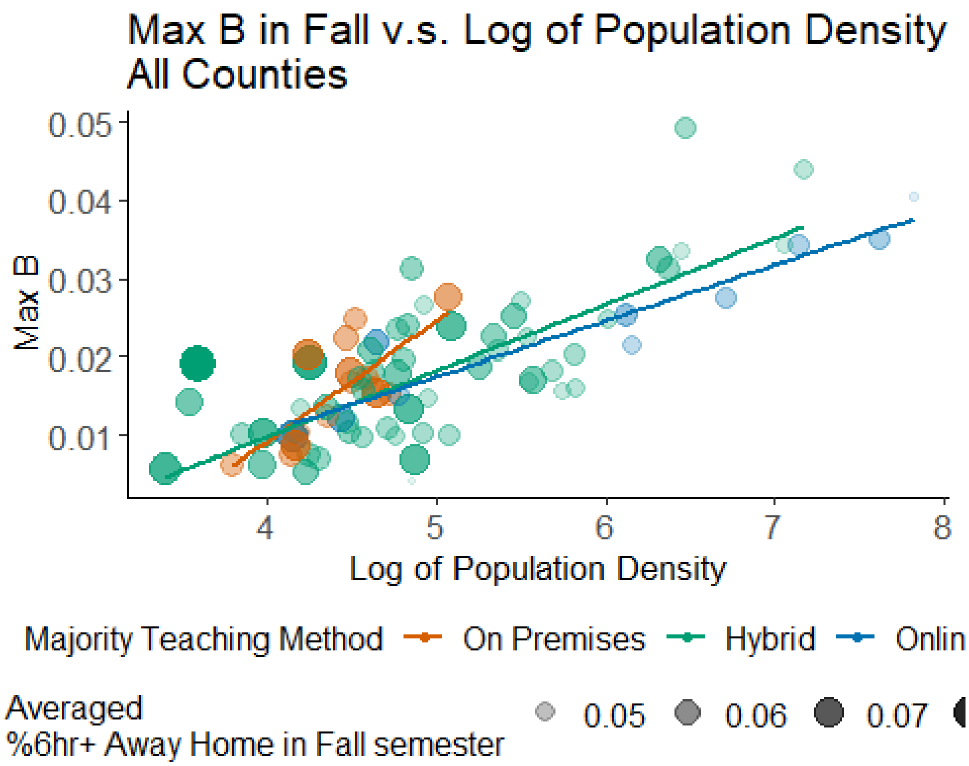
Max B vs. Mobility and Population Density for All Counties

The following plots show how Max Growth Coefficient correlated with Mobility and Log Population Density.

```
na.omit(B0B1)%>%
  drop_na(major_teaching)%>%
  ggplot(aes(x=avg_full_work_prob,y=max_B1,group=major_teaching,color=m
ajor_teaching))+
  geom_point(aes(size=log(Population.density),alpha=log(Population.dens
ity)))+
  geom_smooth(method = "lm", se=F, formula = y ~ x,alpha=0.1)+
  labs(y="Max B",x="Averaged \n%6hr+ Away Home in Fall semester",title=
"Max B in Fall v.s. Average Mobility \nAll Counties",color="Majority Te
aching Method",size = "Log of Population Density",alpha= "Log of Popula
tion Density" )+
  team_theme+theme(legend.position = "bottom")+
  scale_color_manual(values=col_theme)
```




```
na.omit(B0B1)%>%
  drop_na(major_teaching)%>%
  ggplot(aes(x=log(Population.density),y=max_B1,group=major_teaching,co
lor=major_teaching))+
  geom_point(aes(size=avg_full_work_prob,alpha=avg_full_work_prob))+
  geom_smooth(method = "lm", se=F, formula = y ~ x,alpha=0.1)+
  labs(y="Max B",x="Log of Population Density",title="Max B in Fall v.
s. Log of Population Density \nAll Counties",color="Majority Teaching M
ethod",size = "Averaged \n%6hr+ Away Home in Fall semester",alpha= "Ave
raged \n%6hr+ Away Home in Fall semester" )+team_theme+theme(legend.pos
ition = "bottom")+
  scale_color_manual(values=col_theme)
```



Appendix 5: Micropolitan Counties

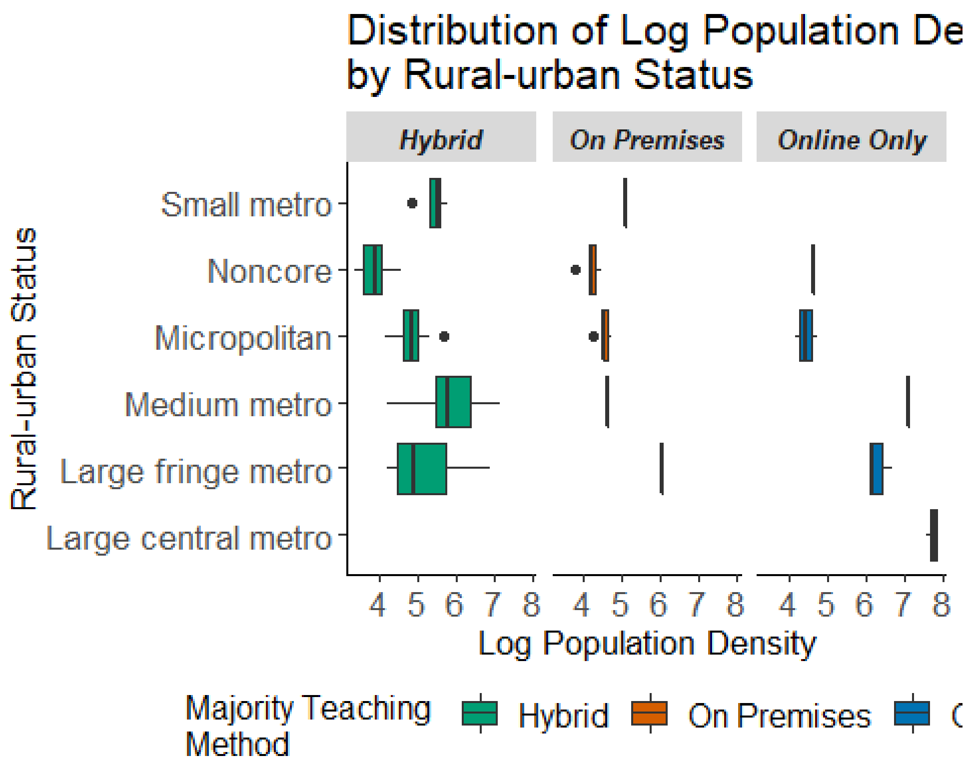
We reduce our sample to micropolitan counties in order to reduce the effect from other confounders. This section gives plots related to micropolitan coungties.

Distribution of Log Population Density by Rural-Urban Status colored by Majority Teaching posture

Micropolitan counties show similar log population density and have data for all three teaching methods.

```
# Pop density vs RURAL
ohio_profile%>%
  left_join(wide_teaching_enroll[,c("county","major_teaching")],
            by = c("County" = "county"))%>%
  drop_na(major_teaching)%>%
  ggplot(aes(y=NCHS.Urban.Rural.Status,x=log(Population.density),
             fill=major_teaching))+
  facet_grid(~major_teaching)+
  geom_boxplot()+
  labs(fill="Majority Teaching \nMethod",
       size="Averaged \n%6hr+ Away Home",
       title="Distribution of Log Population Density \nby Rural-urban S
tatus",
       x="Log Population Density", y= "Rural-urban Status")+
```

