Technical Appendix

Appendix 1: Ohio Maps

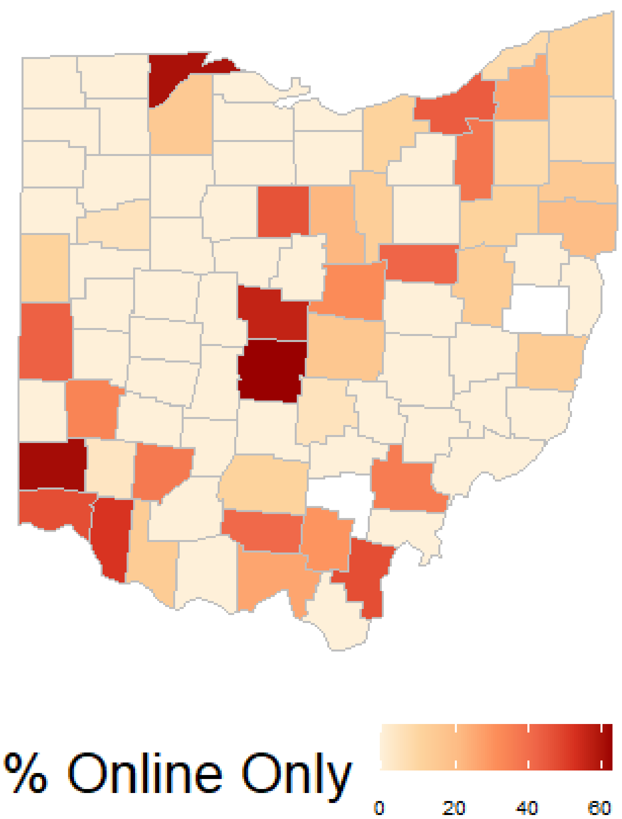
This section contains all types of map in our main paper, including teaching method maps, demographic maps, urban status map and death profile maps.

```
## Set up aesthetic theme for all graphs generated in the report
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"))
```

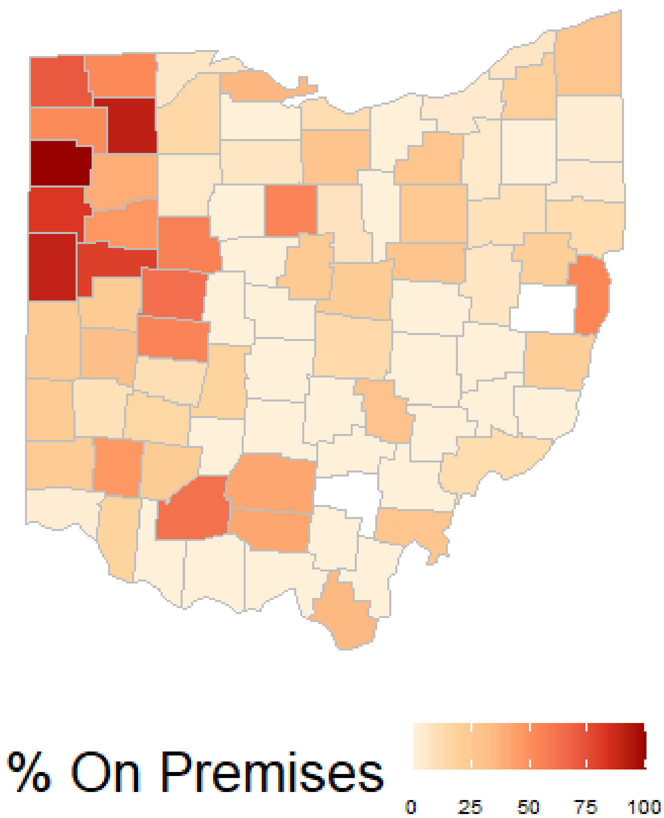
1.1 Geographical distribution of the majority teaching posture, population and student enrollment at county-level

```
ohio_map <- map_data("county") %>%subset(region=="ohio")%>%
  mutate(county=toupper(subregion))%>%select(long,lat,county,group)
# Map of proportion of students taking online-only classes
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() +
```

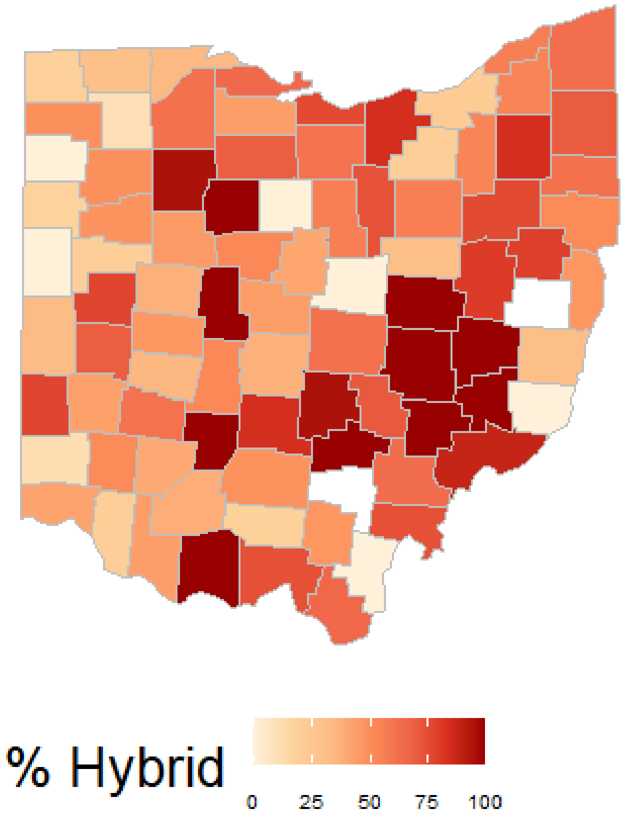
```r
  scale_fill_distiller(palette = "OrRd",direction = 1)+
  labs(fill='% Online Only')+
  theme(legend.position = "bottom",legend.text = element_text(size=),legend.title = element_text(size=20))
```



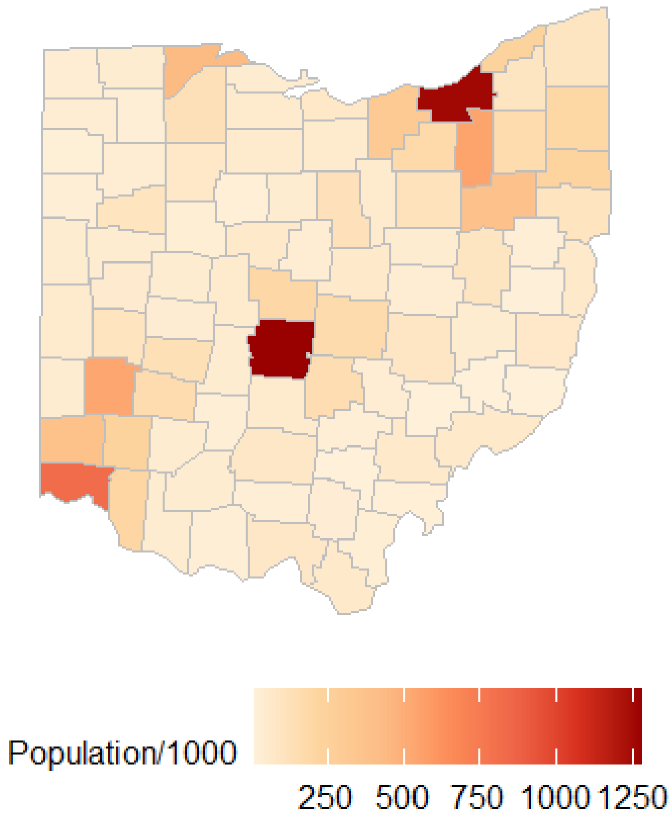

```r
# Map of proportion of students taking on-premises classes
wide_teaching_enroll%>%
  left_join(ohio_map,by='county')%>%
  mutate(On_Premises= On_Premises*100)%>%
  ggplot() +
  geom_polygon(aes(x = long, y = lat, group = group, fill = On_Premises), color = "gray") +
  coord_fixed(1.3) + theme_map() +
  scale_fill_distiller(palette = "OrRd",direction = 1)+
  labs(fill='% On Premises')+
  theme(legend.position = "bottom",legend.text = element_text(size=),legend.title = element_text(size=20))
```



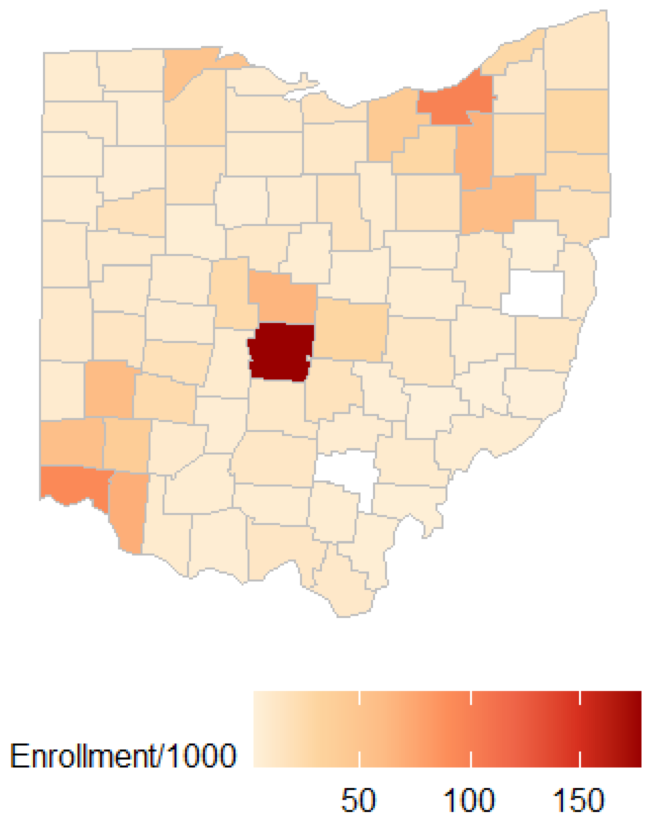

```r
# Map of proportion of students taking hybrid classes
wide_teaching_enroll%>%
  left_join(ohio_map,by='county')%>%
  mutate(Hybrid= Hybrid*100)%>%
  ggplot() +
  geom_polygon(aes(x = long, y = lat, group = group, fill = Hybrid), co
lor = "gray") +
  coord_fixed(1.3) +
  theme_map() +
  scale_fill_distiller(palette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




```r
# Map of population size
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"))
```

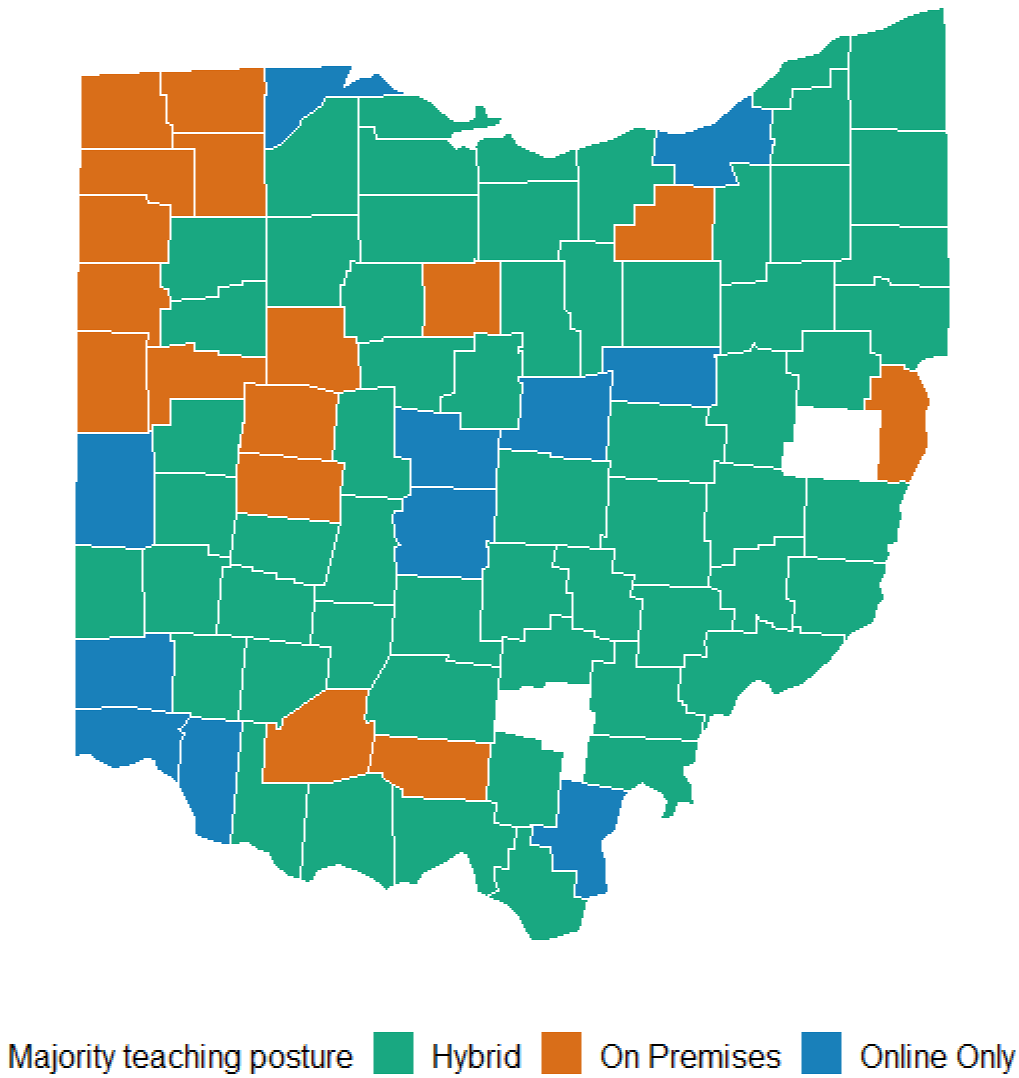