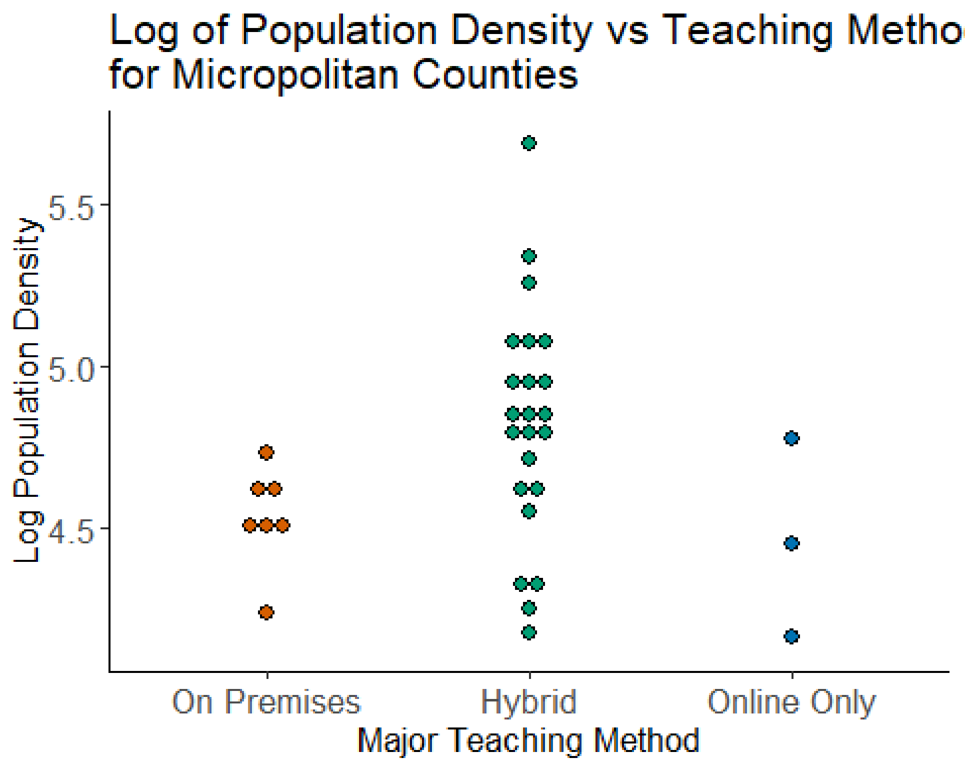
```
  team_theme+
  scale_fill_manual(values=col_theme)+
  theme(legend.position = "bottom")
```



Dotplots of Log Population Density for Micropolitan counties

The dot plots show that the distributions of population density for micropolitan counties taking On Premises and Online Only method are quite similar, which means that it is reasonable to compare these two type of counties.

```
ohio_profile%>%
  filter(NCHS.Urban.Rural.Status=="Micropolitan")%>%
 left_join(B0B1%>%select(COUNTY,major_teaching),by=c("County"="COUNTY
"))%>%
  ggplot(aes(x=major_teaching))+
  geom_dotplot(aes(y=log(Population.density),fill=major_teaching),binax
is='y', stackdir='center')+team_theme+guides(fill=FALSE)+labs(y="Log Po
pulation Density",x="Major Teaching Method",title="Log of Population De
nsity vs Teaching Method \nfor Micropolitan Counties")+scale_fill_manua
l(values=col_theme)
```



Distribution of Maximum Growth Coefficient Micropolitan Counties

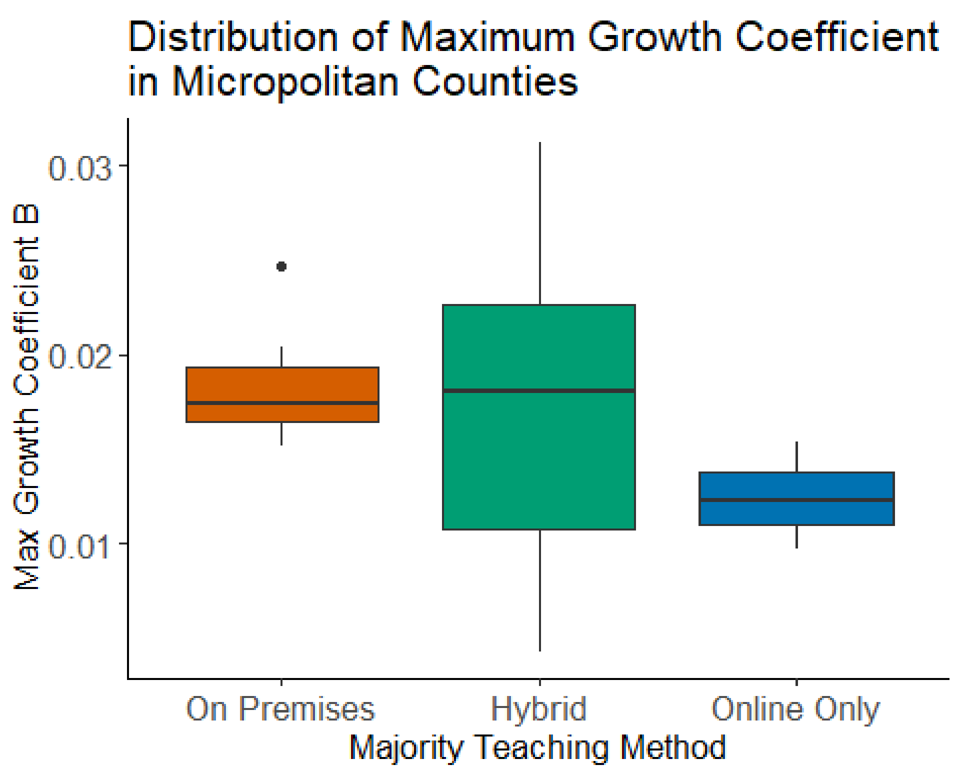
On Premises counties have significant higher maximum growth coefficient than online only counties.

```
##### Micropolitan counties
maxB_major_teaching.aov <- aov(max_B1 ~ major_teaching,data = na.omit(B
0B1)%>%
  filter(NCHS.Urban.Rural.Status=="Micropolitan"))
summary(maxB_major_teaching.aov)
```

```
##                 Df    Sum Sq   Mean Sq F value Pr(>F)
## major_teaching   2 0.0000764 3.821e-05   1.002   0.38
## Residuals       28 0.0010679 3.814e-05
```

```
# p-value of .012
stat.test <- PostHocTest(maxB_major_teaching.aov, method = "duncan")$ma
jor_teaching %>%
  as.data.frame()%>%
  rownames_to_column("group") %>%
  separate(group,"-", into = c("group1","group2")) %>%
  mutate(pval = round(pval,3),
         p = case_when(pval <= .01~ "**",
                       pval <= .05 ~ "*",
                       TRUE ~ "NS"))%>%
  select(group1, group2, pval, p)
```

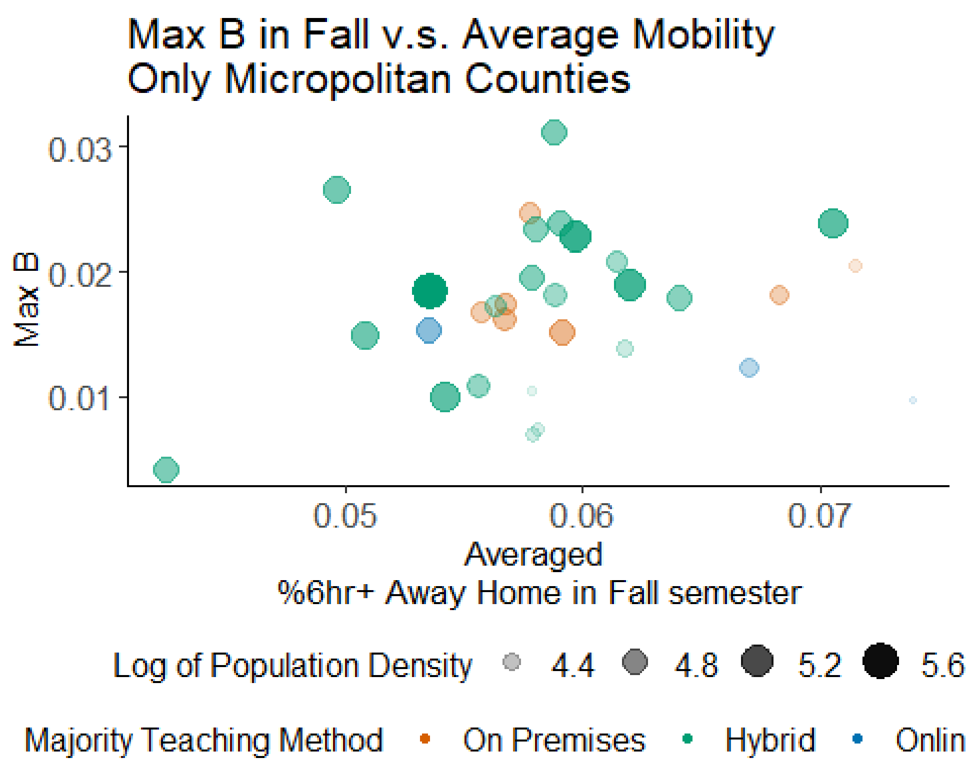
```
na.omit(B0B1)%>%
  filter(NCHS.Urban.Rural.Status=="Micropolitan")%>%
  drop_na(major_teaching)%>%
  ggplot(aes(x=major_teaching,y=max_B1))+
  geom_boxplot(aes(fill=major_teaching))+
  #ylim(c(0,0.05))+
  #stat_compare_means(method = "anova",size=6,label.y.npc=0.96,label.x.
npc = 0.4)+
  #stat_pvalue_manual(stat.test, label = "p",y.position = 0.03, step.in
crease = 0.15,
   #                  size = 6,bracket.nudge.y = 0.001)+
  team_theme+
  theme(legend.position = " ")+
  labs(y="Max Growth Coefficient B",x="Majority Teaching Method",title=
"Distribution of Maximum Growth Coefficient \nin Micropolitan Counties
",
       fill="Majority Teaching Method")+
  scale_fill_manual(values=col_theme)
```