```
# Map of student enrollments
teachingmethod_enroll%>%
  distinct(county,county_enroll)%>%
  left_join(ohio_map,by=c('county'))%>%
  mutate(county_enroll = county_enroll/1000)%>%
  ggplot() +
  geom_polygon(aes(x = long, y = lat, group = group, fill = county_enro
ll), color = "gray") +
  coord_fixed(1.3) + 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"))
```



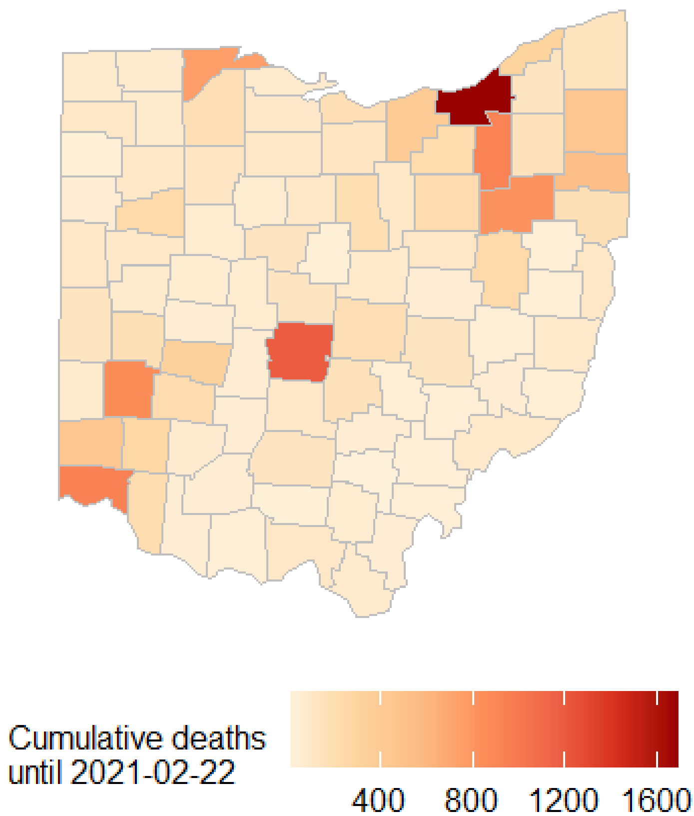
1.2 Map of majority teaching posture at county-level

```
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 posture')+
  theme(legend.position = "bottom",legend.text = element_text(size=12),
legend.title = element_text(size=12))
```

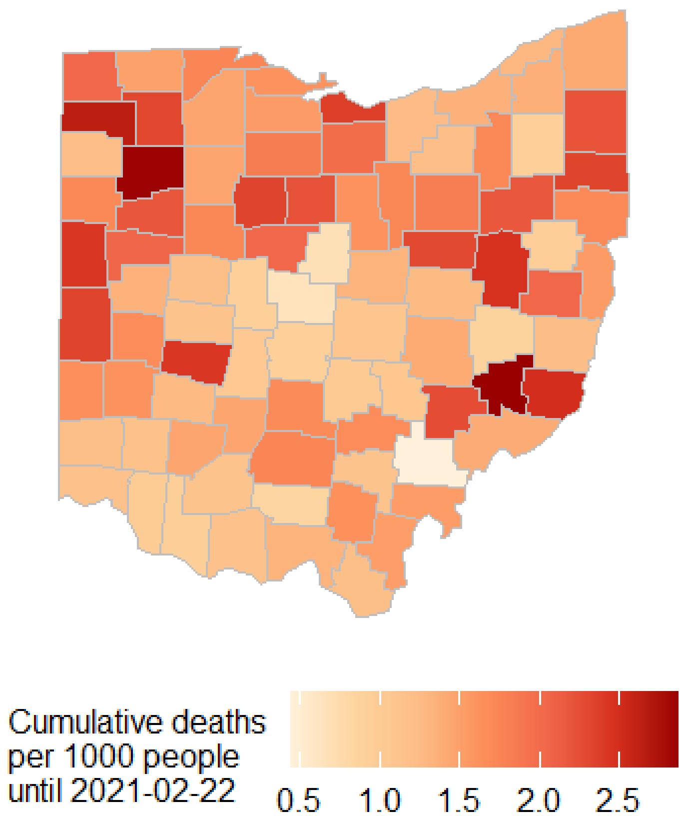


1.3 Geographical distribution of cumulative COVID-19 deaths and deaths incidence until 02/22/2021.

```
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"))
```



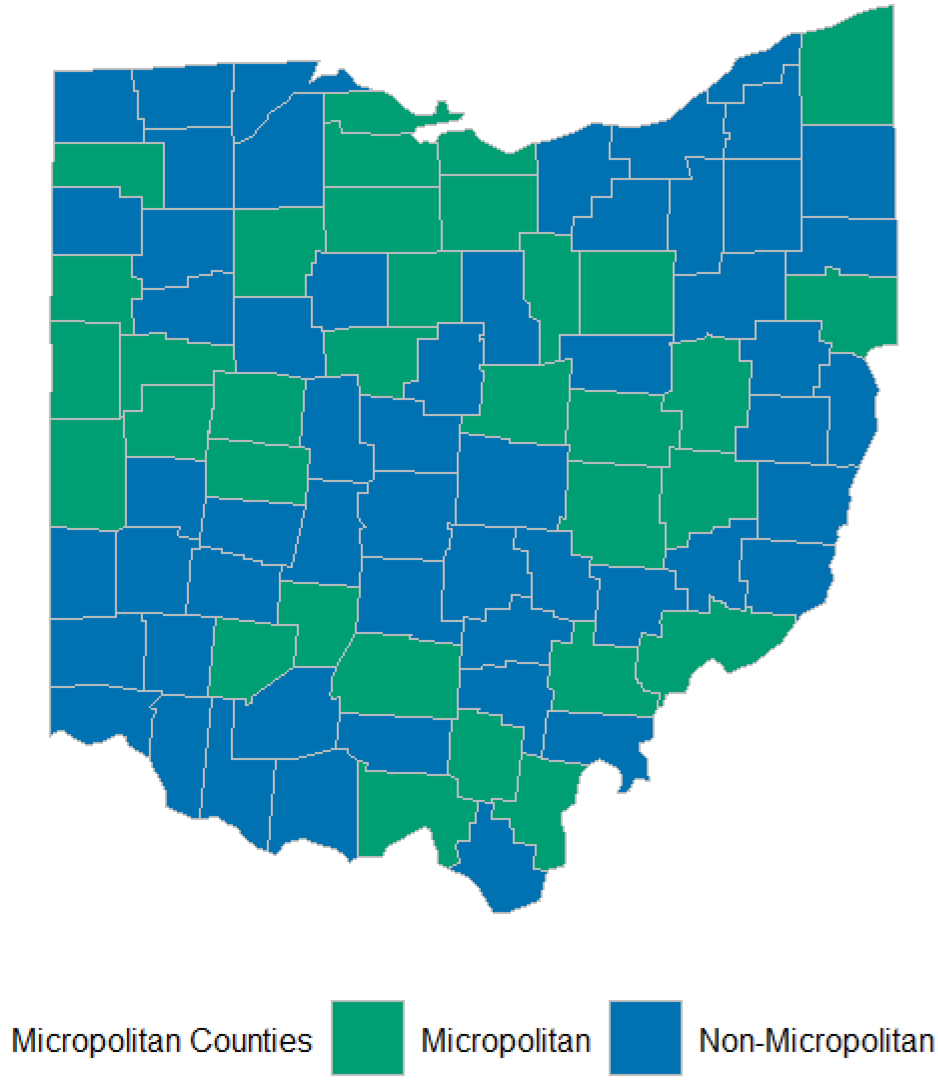

```
death_prop%>%
  left_join(ohio_map,by=c("COUNTY"='county'))%>%
  ggplot() +
  geom_polygon(aes(x = long, y = lat, group=group,fill = death_per_100
0),
               color = "gray") +
  coord_fixed(1.3) + theme_map() +
  scale_fill_distiller(palette = "OrRd",direction = 1)+
  labs(fill='Cumulative deaths \nper 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"))
```



1.4 Map of micropolitan status for counties

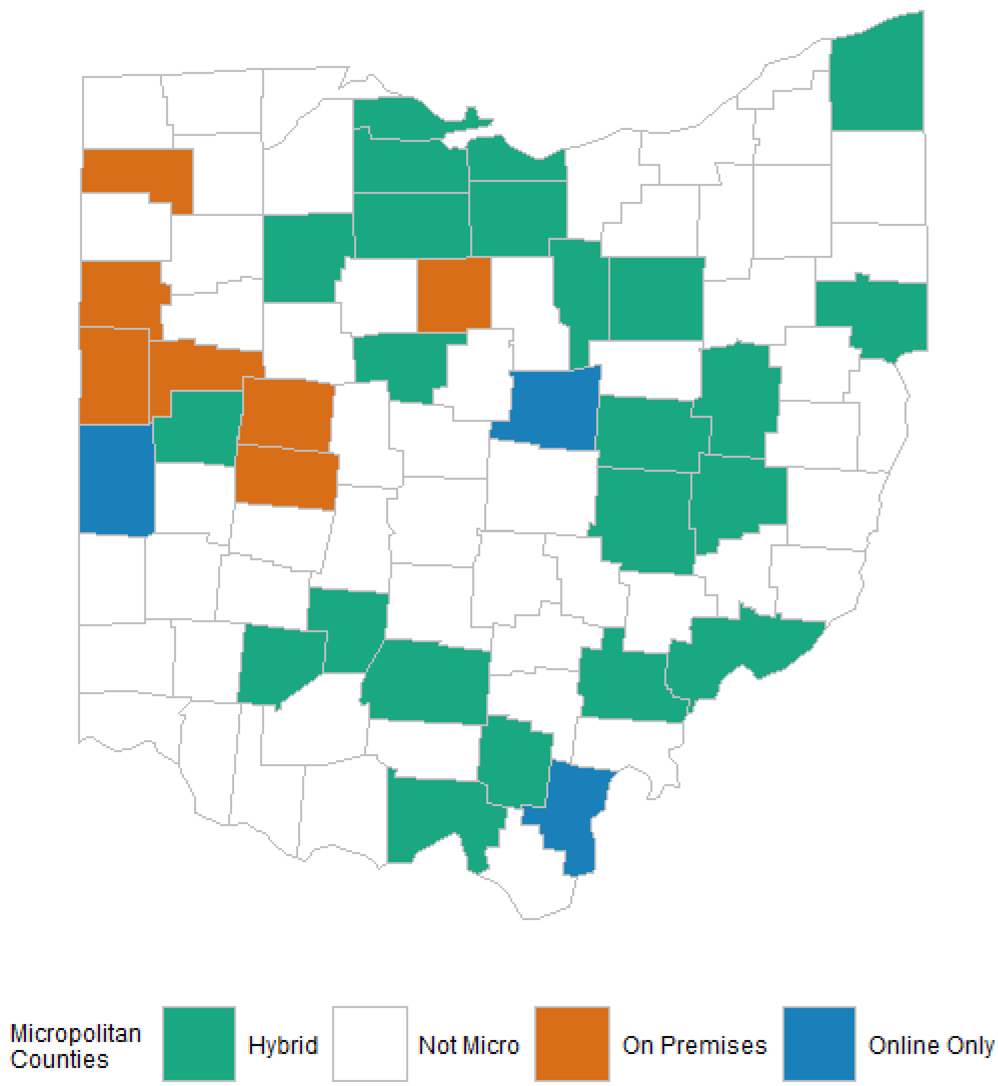
Since we reduced our county samples to micropolitan counties, we also show how micropolitan county distribute in Ohio and which teaching method they used. We can find that micropolitan counties are well-spread.

```
# Micropolitan vs Non-Micropolitan
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"))
```




```r
# 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=9),
        legend.title = element_text(size=9),
        legend.position = "bottom",
        legend.key.size = unit(2,"lines"))
```



Appendix 2: Death Incidence

This section gives all the plots related to death incidence, including Covid cases by age in Ohio, time series death incidence plot and boxplot with pairwise analysis for teaching posture.

2.1 Data process

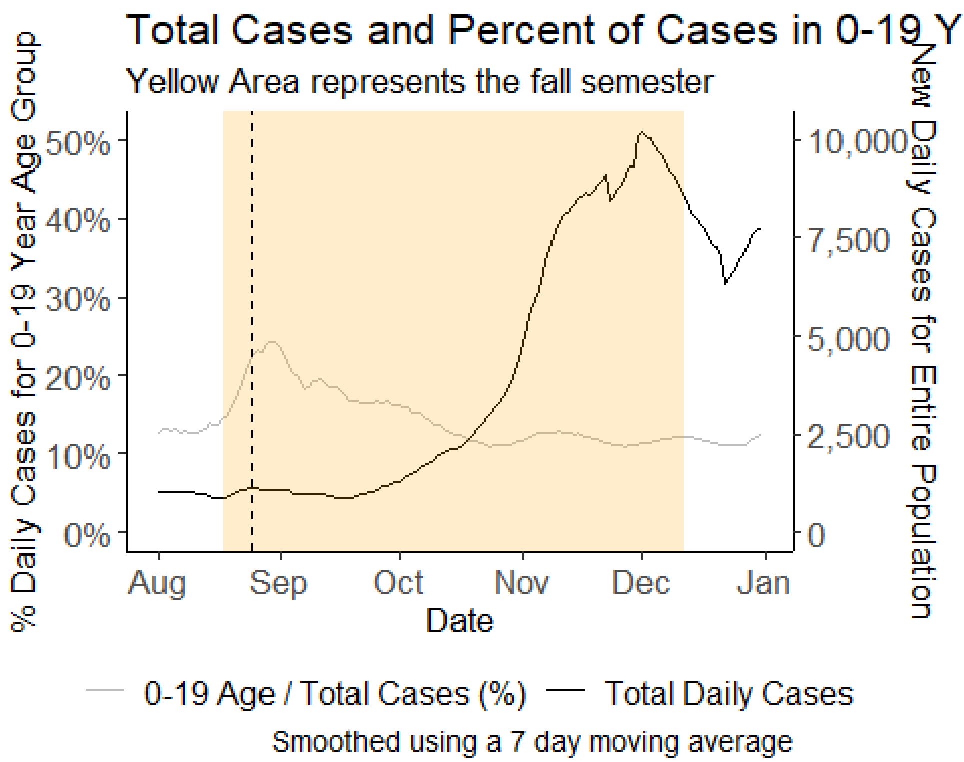
```
library(tidyverse)
library(lubridate)
require(scales)
library(readxl)
cases_by_age <- read_excel("OhiobyAge.xlsx")
rolling_age_cases <- cases_by_age %>%
  mutate(youth_prop_roll = zoo::rollmean(`00_19/total(%)`, k = 7, fill
= NA),
         all_roll = zoo::rollmean(`00_80+`, k = 7, fill = NA))
colors <- 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
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('COUNTY'))
```

2.2 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.

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

## [1] "English_United States.1252"

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)+
  team_theme +
  theme(legend.position='bottom')
```

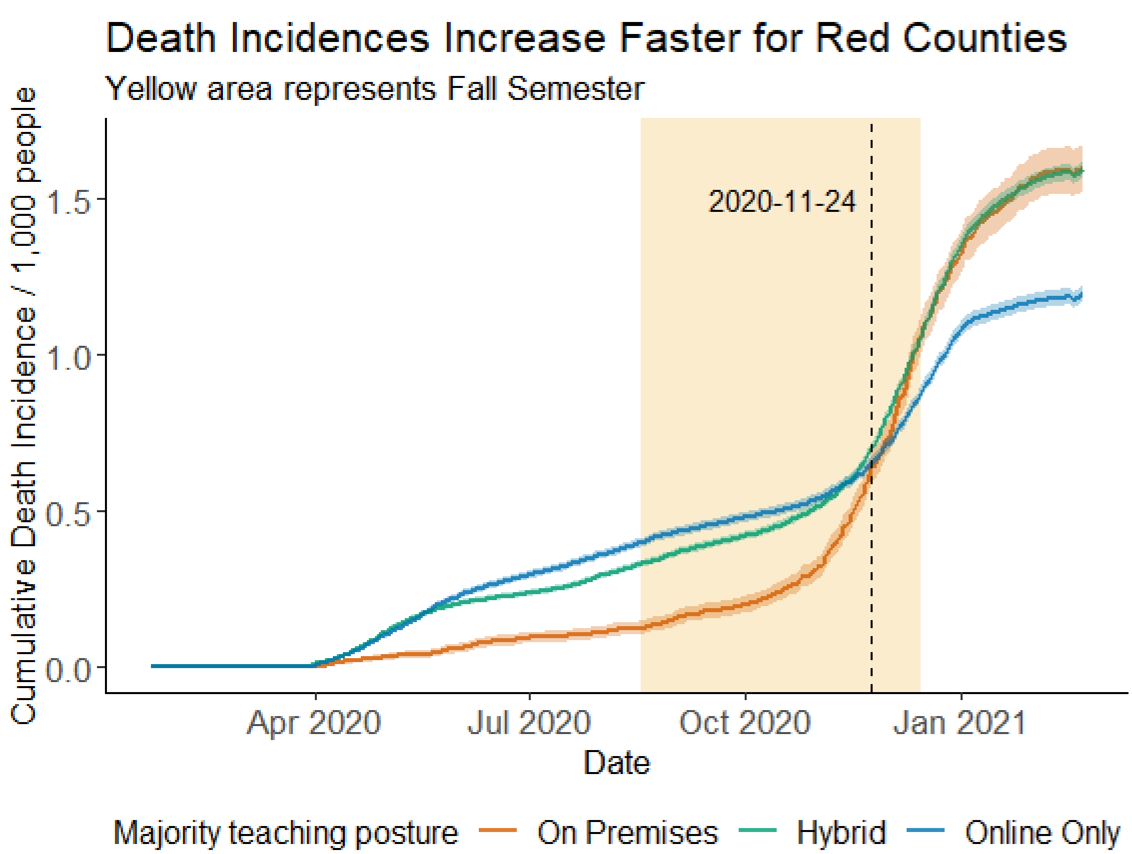


2.3 Death incidence over time by the majority teaching posture

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

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

## [1] "English_United States.1252"

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



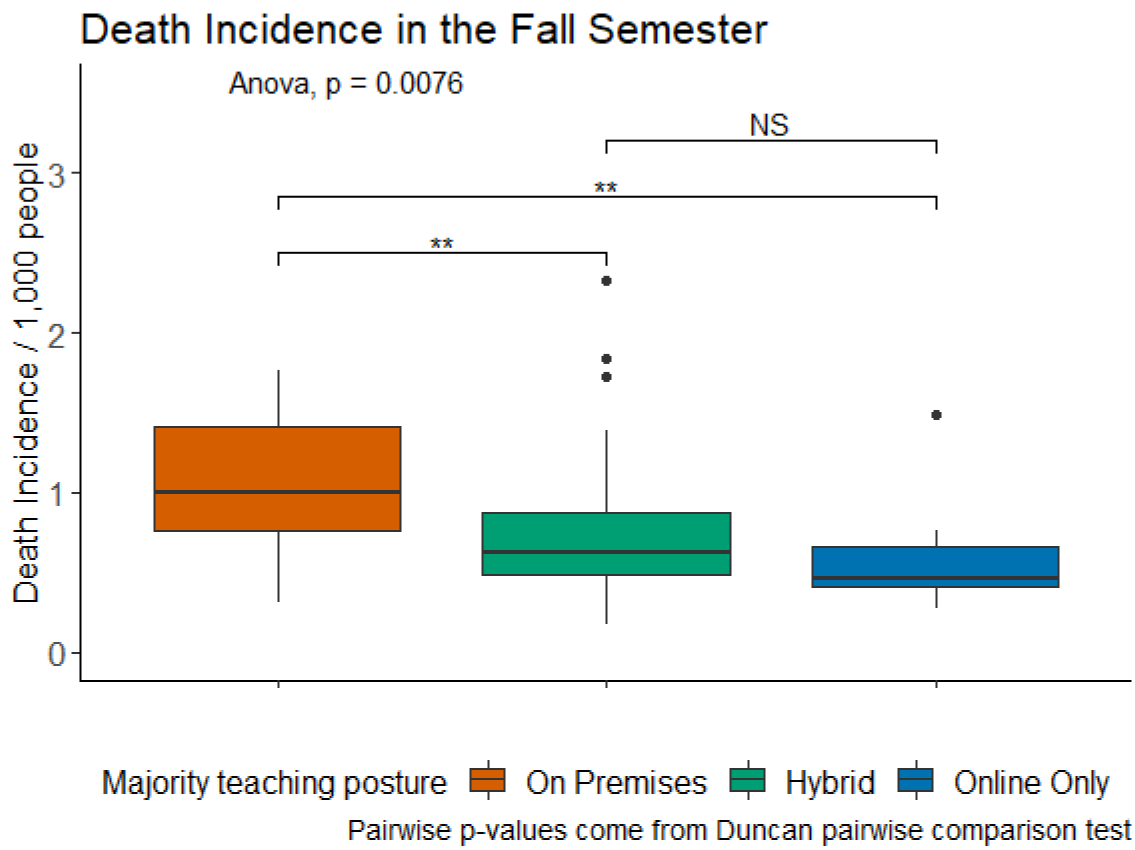

```
ggsave("deathplot.png",width = 6,height = 6)
```

2.4 Pairwise of death incidence

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

```
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)

##                 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)
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 posture",
       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 and their Pairwise Analysis

There are also some other variables which may affect death incidence. We do some pairwise analysis based on teaching methods for these variables. These confounding variables show significant difference for different teahcing methods.

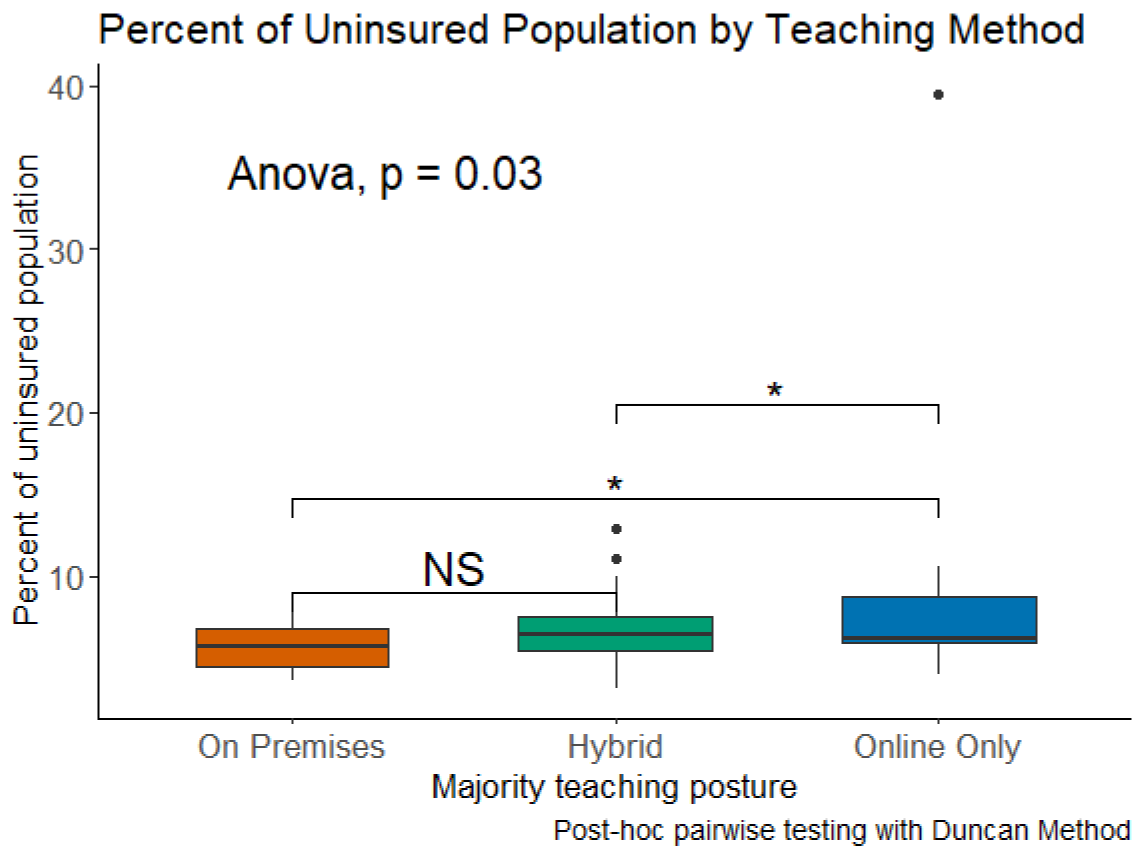
3.1 Uninsured population

Significant at p-value of 0.03

```
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
```

```
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 posture",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)
```

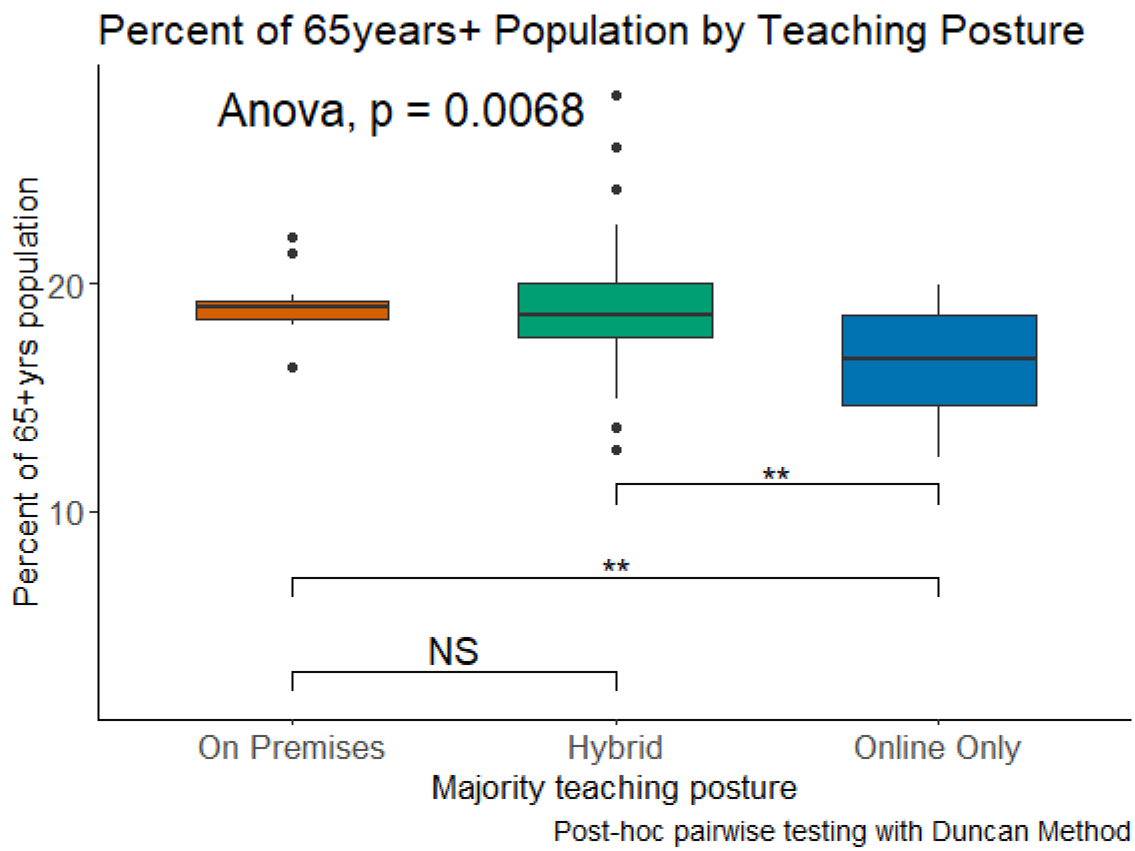


3.2 Percentage of senior

Significant at p-value of 0.0068

```
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

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 Posture",x="Ma
jority teaching posture",y="Percent of 65+yrs population",fill="Majorit
y teaching posture",caption = "Post-hoc pairwise testing with Duncan Me
thod")+team_theme+theme(legend.position = "")+scale_fill_manual(values=
col_theme)
```

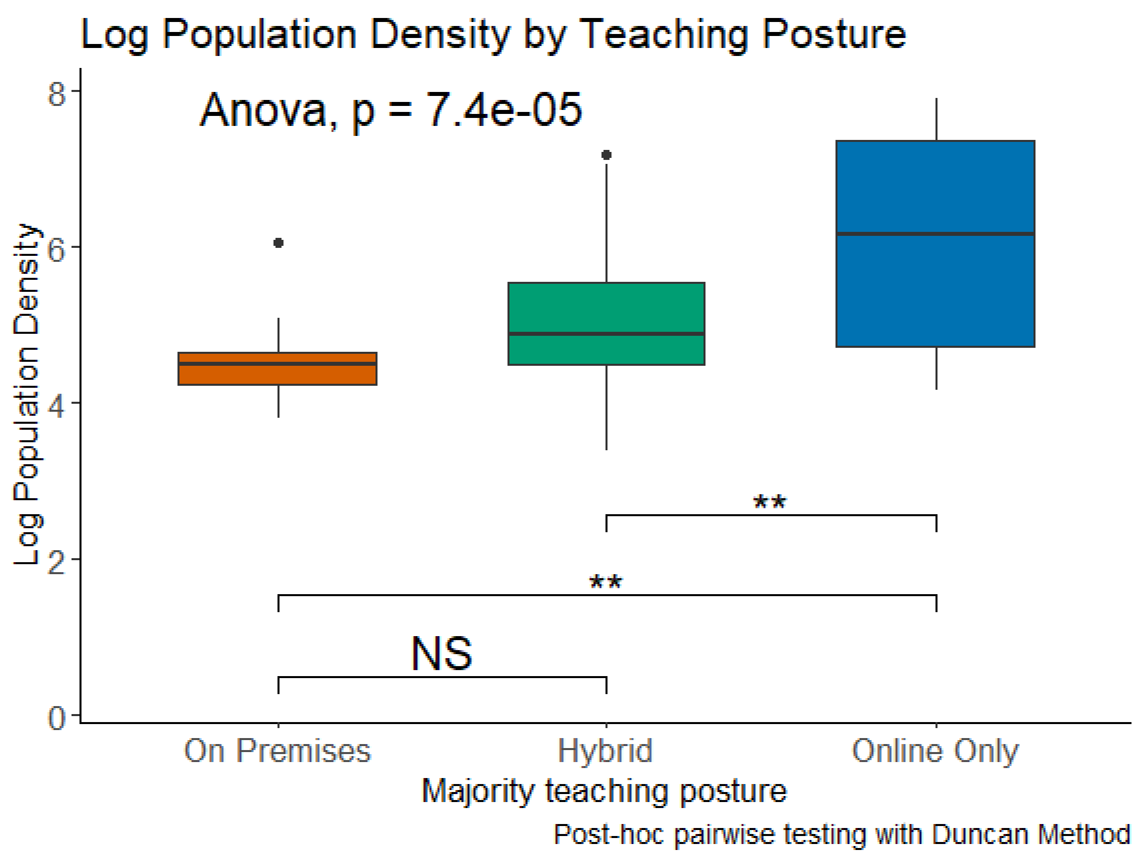


3.3 Log population density

Significant at p-value of 7.4e-05