Max B vs. Mobility and Population Density in Micropolitan Counties

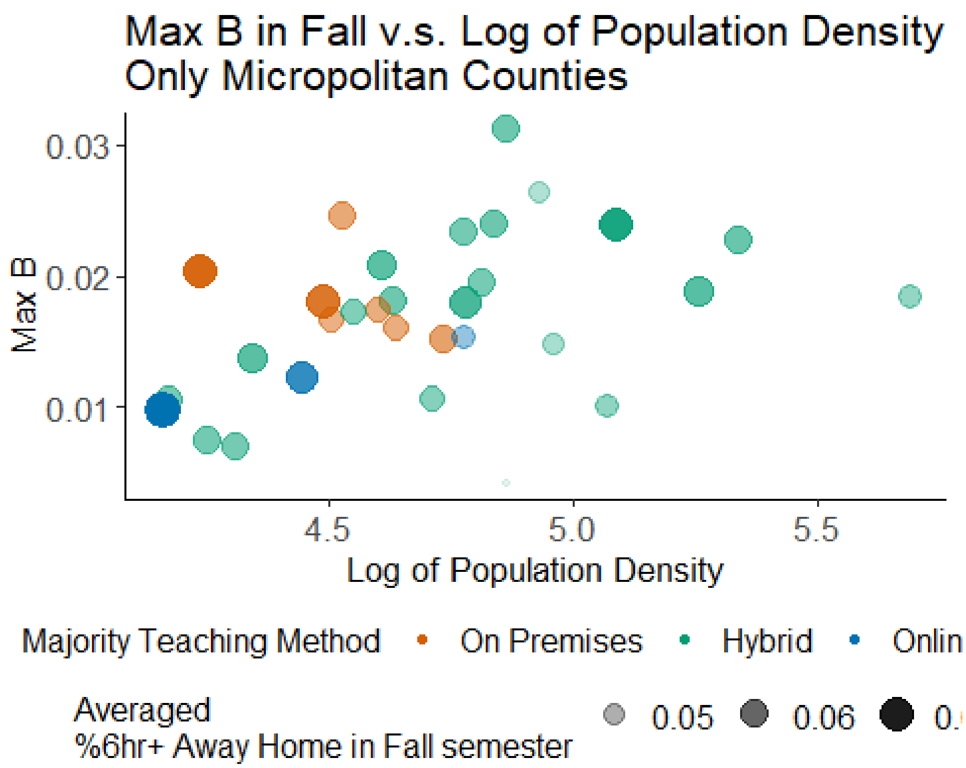
These plots show that after blocking data to micropolitan counties, the relationship between growth coefficient and mobility & log population density is not so obvious.

```
na.omit(B0B1)%>%
  filter(NCHS.Urban.Rural.Status=="Micropolitan")%>%
  drop_na(major_teaching)%>%
  ggplot(aes(x=avg_full_work_prob,y=max_B1,group=major_teaching,color=m
ajor_teaching))+
  geom_point(aes(size=log(Population.density),alpha=log(Population.dens
ity)))+
  #geom_smooth(method = "lm", se=F, formula = y ~ x,alpha=0.1)+
  labs(y="Max B",x="Averaged \n%6hr+ Away Home in Fall semester",
       title="Max B in Fall v.s. Average Mobility \nOnly Micropolitan C
ounties",
       color="Majority Teaching Method",
       size = "Log of Population Density",
       alpha= "Log of Population Density" )+
  team_theme+theme(legend.position = "bottom")+
  scale_color_manual(values=col_theme)+
  guides(
    size = guide_legend(order = 1),
    alpha = guide_legend(order = 1),
    fill = guide_legend(order = 0)
  )
```




```
######
na.omit(B0B1)%>%
  filter(NCHS.Urban.Rural.Status=="Micropolitan")%>%
  drop_na(major_teaching)%>%
  ggplot(aes(x=log(Population.density),y=max_B1,group=major_teaching,co
```

```
lor=major_teaching))+
  geom_point(aes(size=avg_full_work_prob,alpha=avg_full_work_prob))+
  #geom_smooth(method = "lm", se=F, formula = y ~ x,alpha=0.1)+
  labs(y="Max B",x="Log of Population Density",
       title="Max B in Fall v.s. Log of Population Density \nOnly Micro
politan Counties",
       color="Majority Teaching Method",
       size = "Averaged \n%6hr+ Away Home in Fall semester",
       alpha= "Averaged \n%6hr+ Away Home in Fall semester" )+
  team_theme+theme(legend.position = "bottom")+
  scale_color_manual(values=col_theme)
```



Change in Growth vs Mobility and Log Population Density

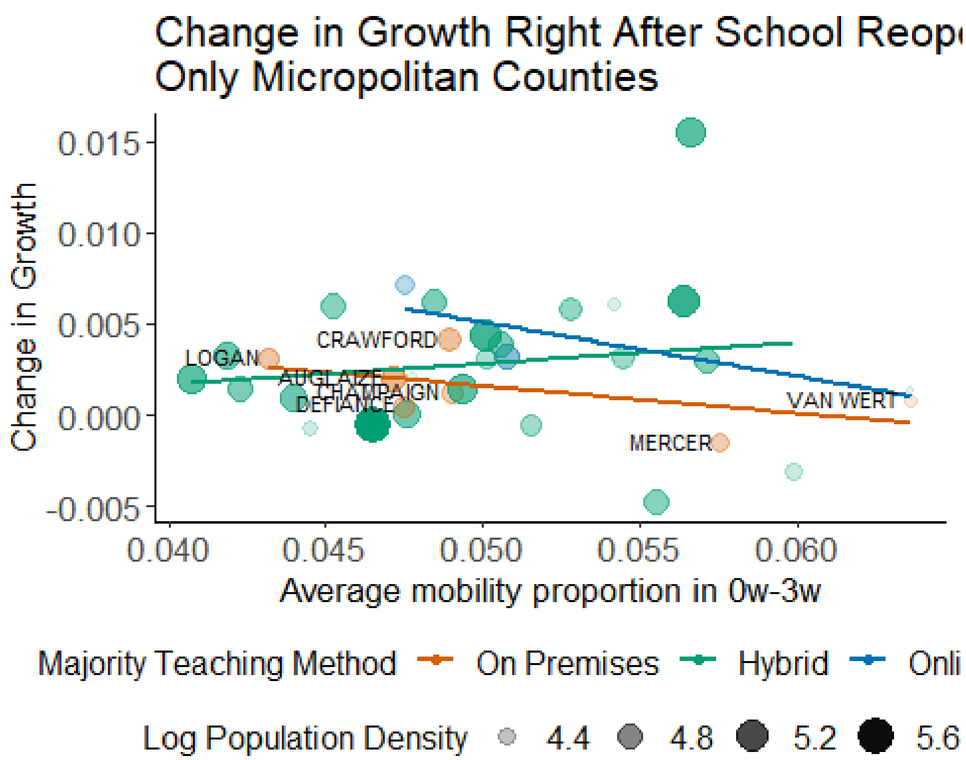
The follwing plots show the change in growth right after school and three weeks later and we observed obvious shifting of red line.

```
B_diff_micro <- B_diff%>%
  drop_na(major_teaching)%>%
  filter(NCHS.Urban.Rural.Status=="Micropolitan") %>%
  mutate(acc = new.slope.diff2 - new.slope.diff)
```

Mobility

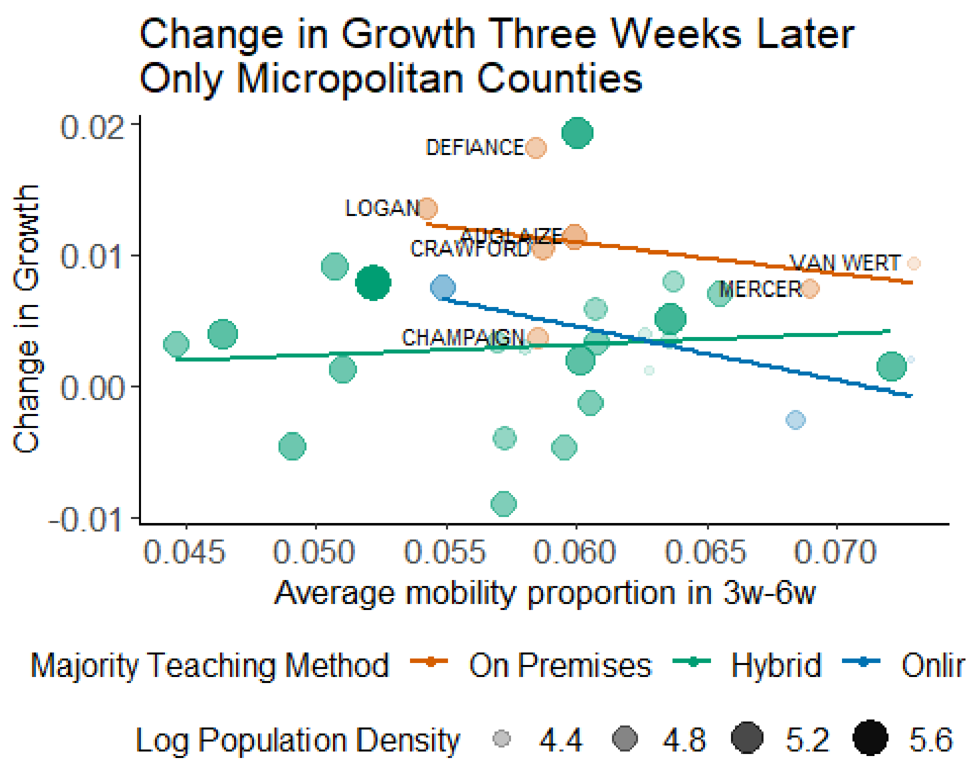
```
B_diff_micro%>%
  ggplot(aes(x=avg_full_work_prob,y=new.slope.diff,group=major_teachin
g,color=major_teaching))+geom_point(aes(size=log(Population.density),al
```

```
pha=log(Population.density)))+geom_smooth(method = "lm", se=F, formula
= y ~ x,alpha=0.1)+
  labs(y="Change in Growth",x="Average mobility proportion in 0w-3w",
       title="Change in Growth Right After School Reopen\nOnly Micropol
itan Counties",
       color="Majority Teaching Method",
       size = "Log Population Density",
       alpha= "Log Population Density")+
  scale_color_manual(values=col_theme)+theme(legend.position = "bottom
")+team_theme+geom_text(data =B_diff_micro%>%filter(major_teaching=="On
 Premises"),aes(label=COUNTY),color='black',size=3,hjust=1.1, vjust=0.
3,size=6)
```



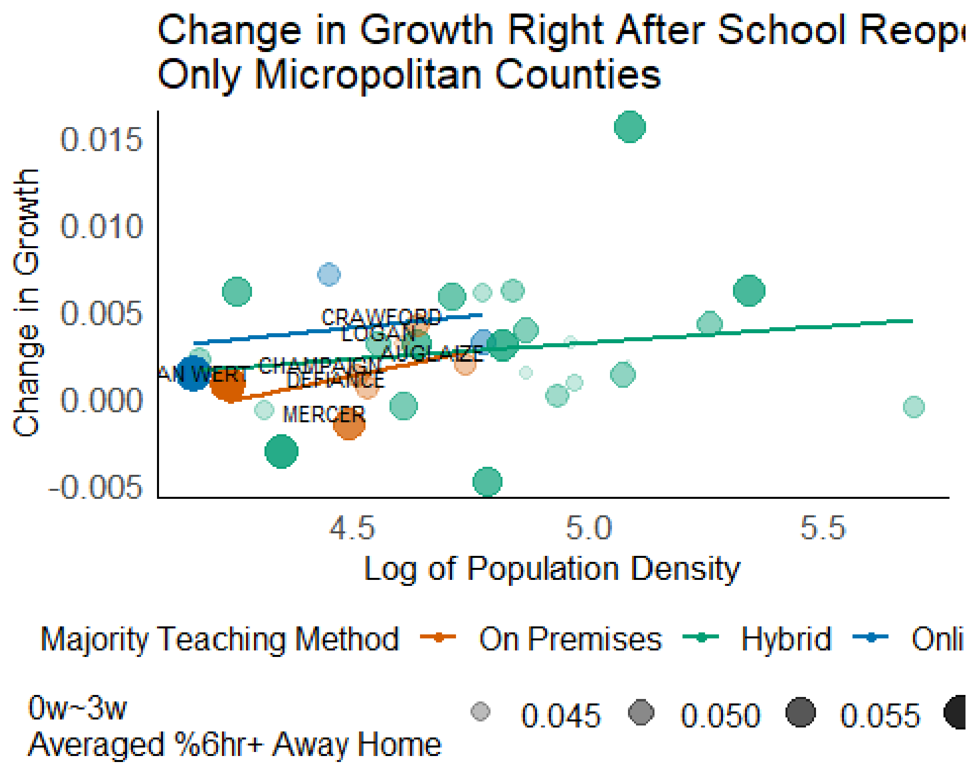

```
B_diff_micro%>%
  ggplot(aes(x=avg2_full_work_prob,y=new.slope.diff2,group=major_teachi
ng,color=major_teaching))+geom_point(aes(size=log(Population.density),a
lpha=log(Population.density)))+geom_smooth(method = "lm", se=F, formula
 = y ~ x,alpha=0.1)+
  labs(y="Change in Growth",x="Average mobility proportion in 3w-6w",
       title="Change in Growth Three Weeks Later\nOnly Micropolitan Cou
nties",
       color="Majority Teaching Method",
       size ="Log Population Density",
       alpha= "Log Population Density")+
  scale_color_manual(values=col_theme)+theme(legend.position = "bottom
")+team_theme+geom_text(data =B_diff_micro%>%filter(major_teaching=="On
```

```
 Premises"),aes(label=COUNTY),color='black',size=3,hjust=1.1, vjust=0.
3,size=6)
```