```
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
```

```
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 Posture",x="Majority t
eaching posture",y="Log Population Density",caption = "Post-hoc pairwis
e testing with Duncan Method")+
  team_theme+theme(legend.position = "")+scale_fill_manual(values=col_t
heme)
```



Appendix 4: Exponential Growth Model

We construct the exponential growth model in order to better measure the state of pandemic. The whole math process can refer to Section 3 Method. This section contains all the plots regarding the growth coefficent B, which mainly related to max B and change in growth coefficient.

4.1 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 posture 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)
```

4.2 Compute the maximum growth coefficent for each county during the Fall semester

Maximum growth coefficent (B values) represent the severity of the disease for the county during the Fall semester.

```
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
```

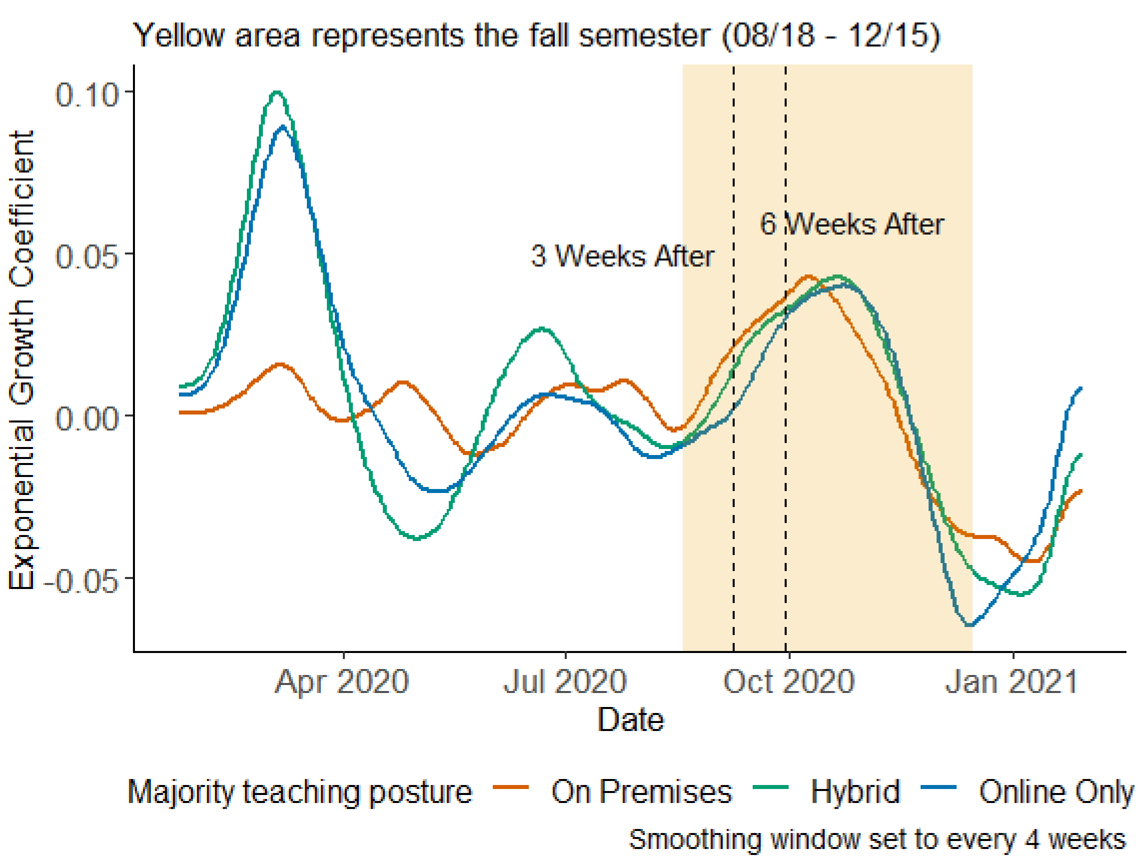
```
1)%>%
  summarise(avg3w_B0 = mean(new.slope), .groups = 'drop')%>%
  left_join(cases_slope_teach%>%
  group_by(COUNTY)%>%
  filter(DATE > as.Date("2020-08-18")-7 & DATE<as.Date("2020-08-18")+1
4)%>%
  summarise(avg1w_2w_B0 = mean(new.slope)),by="COUNTY", .groups = 'drop
')%>%
  left_join(cases_slope_teach%>%
  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"))
```

4.3 Growth coefficient aggregation by counties majority teaching posture

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

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

## [1] "English_United States.1252"

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 posture",
       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)
```



4.4 Difference in growth coefficient(B(t))

We capture the B values in some specific time point(from three weeks before the start of the semester and 7 weeks after the start of the semester).

```
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%>%
```

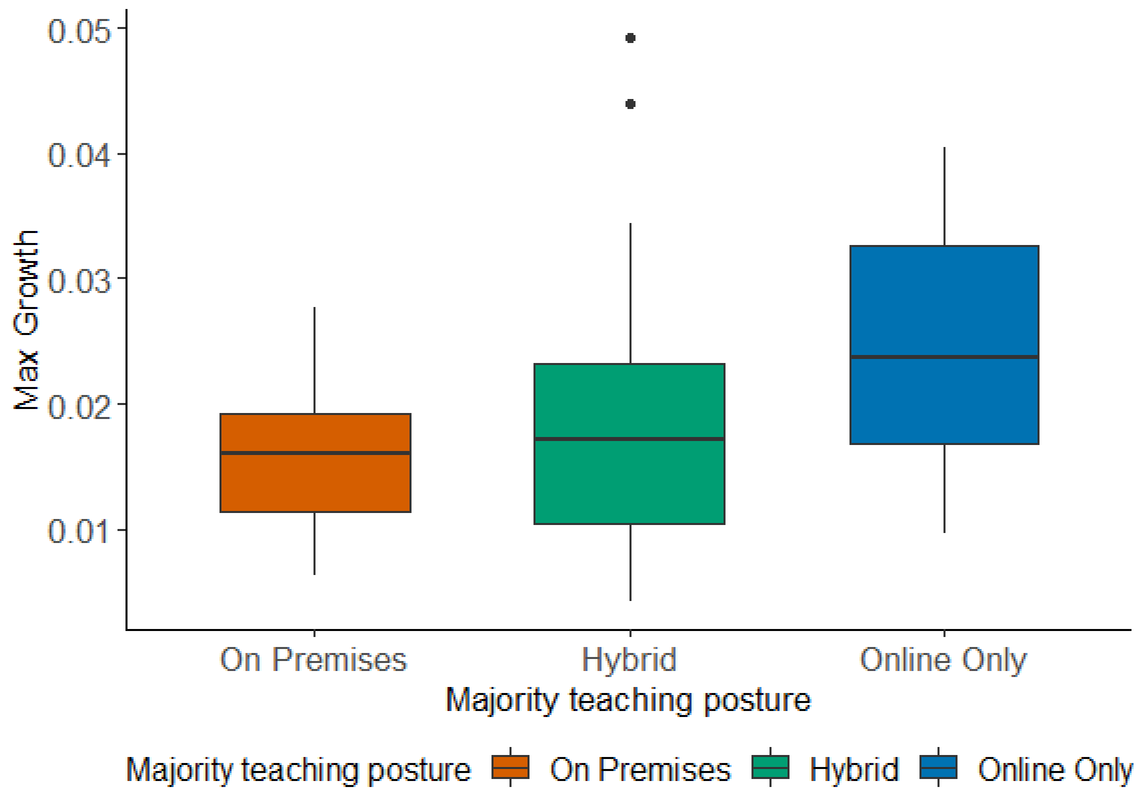
```
  left_join(major_reopening,by=c("COUNTY"))%>%
  group_by(COUNTY)%>%
  filter(DATE >= as.Date("2020-08-18")& DATE <as.Date("2020-08-18") + 2
1)%>%
  summarise(avg_full_work_prob = mean(full_work_prop_7d))
avg_mobi_3w6w <- case_mobility%>%
  left_join(major_reopening,by=c("COUNTY"))%>%
  group_by(COUNTY)%>%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

4.5 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.

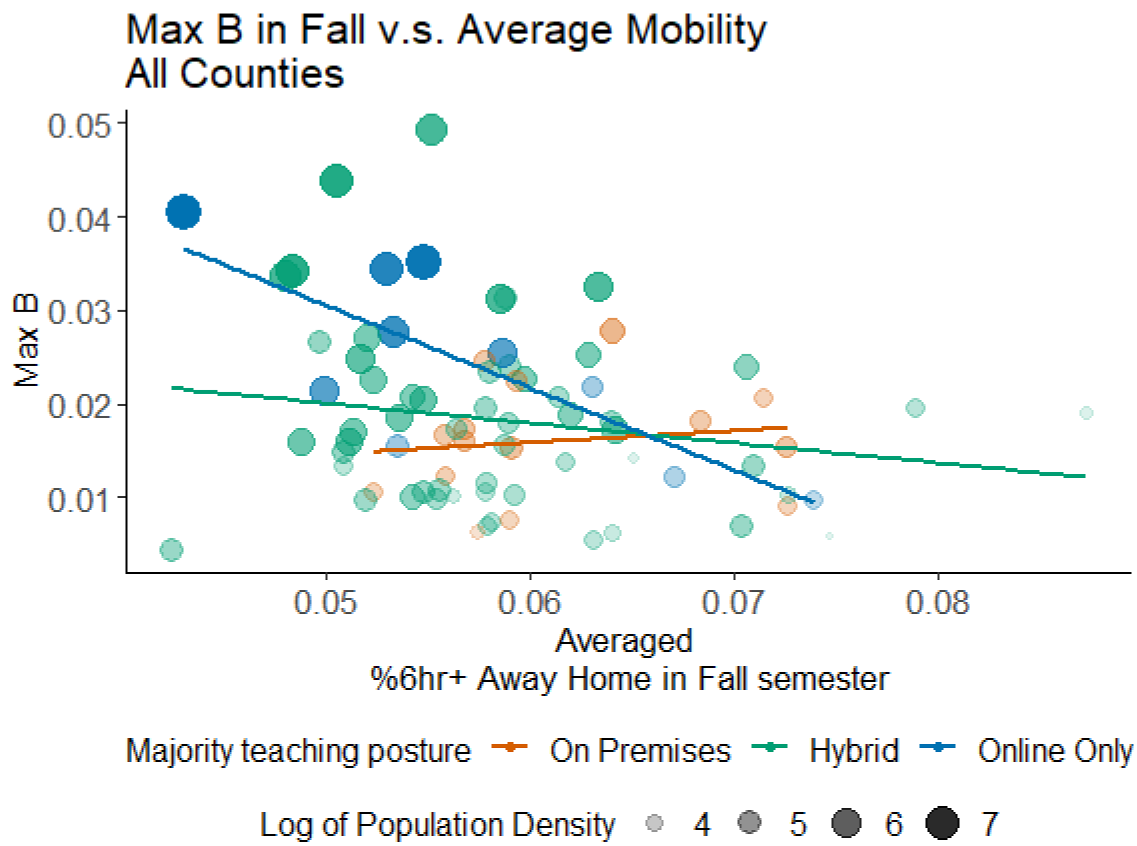
```
na.omit(B0B1)%>%
  ggplot(aes(x=major_teaching,y=max_B1))+geom_boxplot(aes(fill=major_te
aching),width=0.6)+
  labs(title="",x="Majority teaching posture",y="Max Growth",fill="Majo
rity teaching posture")+
  team_theme+theme(legend.position = "bottom")+scale_fill_manual(values
=col_theme)
```



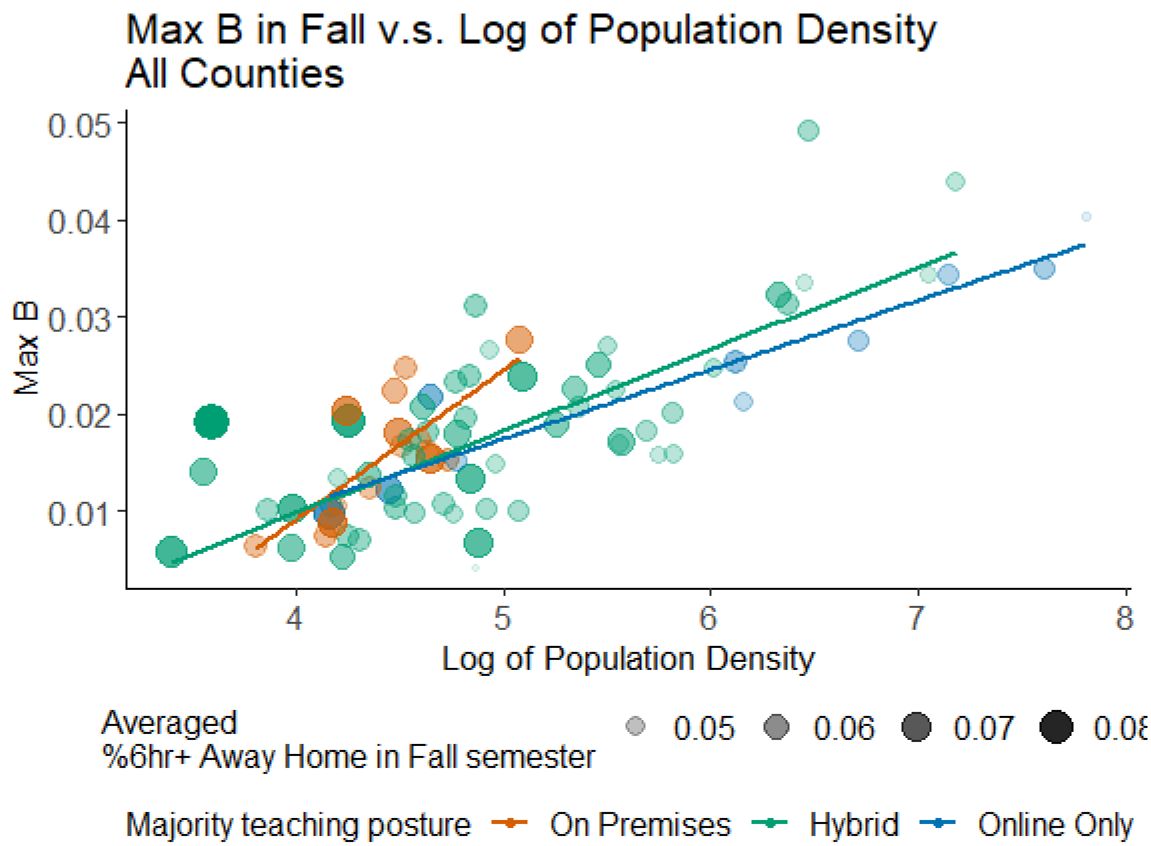
4.6 Max B vs. mobility and log population density for all counties