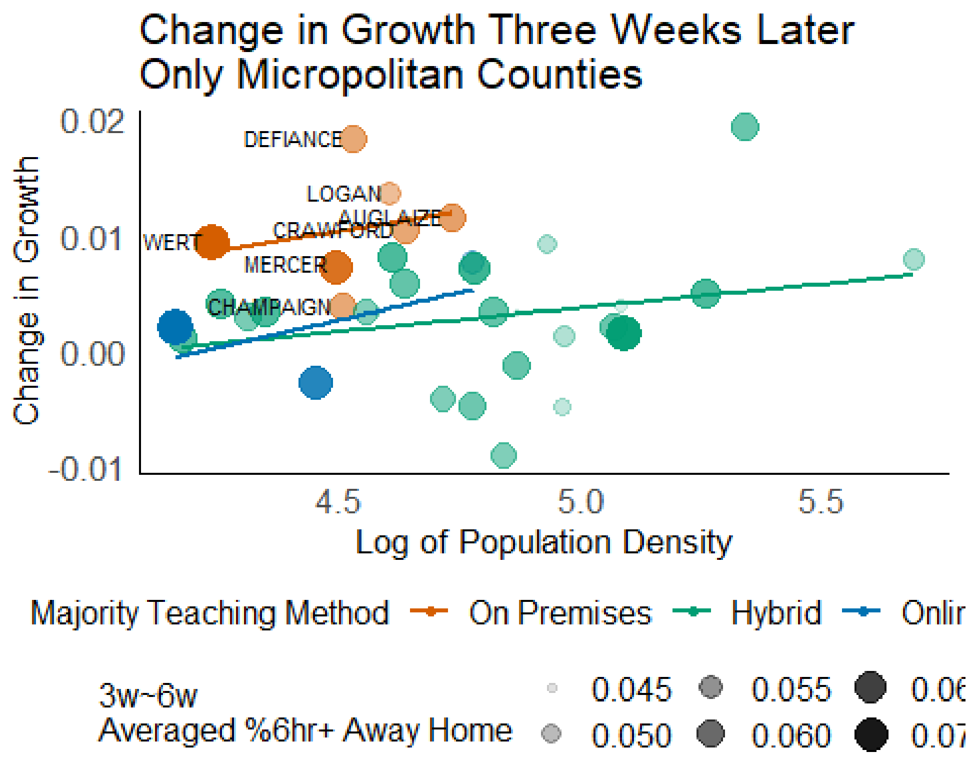


Log Population Density

```
B_diff_micro%>%
  ggplot(aes(x=log(Population.density),y=new.slope.diff,group=major_tea
ching,color=major_teaching))+geom_point(aes(size=avg_full_work_prob,alp
ha=avg_full_work_prob))+geom_smooth(method = "lm", se=F, formula = y ~
x,alpha=0.1)+theme_minimal()+team_theme+
  labs(y="Change in Growth",x="Log of Population Density",
       title="Change in Growth Right After School Reopen\nOnly Micropol
itan Counties",
       color="Majority Teaching Method",
       size = "0w~3w\nAveraged %6hr+ Away Home",
       alpha= "0w~3w\nAveraged %6hr+ Away Home" ,fill="Majority Teachin
g Method")+scale_color_manual(values=col_theme)+theme(legend.position =
 "bottom")+geom_text(data =B_diff_micro%>%filter(major_teaching=="On Pr
emises"),aes(label=COUNTY),color='black',size=3,hjust=0.8, vjust=-0.2)
```




```
B_diff_micro%>%
  ggplot(aes(x=log(Population.density),y=new.slope.diff2,group=major_te
aching,color=major_teaching))+geom_point(aes(size=avg2_full_work_prob,a
lpha=avg2_full_work_prob))+geom_smooth(method = "lm", se=F, formula = y
 ~ x,alpha=0.1)+theme_minimal()+team_theme+
  labs(y="Change in Growth",x="Log of Population Density",
       title="Change in Growth Three Weeks Later\nOnly Micropolitan Cou
nties",
       color="Majority Teaching Method",
       size = "3w~6w\nAveraged %6hr+ Away Home",
       alpha= "3w~6w\nAveraged %6hr+ Away Home" ,fill="Majority Teachin
g Method")+scale_color_manual(values=col_theme)+theme(legend.position =
 "bottom")+geom_text(data =B_diff_micro%>%filter(major_teaching=="On Pr
emises"),aes(label=COUNTY),color='black',size=3,hjust=1.1, vjust=0.3)
```



Sensitive Analysis

In order to make sure that the shifting of the red line (On Premises counties) is not brought by chance, we will conduct a sensitive analysis to detect how the change in growth varies throughout time. The whole sensitive analysis is based on ‘Change in growth versus Log Population Density.

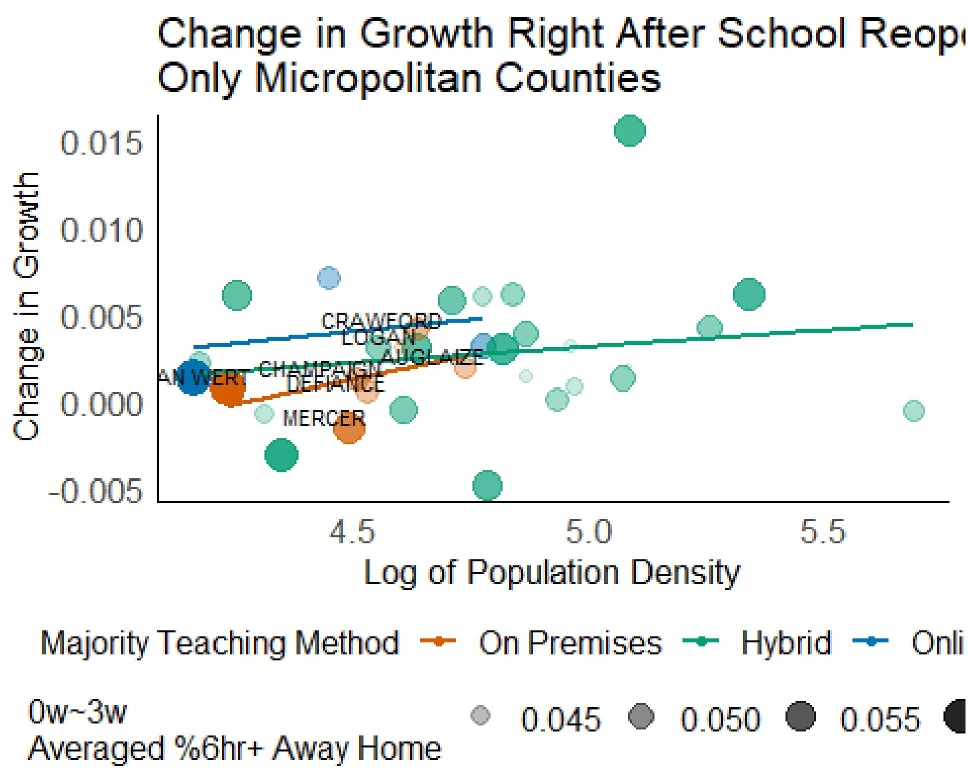
Since we assume that the school posture takes three weeks to reflect on the growth coefficient, the growth coefficients before 3 weeks after the start of school are all regarded as not taking effect. So, we use B(3) as a turning point. The changes in growth we want to test are as below:

Before school posture taking effect: B(0)-B(-3), B(1)-B(-2), B(2)-B(-1), B(3)-B(0) (also known as change in growth right after the start of school reopen).

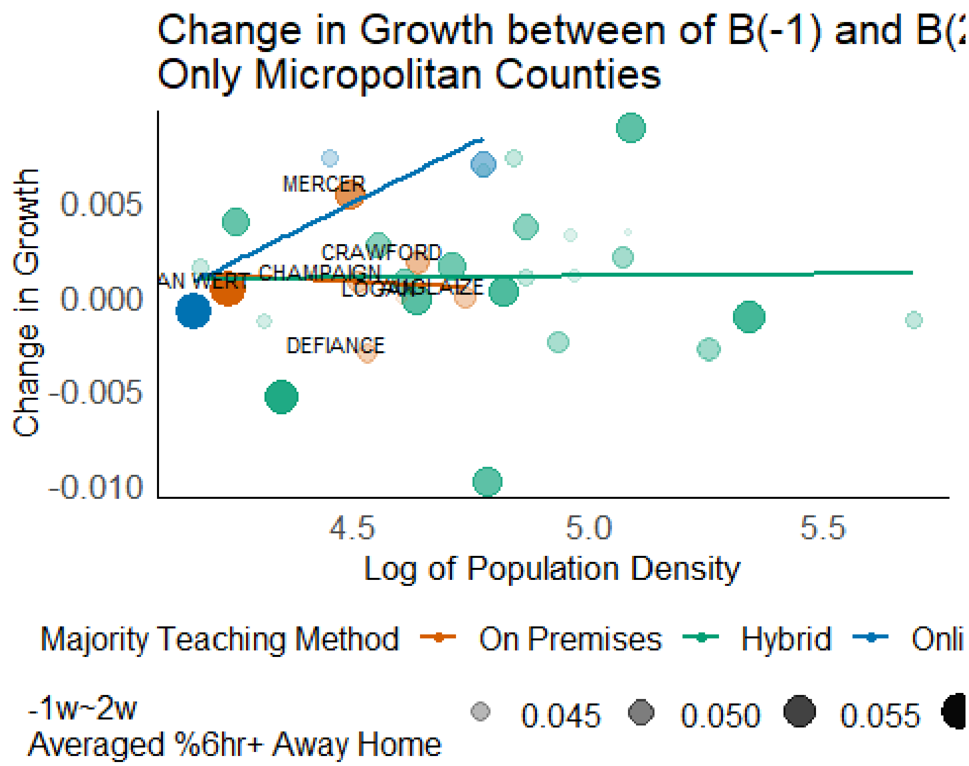
After school posture taking effect: B(4)-B(1), B(5)-B(2), B(6)-B(3) (also known as change in growth three weeks later), B(7)-B(4)

```
#Before reopen
##3w-0w
B_diff_micro%>%
  ggplot(aes(x=log(Population.density),y=new.slope.diff,group=major_tea
ching,color=major_teaching))+geom_point(aes(size=avg_full_work_prob,alp
ha=avg_full_work_prob))+geom_smooth(method = "lm", se=F, formula = y ~
x,alpha=0.1)+theme_minimal()+team_theme+
  labs(y="Change in Growth",x="Log of Population Density",
      title="Change in Growth Right After School Reopen\nOnly Micropol
```