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 posture",size = "Log of Population Density",alpha= "Log of Popul
ation Density" )+
  team_theme+theme(legend.position = "bottom")+
  scale_color_manual(values=col_theme)
```




```r
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 p
osture",size = "Averaged \n%6hr+ Away Home in Fall semester",alpha= "Av
eraged \n%6hr+ Away Home in Fall semester" )+team_theme+theme(legend.po
sition = "bottom")+
  scale_color_manual(values=col_theme)
```



Appendix 5: Micropolitan Counties

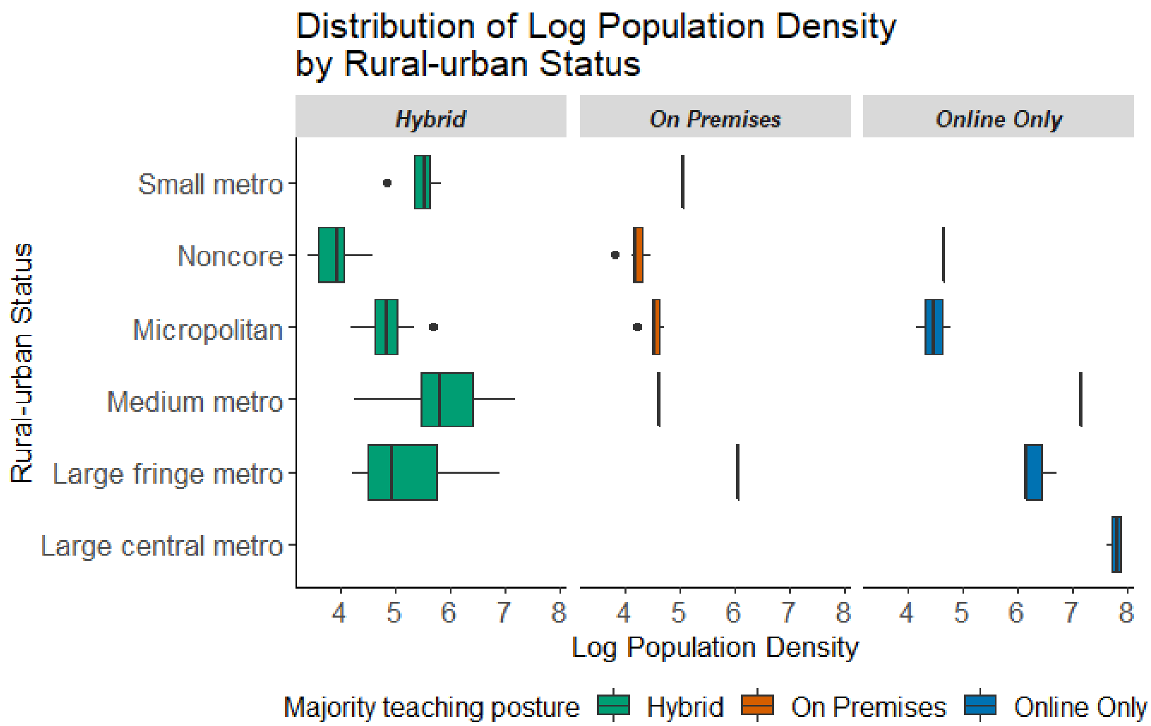
We reduce our sample to micropolitan counties in order to reduce the effect from other confounders. This section gives plots related to micropolitan coungties.

5.1 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 posture",
       size="Averaged \n%6hr+ Away Home",
       title="Distribution of Log Population Density \nby Rural-urban S
```

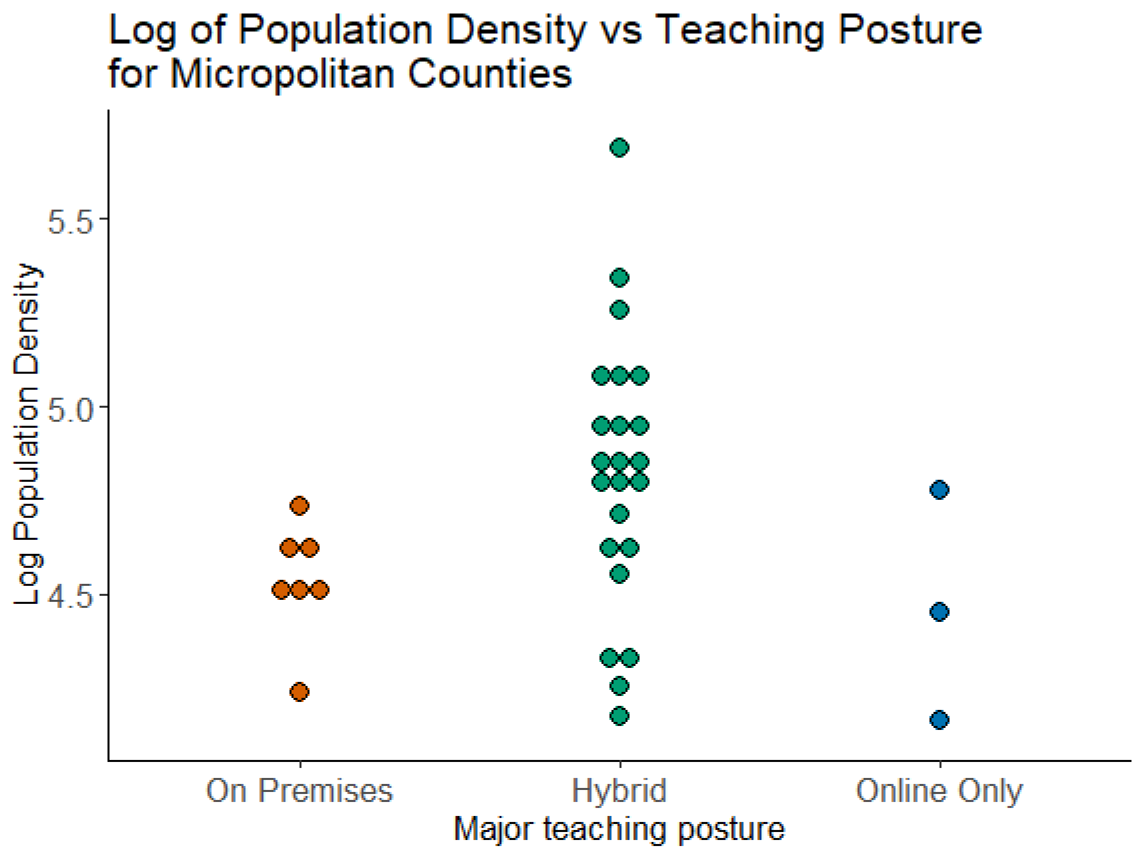
```
tatus",
       x="Log Population Density", y= "Rural-urban Status")+
  team_theme+
  scale_fill_manual(values=col_theme)+
  theme(legend.position = "bottom")
```



5.2 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.

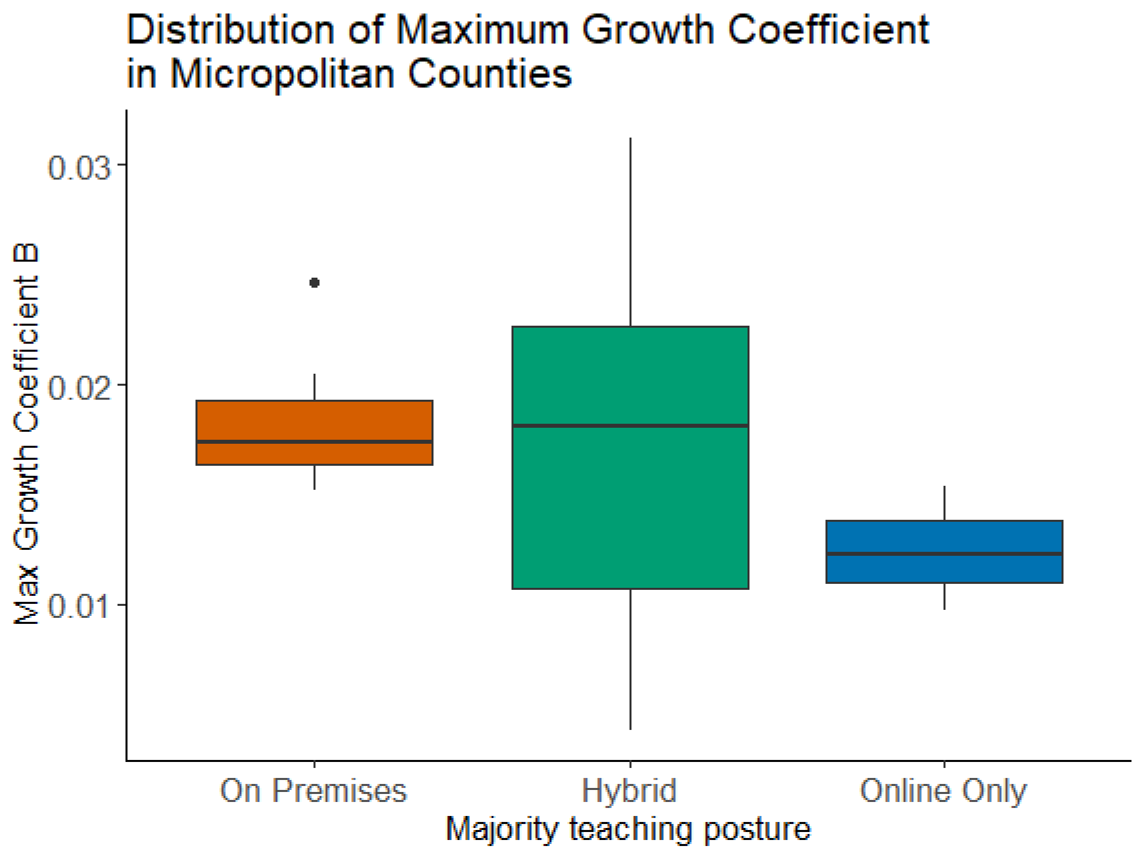
```
ohio_profile%>%
  filter(NCHS.Urban.Rural.Status=="Micropolitan")%>%
 left_join(B0B1%>%select(COUNTY,major_teaching),by=c("County"="COUNTY
"))%>%
  ggplot(aes(x=major_teaching))+
  geom_dotplot(aes(y=log(Population.density),fill=major_teaching),binax
is='y', stackdir='center')+team_theme+guides(fill=FALSE)+labs(y="Log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



5.3 Distribution of Maximum Growth Coefficient Micropolitan Counties

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

```
#Micropolitan counties
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))+
  team_theme+
  theme(legend.position = " ")+
  labs(y="Max Growth Coefficient B",x="Majority teaching posture",title
="Distribution of Maximum Growth Coefficient \nin Micropolitan Counties
",
      fill="Majority teaching posture")+
  scale_fill_manual(values=col_theme)
```

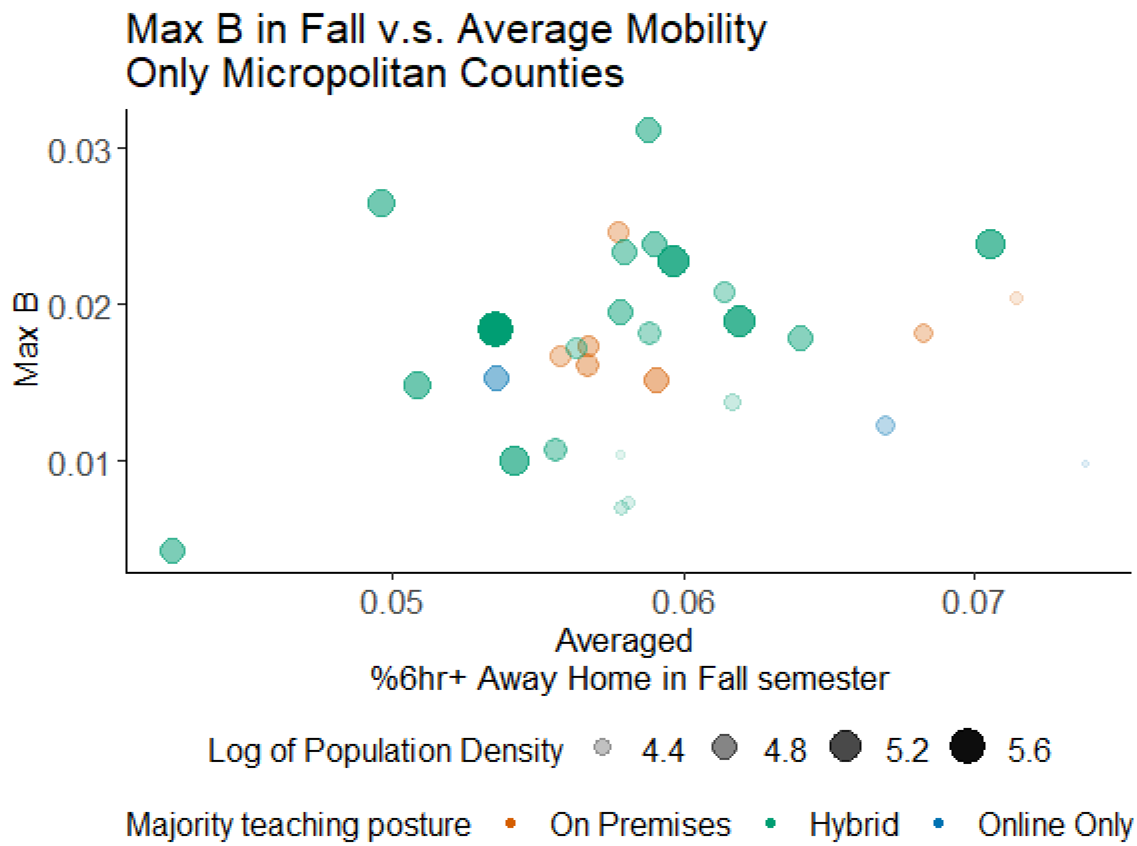


5.4 Max B vs. Mobility and Population Density in Micropolitan Counties

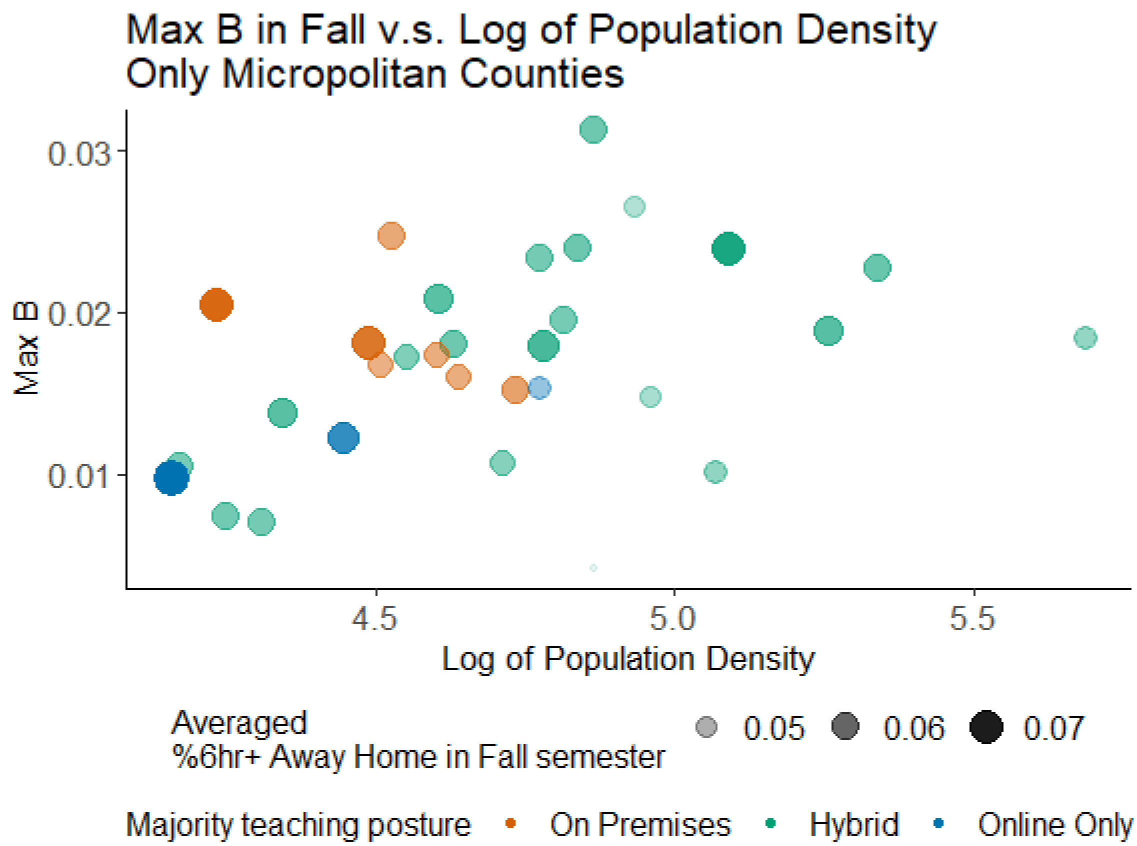
These plots show that after blocking data to micropolitan counties, the relationship between growth coefficient and mobility & log population density is not obvious.

```
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)))+
  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 posture",
       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))+
  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 posture",
       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)
```



5.5 Change in Growth vs Mobility and Log Population Density

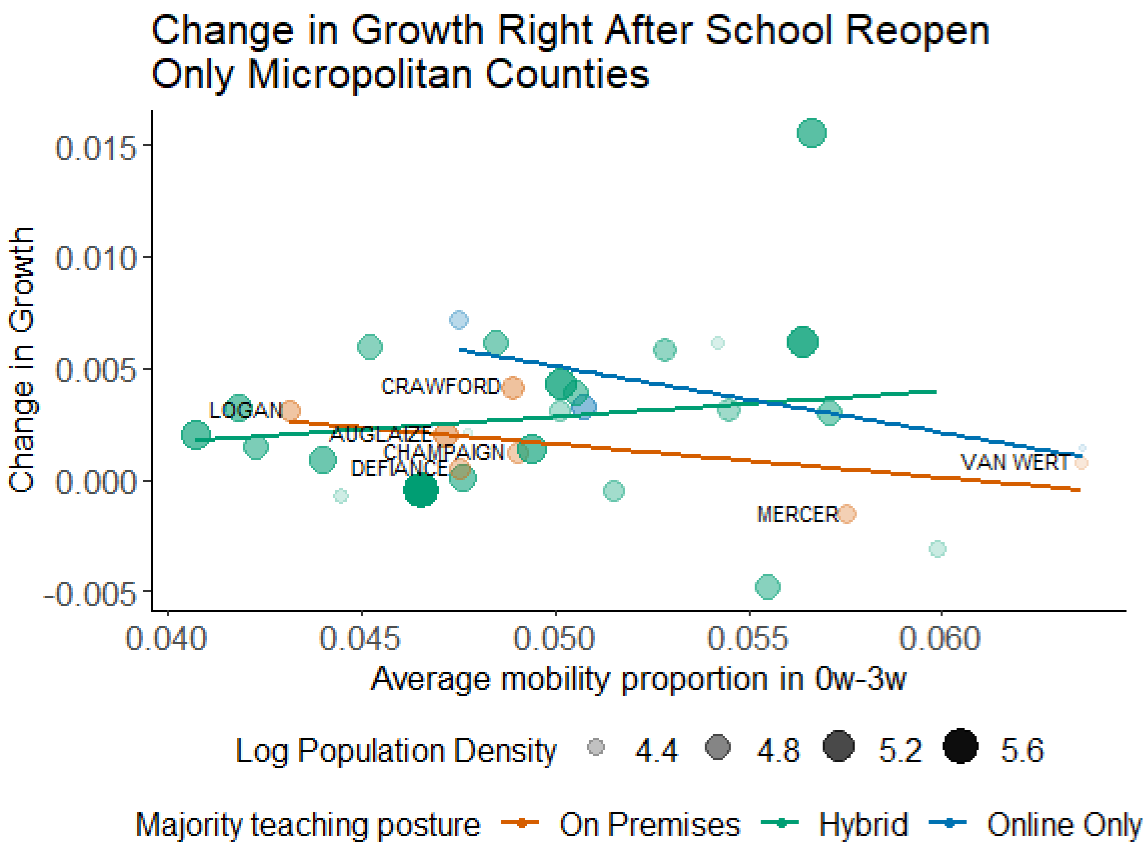
The follwing plots show the change in growth right after school and three weeks later and we observed obvious shifting of red line.

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

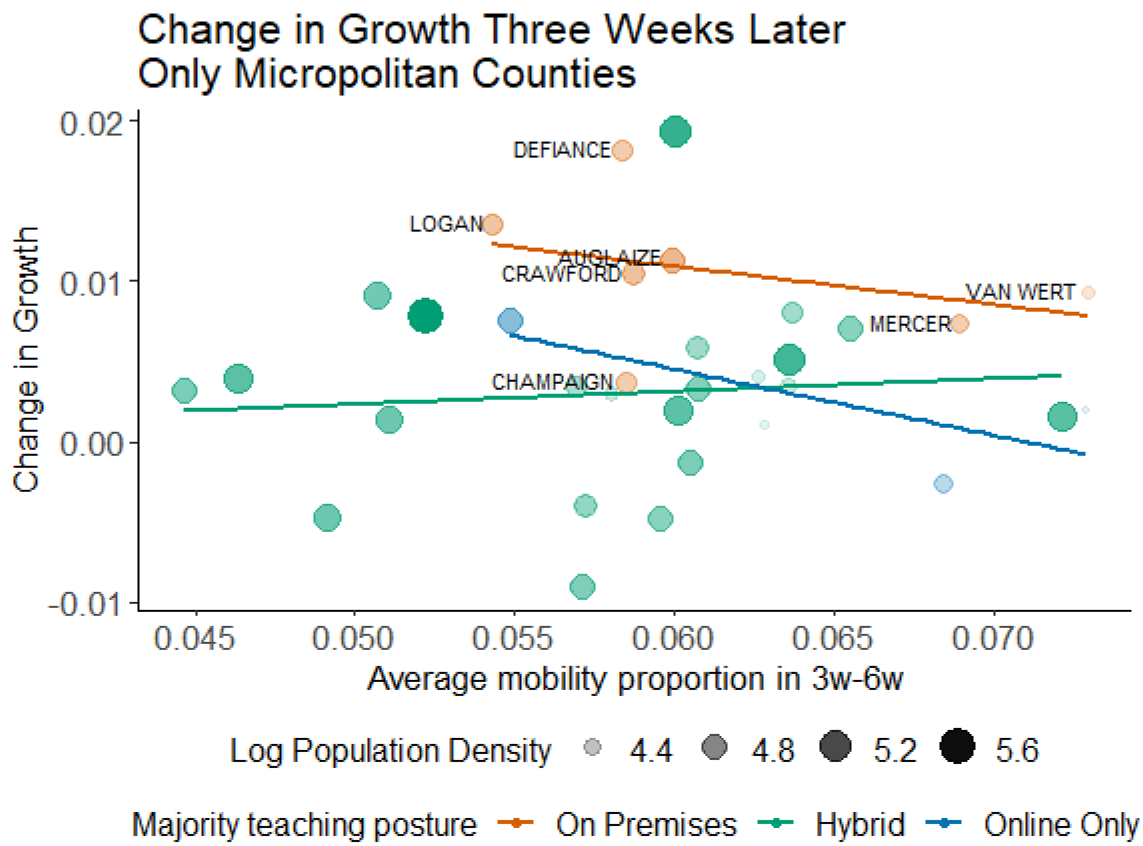
Mobility

```
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 posture",
       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)
```

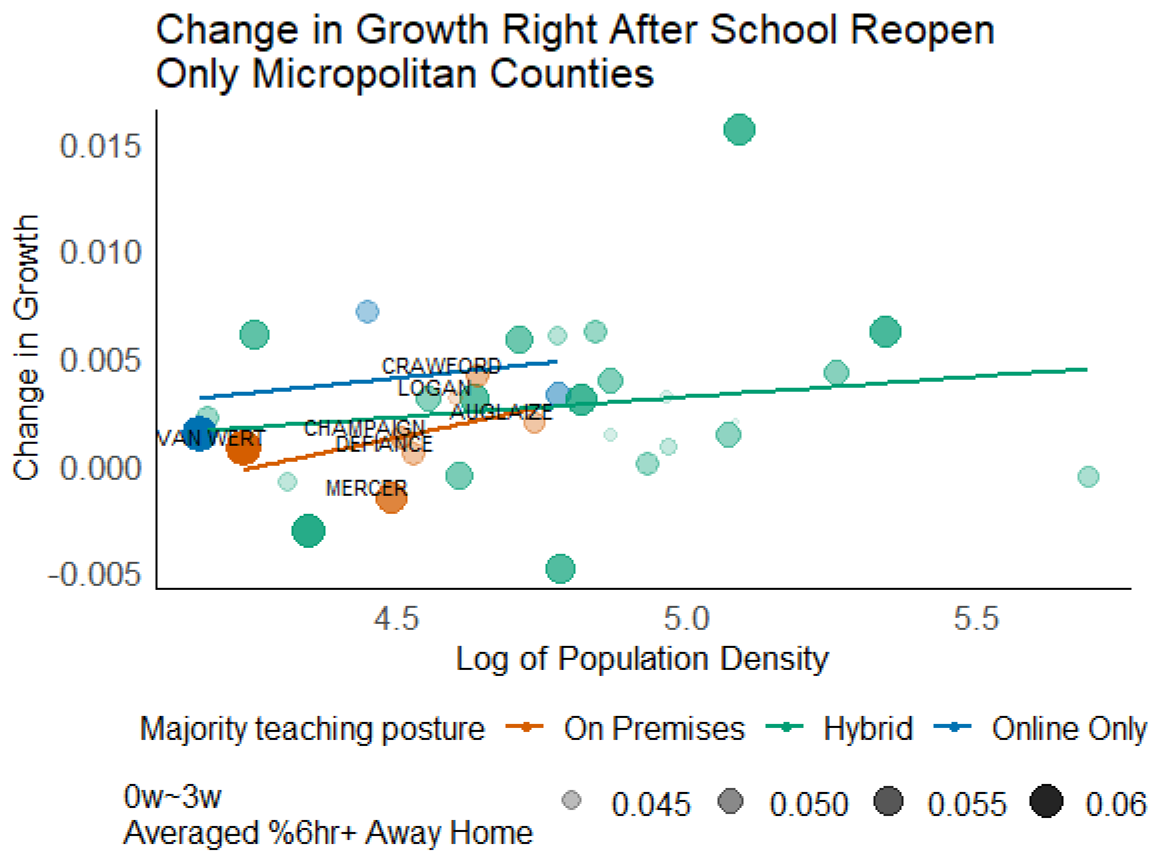



```
B_diff_micro%>%
  ggplot(aes(x=avg2_full_work_prob,y=new.slope.diff2,group=major_teachi
ng,color=major_teaching))+geom_point(aes(size=log(Population.density),a
lpha=log(Population.density)))+geom_smooth(method = "lm", se=F, formula
 = y ~ x,alpha=0.1)+
  labs(y="Change in Growth",x="Average mobility proportion in 3w-6w",
       title="Change in Growth Three Weeks Later\nOnly Micropolitan Cou
nties",
       color="Majority teaching posture",
       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)
```

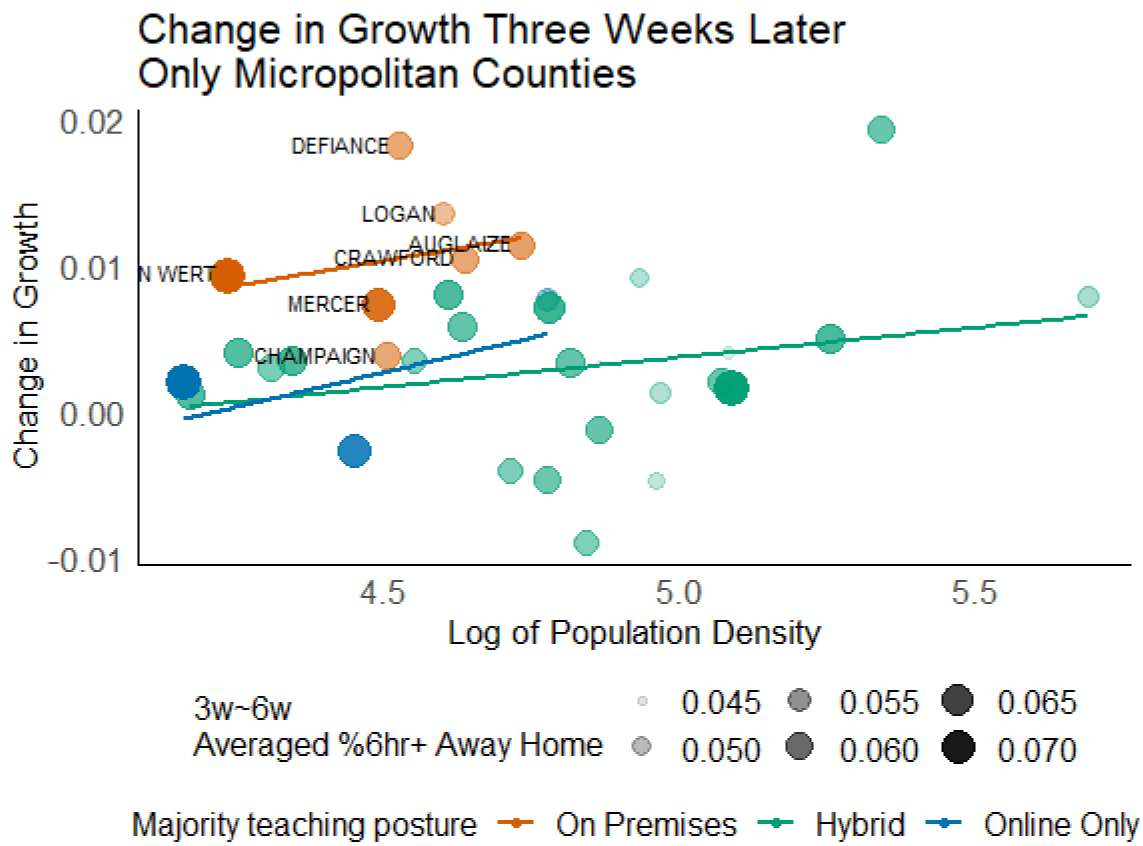


Log Population Density