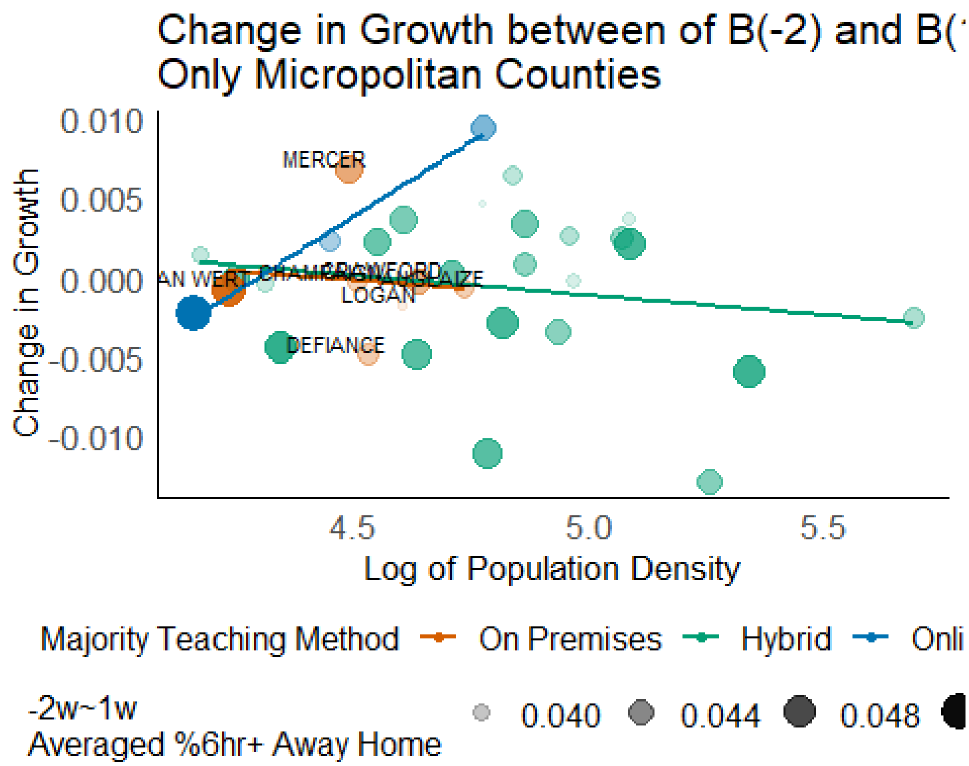
```
itan Counties",
       color="Majority Teaching Method",
       size = "0w~3w\nAveraged %6hr+ Away Home",
       alpha= "0w~3w\nAveraged %6hr+ Away Home" ,fill="Majority Teachin
g Method")+scale_color_manual(values=col_theme)+theme(legend.position =
 "bottom")+geom_text(data =B_diff_micro%>%filter(major_teaching=="On Pr
emises"),aes(label=COUNTY),color='black',size=3,hjust=0.8, vjust=-0.2)
```



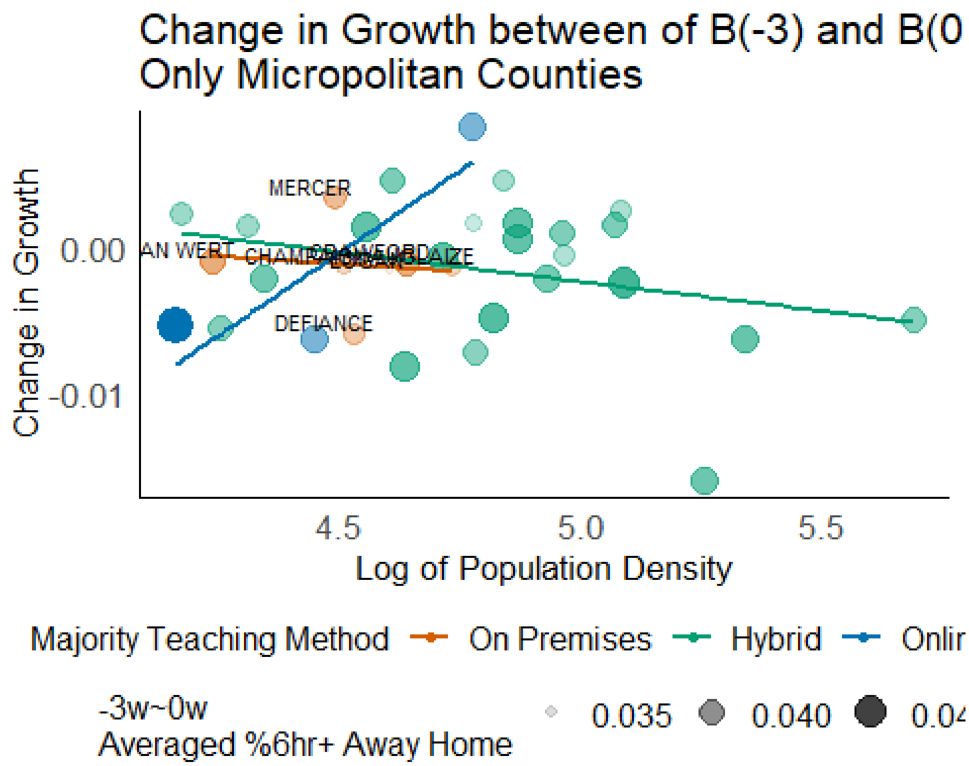

```
##2w-(-1w)
B_diff_micro%>%
  ggplot(aes(x=log(Population.density),y=new.slope.diff2m1,group=major_
teaching,color=major_teaching))+geom_point(aes(size=avg_full_work_prob_
m1w2w,alpha=avg_full_work_prob_m1w2w))+geom_smooth(method = "lm", se=F,
 formula = y ~ x,alpha=0.1)+theme_minimal()+team_theme+
  labs(y="Change in Growth",x="Log of Population Density",
       title="Change in Growth between of B(-1) and B(2)\nOnly Micropol
itan Counties",
       color="Majority Teaching Method",
       size = "-1w~2w\nAveraged %6hr+ Away Home",
       alpha= "-1w~2w\nAveraged %6hr+ Away Home" ,fill="Majority Teachi
ng Method")+scale_color_manual(values=col_theme)+theme(legend.position
= "bottom")+geom_text(data =B_diff_micro%>%filter(major_teaching=="On P
remises"),aes(label=COUNTY),color='black',size=3,hjust=0.8, vjust=-0.2)
```