```
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 posture",
       size = "0w~3w\nAveraged %6hr+ Away Home",
       alpha= "0w~3w\nAveraged %6hr+ Away Home" ,fill="Majority teachin
g posture")+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)
```




```
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 posture",
       size = "3w~6w\nAveraged %6hr+ Away Home",
       alpha= "3w~6w\nAveraged %6hr+ Away Home" ,fill="Majority teachin
g posture")+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=1.1, vjust=0.3)
```



5.6 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.

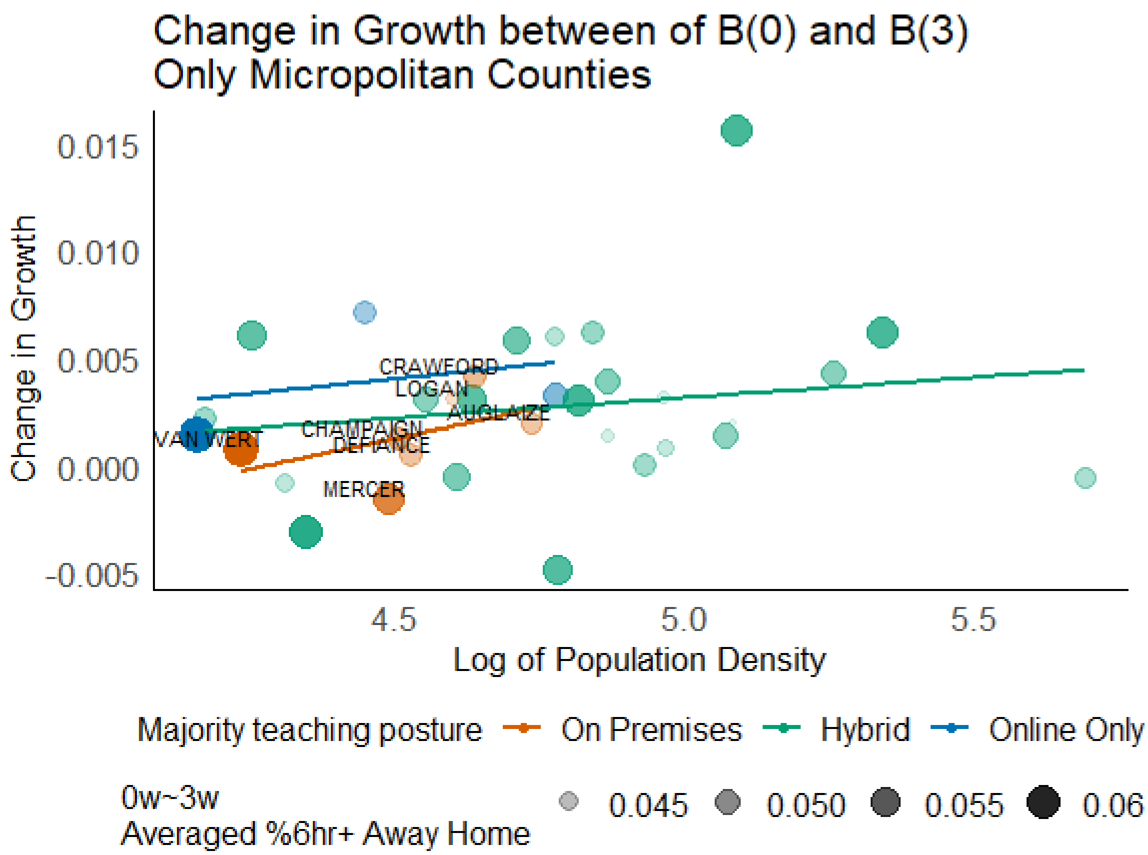
Since we assume that the school posture takes three weeks to reflect on the growth coefficient, the growth coefficients before 3 weeks after the start of school are all regarded as not taking effect. So, we use B(3) as a turning point. The changes in growth we want to test are as below:

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)

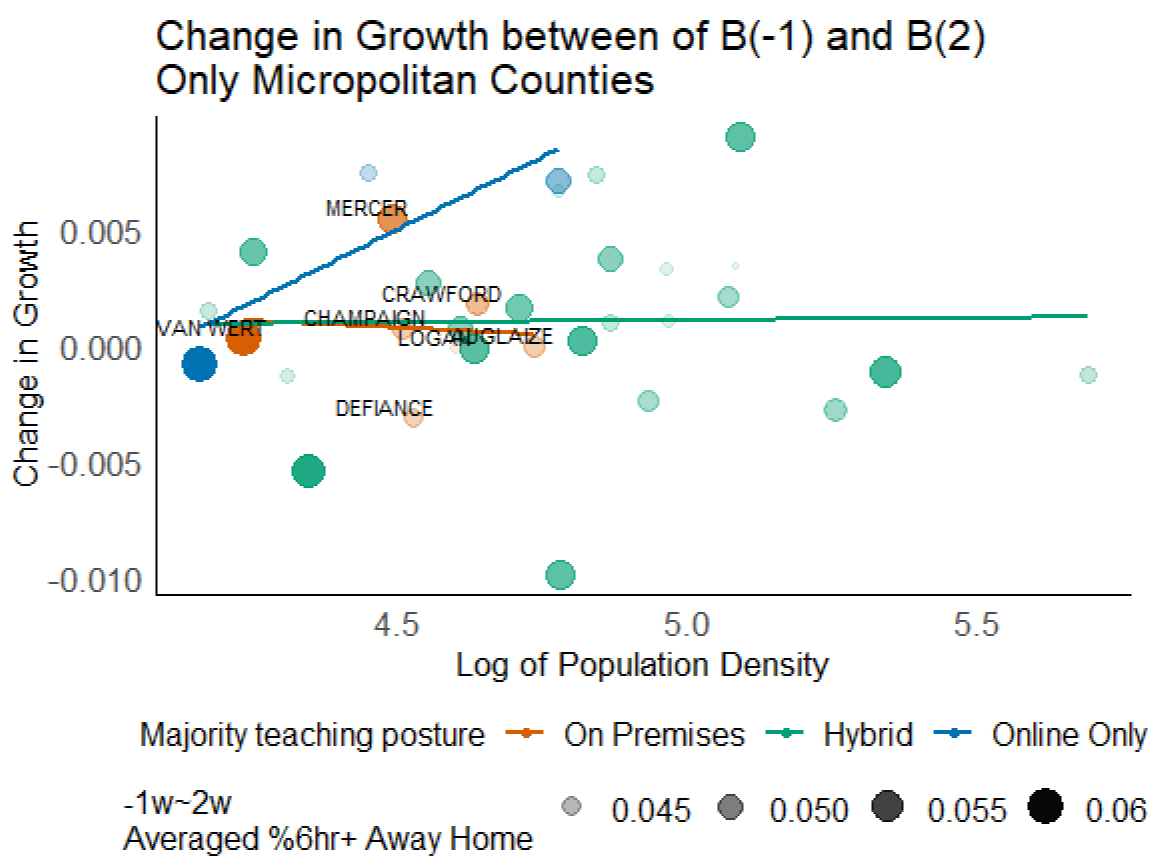
```
#Before reopen
##3w-0w
B_diff_micro%>%
  ggplot(aes(x=log(Population.density),y=new.slope.diff,group=major_tea
ching,color=major_teaching))+geom_point(aes(size=avg_full_work_prob,alp
ha=avg_full_work_prob))+geom_smooth(method = "lm", se=F, formula = y ~
```

```
x,alpha=0.1)+theme_minimal()+team_theme+
  labs(y="Change in Growth",x="Log of Population Density",
       title="Change in Growth between of B(0) and B(3)\nOnly Micropoli
tan Counties",
       color="Majority teaching posture",
       size = "0w~3w\nAveraged %6hr+ Away Home",
       alpha= "0w~3w\nAveraged %6hr+ Away Home" ,fill="Majority teachin
g posture")+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)
```

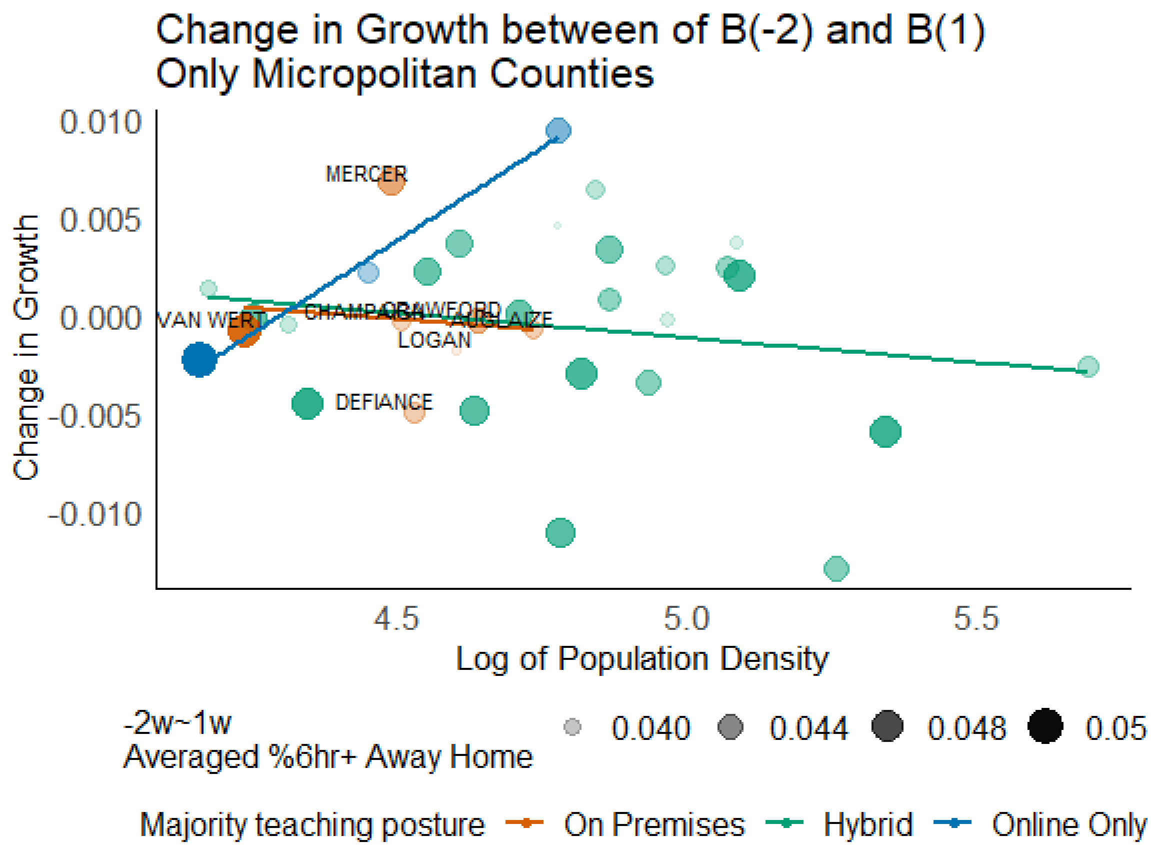



```
ggsave("p1.png",height = 6,width = 7)

##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 posture",
       size = "-1w~2w\nAveraged %6hr+ Away Home",
```

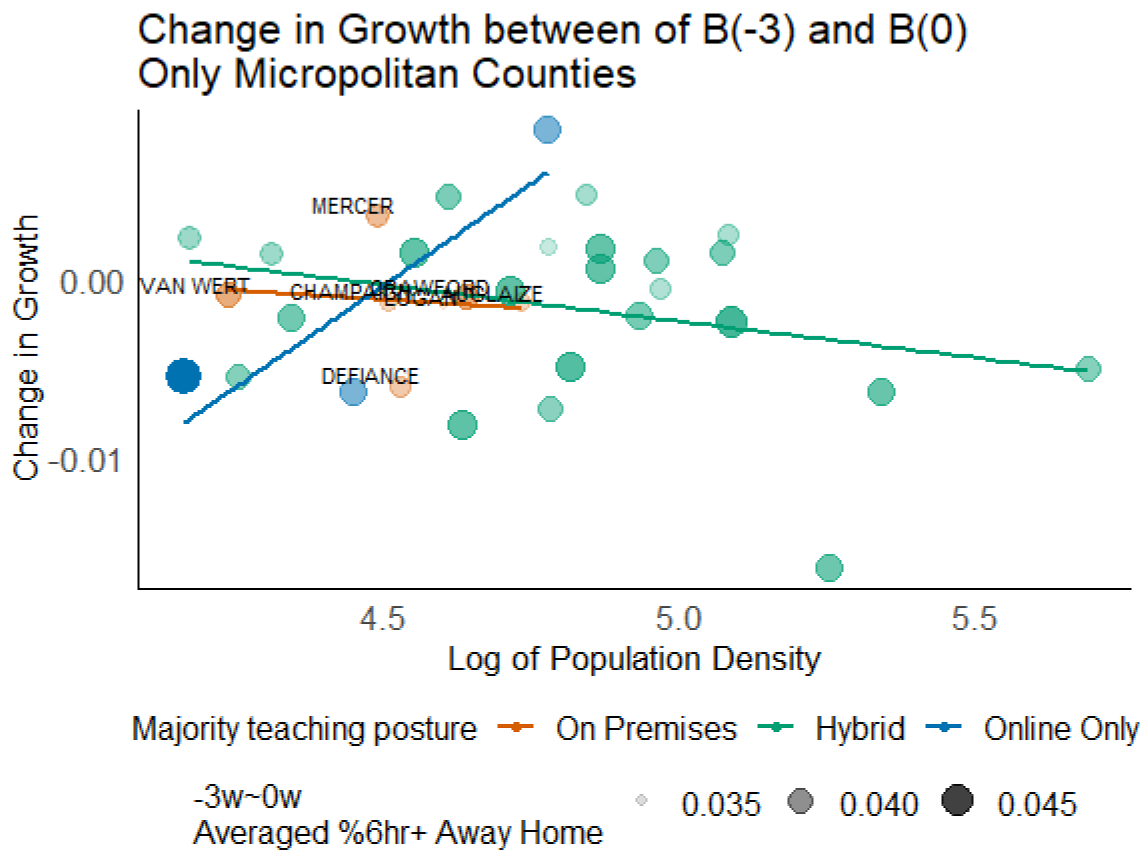
```
       alpha= "-1w~2w\nAveraged %6hr+ Away Home" ,fill="Majority teachi
ng posture")+scale_color_manual(values=col_theme)+theme(legend.position
 = "bottom")+geom_text(data =B_diff_micro%>%filter(major_teaching=="On
Premises"),aes(label=COUNTY),color='black',size=3,hjust=0.8, vjust=-0.
2)
```



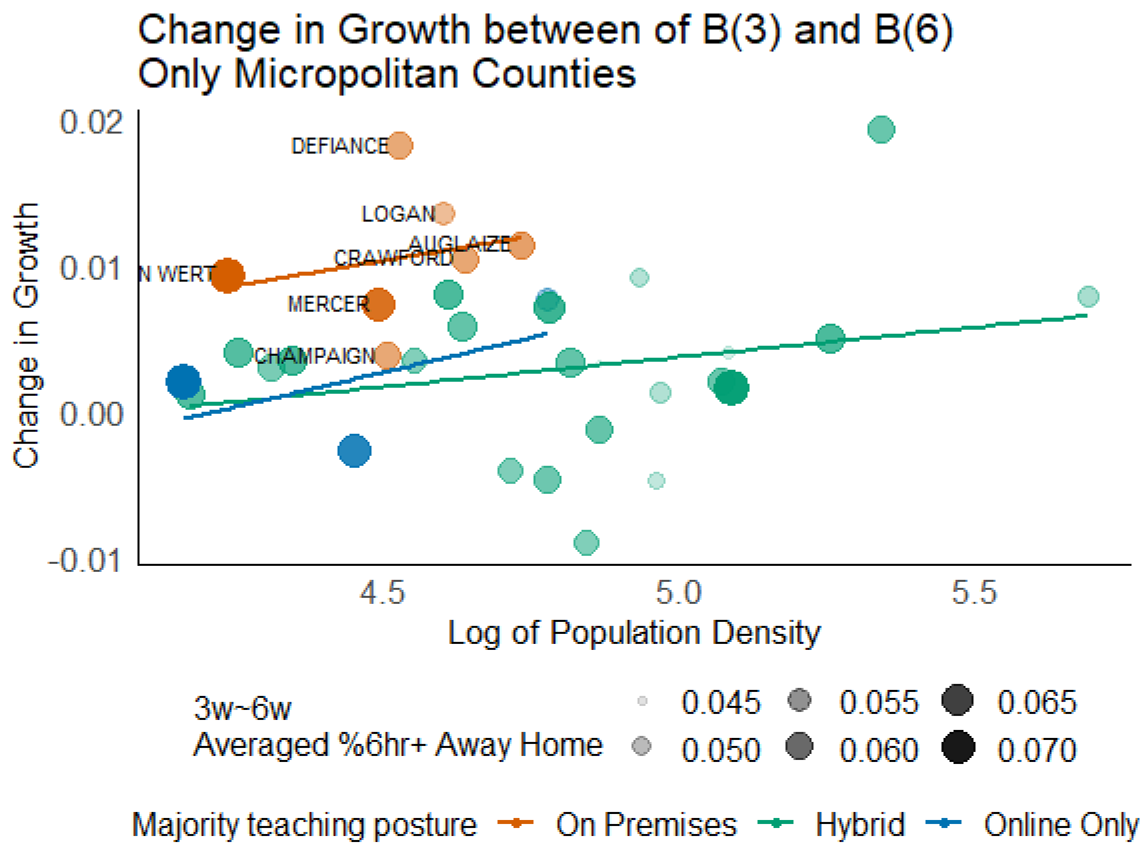