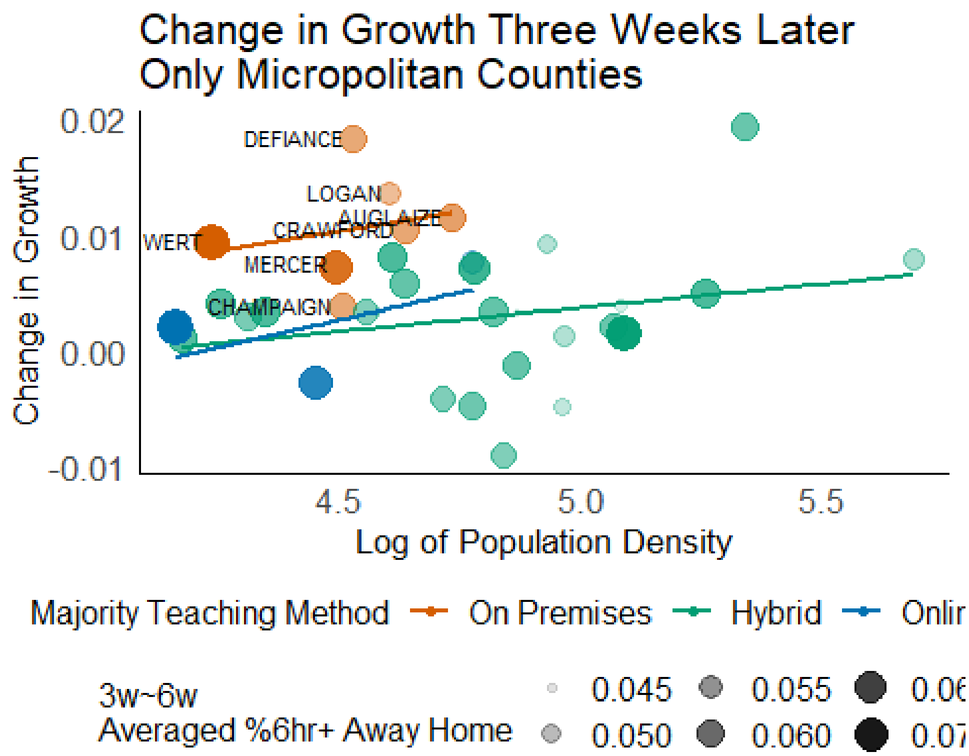

```
##1w-(-2w)
B_diff_micro%>%
  ggplot(aes(x=log(Population.density),y=new.slope.diff1m2,group=major_
teaching,color=major_teaching))+geom_point(aes(size=avg_full_work_prob_
m2w1w,alpha=avg_full_work_prob_m2w1w))+geom_smooth(method = "lm", se=F,
 formula = y ~ x,alpha=0.1)+theme_minimal()+team_theme+
  labs(y="Change in Growth",x="Log of Population Density",
       title="Change in Growth between of B(-2) and B(1)\nOnly Micropol
itan Counties",
       color="Majority Teaching Method",
       size = "-2w~1w\nAveraged %6hr+ Away Home",
       alpha= "-2w~1w\nAveraged %6hr+ Away Home" ,fill="Majority Teachi
ng Method")+scale_color_manual(values=col_theme)+theme(legend.position
= "bottom")+geom_text(data =B_diff_micro%>%filter(major_teaching=="On P
remises"),aes(label=COUNTY),color='black',size=3,hjust=0.8, vjust=-0.2)
```



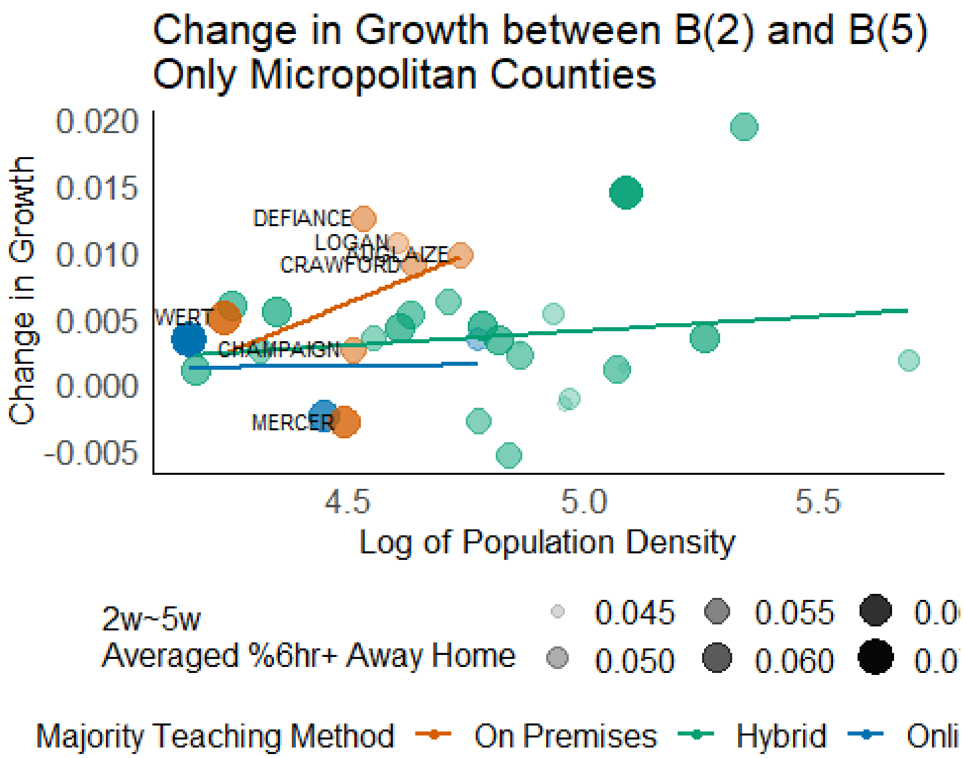

```
##0w-(-3w)
B_diff_micro%>%
  ggplot(aes(x=log(Population.density),y=new.slope.diff0m3,group=major_
teaching,color=major_teaching))+geom_point(aes(size=avg_full_work_prob_
m3w0w,alpha=avg_full_work_prob_m3w0w))+geom_smooth(method = "lm", se=F,
 formula = y ~ x,alpha=0.1)+theme_minimal()+team_theme+
  labs(y="Change in Growth",x="Log of Population Density",
       title="Change in Growth between of B(-3) and B(0)\nOnly Micropol
itan Counties",
       color="Majority Teaching Method",
       size = "-3w~0w\nAveraged %6hr+ Away Home",
       alpha= "-3w~0w\nAveraged %6hr+ Away Home" ,fill="Majority Teachi
ng Method")+scale_color_manual(values=col_theme)+theme(legend.position
= "bottom")+geom_text(data =B_diff_micro%>%filter(major_teaching=="On P
remises"),aes(label=COUNTY),color='black',size=3,hjust=0.8, vjust=-0.2)
```



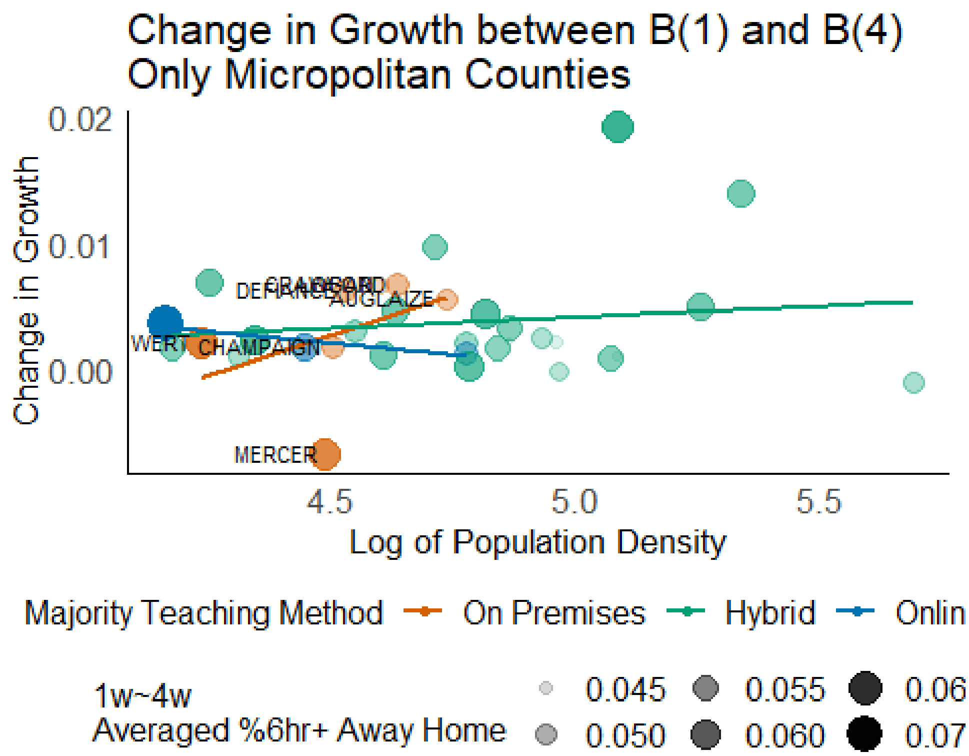

```
#After reopen
##6w-3w
B_diff_micro%>%
  ggplot(aes(x=log(Population.density),y=new.slope.diff2,group=major_te
aching,color=major_teaching))+geom_point(aes(size=avg2_full_work_prob,a
lpha=avg2_full_work_prob))+geom_smooth(method = "lm", se=F, formula = y
 ~ x,alpha=0.1)+theme_minimal()+team_theme+
  labs(y="Change in Growth",x="Log of Population Density",
       title="Change in Growth Three Weeks Later\nOnly Micropolitan Cou
nties",
       color="Majority Teaching Method",
       size = "3w~6w\nAveraged %6hr+ Away Home",
       alpha= "3w~6w\nAveraged %6hr+ Away Home" ,fill="Majority Teachin
g Method")+scale_color_manual(values=col_theme)+theme(legend.position =
 "bottom")+geom_text(data =B_diff_micro%>%filter(major_teaching=="On Pr
emises"),aes(label=COUNTY),color='black',size=3,hjust=1.1, vjust=0.3)
```