```
ggsave("p2.png",height = 6,width = 7)

##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 posture",
       size = "-2w~1w\nAveraged %6hr+ Away Home",
       alpha= "-2w~1w\nAveraged %6hr+ Away Home" ,fill="Majority teachi
ng posture")+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=0.8, vjust=-0.
2)
```



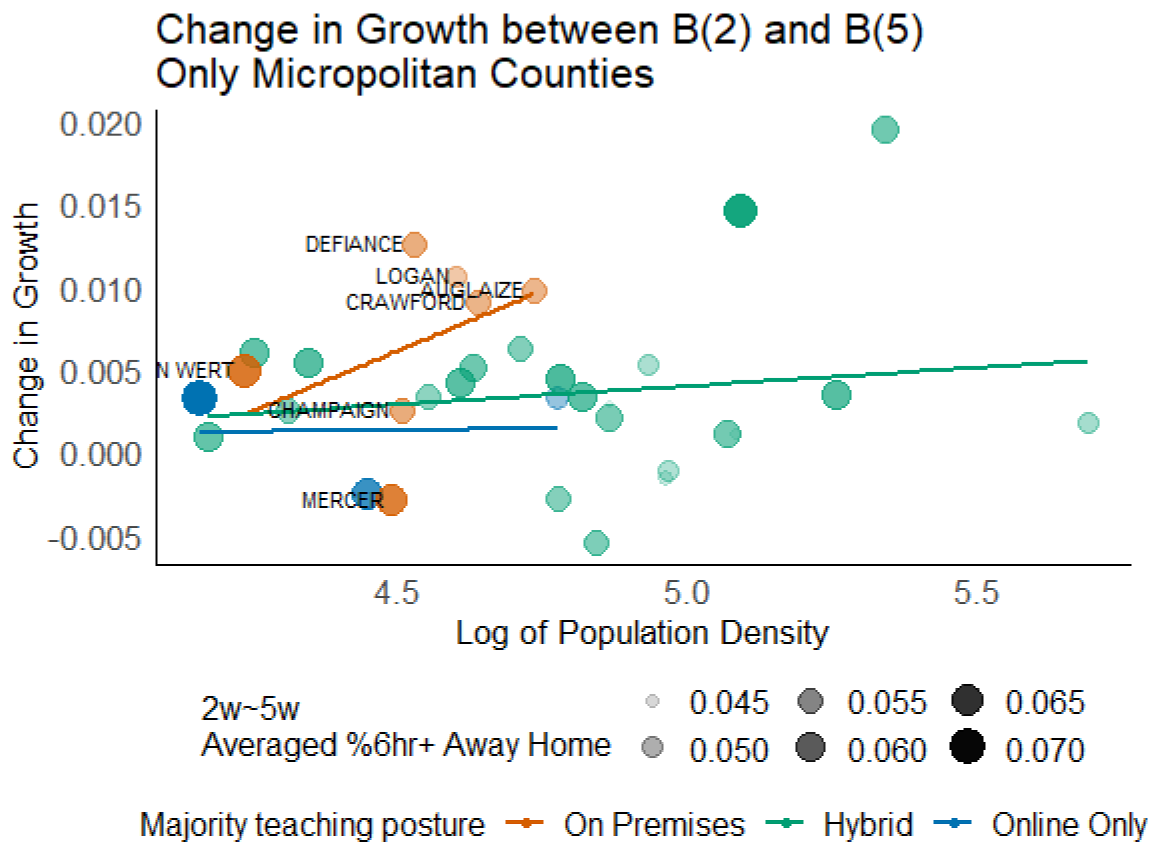

```
ggsave("p3.png",height = 6,width = 7)

##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 Micropolitan Counties",
       color="Majority teaching posture",
       size = "-3w~0w\nAveraged %6hr+ Away Home",
       alpha= "-3w~0w\nAveraged %6hr+ Away Home" ,fill="Majority teaching posture")+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=0.8, vjust=-0.2)
```



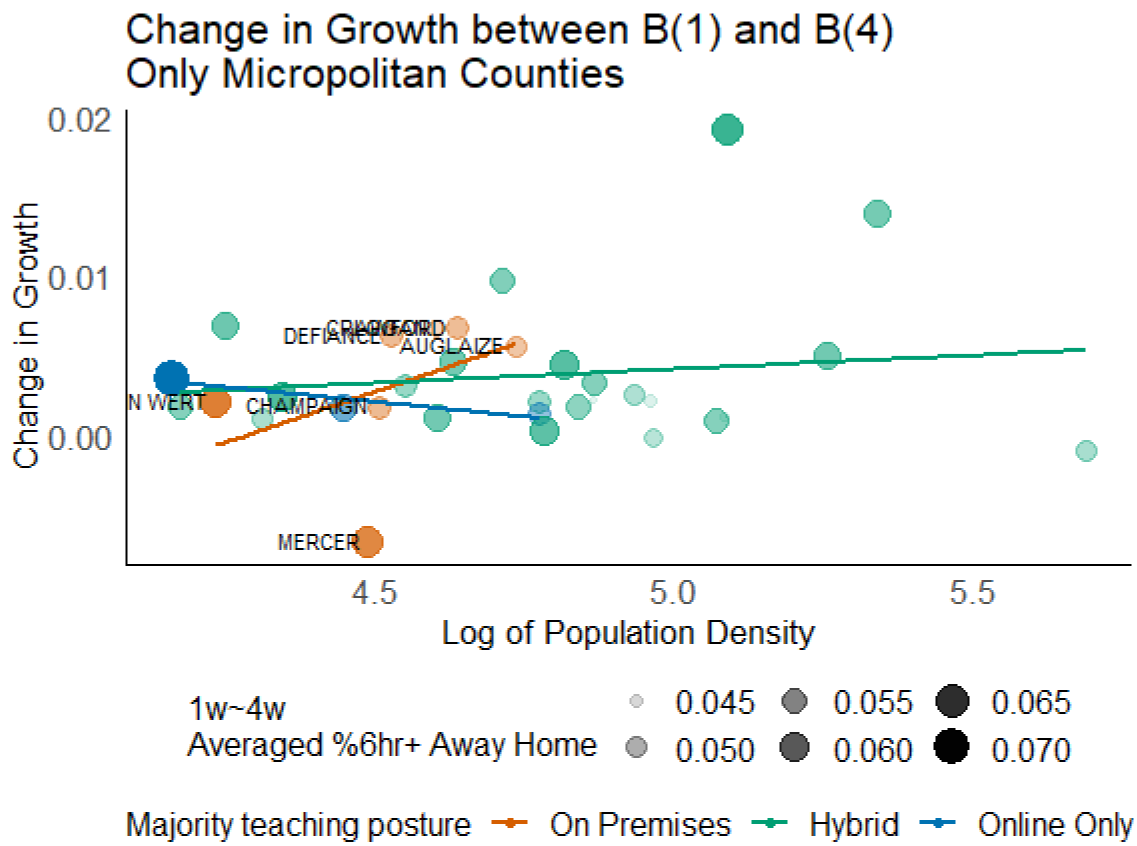

```
ggsave("p4.png",height = 6,width = 7)

#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 between of B(3) and B(6)\nOnly Micropoli
tan Counties",
       color="Majority teaching posture",
       size = "3w~6w\nAveraged %6hr+ Away Home",
       alpha= "3w~6w\nAveraged %6hr+ Away Home" ,fill="Majority teachin
g posture")+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=1.1, vjust=0.3)
```



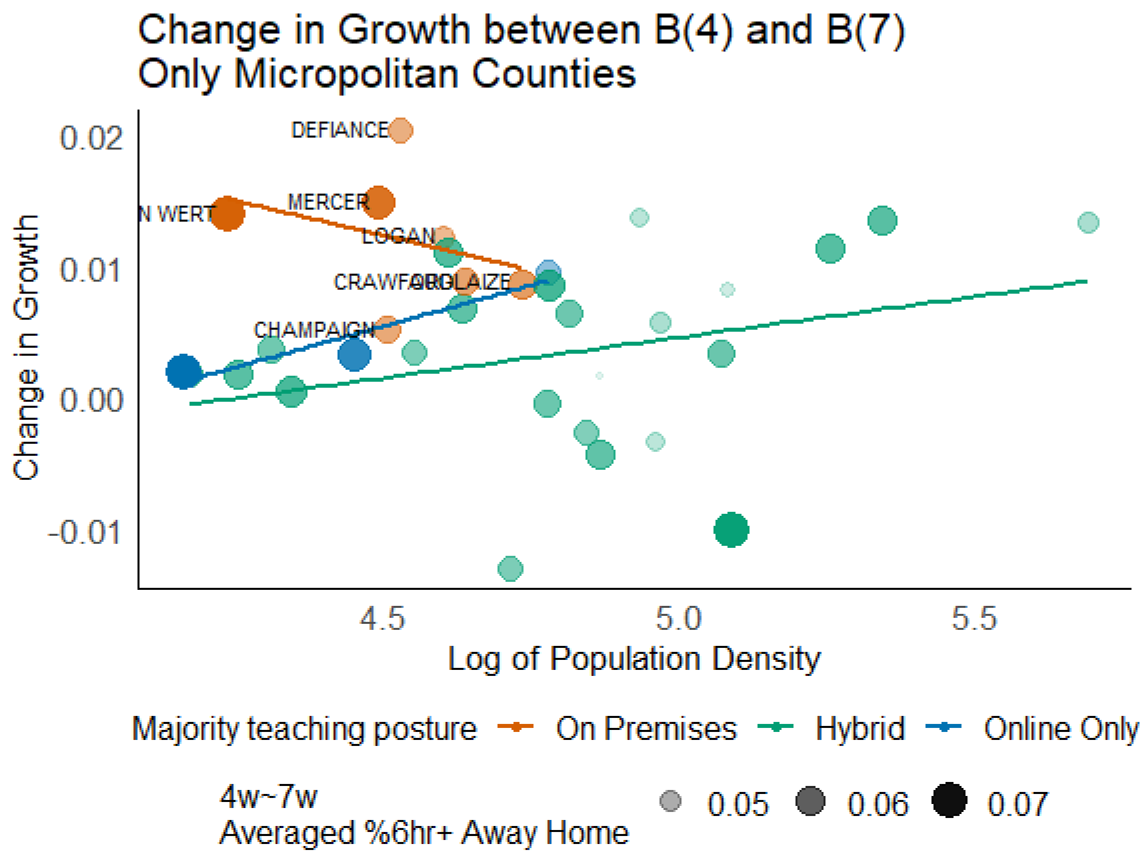

```r
ggsave("p5.png",height = 6,width = 7)

##5w-2w
B_diff_micro%>%
  ggplot(aes(x=log(Population.density),y=new.slope.diff52,group=major_teaching,color=major_teaching))+geom_point(aes(size=avg_full_work_prob_2w5w,alpha=avg_full_work_prob_2w5w))+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(2) and B(5)\nOnly Micropolitan Counties",
       color="Majority teaching posture",
       size = "2w~5w\nAveraged %6hr+ Away Home",
       alpha= "2w~5w\nAveraged %6hr+ Away Home" ,fill="Majority teaching posture")+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)
```




```r
ggsave("p6.png",height = 6,width = 7)

##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 posture",
       size = "1w~4w\nAveraged %6hr+ Away Home",
       alpha= "1w~4w\nAveraged %6hr+ Away Home" ,fill="Majority teaching posture")+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)
```




```
ggsave("p7.png",height = 6,width = 7)

##7w-4w
B_diff_micro%>%
  ggplot(aes(x=log(Population.density),y=new.slope.diff74,group=major_teaching,color=major_teaching))+geom_point(aes(size=avg_full_work_prob_4w7w,alpha=avg_full_work_prob_4w7w))+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(4) and B(7)\nOnly Micropolitan Counties",
       color="Majority teaching posture",
       size = "4w~7w\nAveraged %6hr+ Away Home",
       alpha= "4w~7w\nAveraged %6hr+ Away Home" ,fill="Majority teaching posture")+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)
```




```
ggsave("p8.png",height = 6,width = 7)
```

Appendix 6: Math Plots

6.1 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")
```