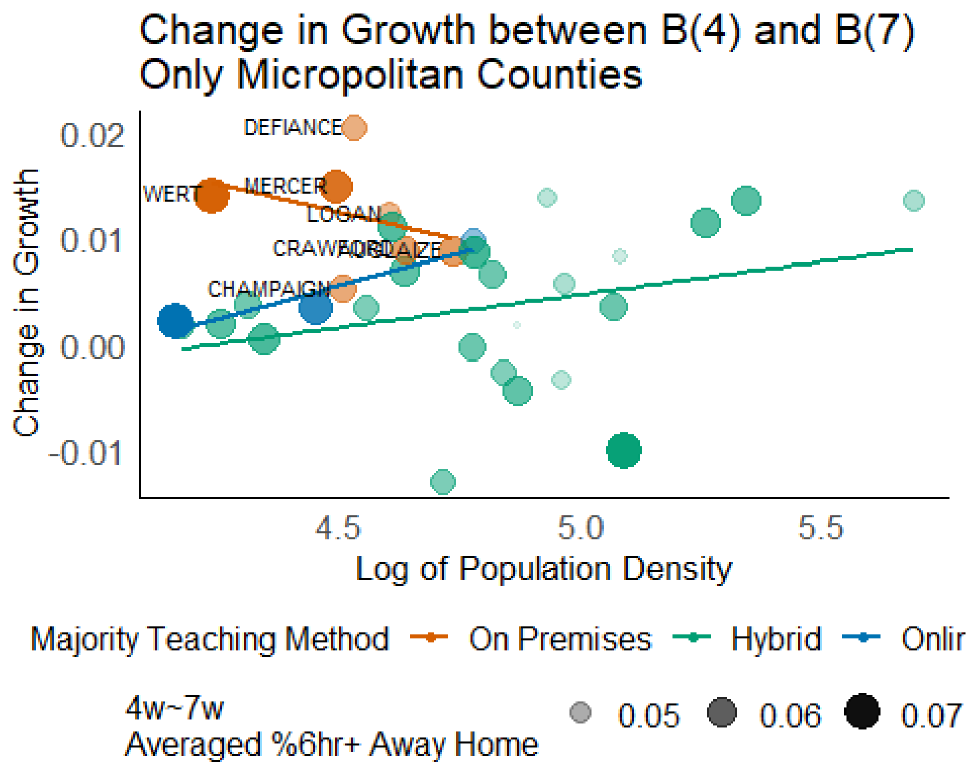

```
##5w-2w
B_diff_micro%>%
  ggplot(aes(x=log(Population.density),y=new.slope.diff52,group=major_t
eaching,color=major_teaching))+geom_point(aes(size=avg_full_work_prob_2
w5w,alpha=avg_full_work_prob_2w5w))+geom_smooth(method = "lm", se=F, fo
rmula = y ~ x,alpha=0.1)+theme_minimal()+team_theme+
  labs(y="Change in Growth",x="Log of Population Density",
       title="Change in Growth between B(2) and B(5)\nOnly Micropolitan
 Counties",
       color="Majority Teaching Method",
       size = "2w~5w\nAveraged %6hr+ Away Home",
       alpha= "2w~5w\nAveraged %6hr+ Away Home" ,fill="Majority Teachin
g Method")+scale_color_manual(values=col_theme)+theme(legend.position =
 "bottom")+geom_text(data =B_diff_micro%>%filter(major_teaching=="On Pr
emises"),aes(label=COUNTY),color='black',size=3,hjust=1.1, vjust=0.3)
```




```
##4w-1w
B_diff_micro%>%
  ggplot(aes(x=log(Population.density),y=new.slope.diff41,group=major_teaching,color=major_teaching))+geom_point(aes(size=avg_full_work_prob_1w4w,alpha=avg_full_work_prob_1w4w))+geom_smooth(method = "lm", se=F, formula = y ~ x,alpha=0.1)+theme_minimal()+team_theme+
  labs(y="Change in Growth",x="Log of Population Density",
       title="Change in Growth between B(1) and B(4)\nOnly Micropolitan Counties",
       color="Majority Teaching Method",
       size = "1w~4w\nAveraged %6hr+ Away Home",
       alpha= "1w~4w\nAveraged %6hr+ Away Home" ,fill="Majority Teaching Method")+scale_color_manual(values=col_theme)+theme(legend.position = "bottom")+geom_text(data =B_diff_micro%>%filter(major_teaching=="On Premises"),aes(label=COUNTY),color='black',size=3,hjust=1.1, vjust=0.3)
```




```
##7w-4w
B_diff_micro%>%
  ggplot(aes(x=log(Population.density),y=new.slope.diff74,group=major_t
eaching,color=major_teaching))+geom_point(aes(size=avg_full_work_prob_4
w7w,alpha=avg_full_work_prob_4w7w))+geom_smooth(method = "lm", se=F, fo
rmula = y ~ x,alpha=0.1)+theme_minimal()+team_theme+
  labs(y="Change in Growth",x="Log of Population Density",
       title="Change in Growth between B(4) and B(7)\nOnly Micropolitan
 Counties",
       color="Majority Teaching Method",
       size = "4w~7w\nAveraged %6hr+ Away Home",
       alpha= "4w~7w\nAveraged %6hr+ Away Home" ,fill="Majority Teachin
g Method")+scale_color_manual(values=col_theme)+theme(legend.position =
 "bottom")+geom_text(data =B_diff_micro%>%filter(major_teaching=="On Pr
emises"),aes(label=COUNTY),color='black',size=3,hjust=1.1, vjust=0.3)
```



Appendix 6: Math Plots

Gamma distribution for the time lengths from infections to deaths

We know from previous study that the mean for this Gamma distribution is 23.9, with a coefficient of variation being 0.4.

```
# package for The Gamma Distribution (Alternative Parameterization)
# install.packages("EnvStats")
library(EnvStats)
time_to_deaths <- 1:50
prob_time_to_deaths <- dgammaAlt(x = time_to_deaths,mean = 23.9, cv =
0.4)
## shift x
gamma_plot <- data.frame(prob_time_to_deaths,time_to_deaths,time_to_dea
ths+5,time_to_deaths+10,time_to_deaths+15)
colnames(gamma_plot) <- c("prob","time1","time2","time3","time4")
ggplot(gamma_plot)+
  geom_line(aes(x=time1,y=prob),colour = "black")+
  geom_vline(xintercept = 5.2,lty=2,colour="darkgreen")+
  geom_vline(xintercept = 15.2,lty=2,colour="darkgreen")+
  geom_vline(xintercept = 25.2,lty=2,colour="darkgreen")+
  labs(x="Time from infections to deaths",
```

```
       y="Probability of died after x days")+team_theme+theme(legend.po
sition = "bottom")
```