COVID-19-Spain-Analysis

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This notebook reports our initial analysis of COVID-19 incidence in Spain and the climatic correlates of incidence. The data have been organized in a package for ease of access and distribution. The name of the package is `covid19env` and if necessary can be installed from the GitHub repository.

Preliminaries

Load packages:

```
library(covid19env)
library(ggthemes)
library(gridExtra)
library(lubridate)
library(sf)
library(spdep)
library(spsur)
library(tidyverse)
library(units)
#library(spatialreg)
#library(systemfit)
#library(plm)
#library(splm)
```

Load data from package `covid19env`

```
data("covid19_spain")
data("provinces_spain")
```

Summarize the data:

```
covid19_spain %>%
  summary()
```

```
##              province                         CCAA         ID_INE
##  Albacete        :  30   Castilla y Leon     :270   Min.   : 1.0
##  Alicante/Alacant:  30   Andalucia           :240   1st Qu.:13.0
##  Almeria         :  30   Castilla - La Mancha:150   Median :25.5
##  Araba/alava     :  30   CataluÃ±a           :120   Mean   :25.5
##  Asturias        :  30   Galicia             :120   3rd Qu.:38.0
##  Avila           :  30   Aragon              : 90   Max.   :50.0
##  (Other)         :1320   (Other)             :510
##       Date                Cases            Incidence           Population
##  Min.   :2020-03-13   Min.   :    1.0   Min.   :   0.3832   Min.   :  88636
##  1st Qu.:2020-03-20   1st Qu.:  168.0   1st Qu.:  26.6722   1st Qu.: 331549
##  Median :2020-03-27   Median :  547.5   Median :  88.3491   Median : 684202
##  Mean   :2020-03-27   Mean   : 1485.7   Mean   : 153.6087   Mean   : 974257
```

```
##  3rd Qu.:2020-04-04   3rd Qu.: 1290.0   3rd Qu.: 209.6307   3rd Qu.:1149460
##  Max.   :2020-04-11   Max.   :45849.0   Max.   :1149.3577   Max.   :6663394
##
##      Older          Median_Age      Male2Female         GDPpc          Transit
##  Min.   :15.16   Min.   :40.19   Min.   : 91.59   Min.   :16666   Min.   :0.0
##  1st Qu.:18.02   1st Qu.:42.35   1st Qu.: 95.43   1st Qu.:18813   1st Qu.:0.0
##  Median :19.93   Median :43.70   Median : 98.06   Median :20870   Median :0.0
##  Mean   :21.03   Mean   :44.55   Mean   : 97.83   Mean   :22506   Mean   :0.1
##  3rd Qu.:23.07   3rd Qu.:46.01   3rd Qu.:100.08   3rd Qu.:25901   3rd Qu.:0.0
##  Max.   :31.36   Max.   :50.68   Max.   :103.01   Max.   :36001   Max.   :1.0
##
##       Area               Altitude          Coast       Meteo_Station
##  Min.   :1.979e+09   Min.   :   5.0   Min.   :0.00   0016A  :  30
##  1st Qu.:6.637e+09   1st Qu.:  24.0   1st Qu.:0.00   0076   :  30
##  Median :1.001e+10   Median : 215.5   Median :0.00   0367   :  30
##  Mean   :1.012e+10   Mean   : 369.0   Mean   :0.42   1024E  :  30
##  3rd Qu.:1.377e+10   3rd Qu.: 685.0   3rd Qu.:1.00   1082   :  30
##  Max.   :2.179e+10   Max.   :1131.0   Max.   :1.00   1111X  :  30
##                                                      (Other):1320
##     Max_Temp         Min_Temp         Mean_Temp     Mean_Temp_lag8
##  Min.   : 3.10   Min.   :-4.700   Min.   : 1.00   Min.   : 4.275
##  1st Qu.:14.68   1st Qu.: 4.400   1st Qu.: 9.80   1st Qu.: 9.637
##  Median :17.30   Median : 7.600   Median :12.40   Median :11.600
##  Mean   :17.07   Mean   : 7.289   Mean   :12.18   Mean   :11.779
##  3rd Qu.:19.80   3rd Qu.:10.200   3rd Qu.:14.60   3rd Qu.:13.713
##  Max.   :27.10   Max.   :20.600   Max.   :23.20   Max.   :20.200
##
##  Mean_Temp_lag11  Mean_Temp_lag11w Sunshine_Hours   Sunshine_Hours_lag8
##  Min.   : 5.118   Min.   : 4.201   Min.   : 0.000   Min.   : 0.000
##  1st Qu.: 9.770   1st Qu.: 9.803   1st Qu.: 1.800   1st Qu.: 4.938
##  Median :11.795   Median :11.781   Median : 6.100   Median : 6.275
##  Mean   :11.872   Mean   :11.903   Mean   : 5.738   Mean   : 6.221
##  3rd Qu.:13.598   3rd Qu.:13.941   3rd Qu.: 9.400   3rd Qu.: 7.781
##  Max.   :20.700   Max.   :21.167   Max.   :12.400   Max.   :10.938
##
##  Sunshine_Hours_lag11 Sunshine_Hours_lag11w Precipitation    Precipitation_lag8
##  Min.   : 0.000       Min.   : 0.000        Min.   :0.0000   Min.   :0.0000
##  1st Qu.: 5.164       1st Qu.: 4.771        1st Qu.:0.0000   1st Qu.:0.2500
##  Median : 6.273       Median : 6.313        Median :0.0000   Median :0.3750
##  Mean   : 6.188       Mean   : 6.212        Mean   :0.4447   Mean   :0.3762
##  3rd Qu.: 7.518       3rd Qu.: 7.862        3rd Qu.:1.0000   3rd Qu.:0.5000
##  Max.   :10.136       Max.   :11.041        Max.   :1.0000   Max.   :1.0000
##
##  Precipitation_lag11 Precipitation_lag11w    Humidity      Humidity_lag8
##  Min.   :0.0000      Min.   :0.0000       Min.   :  2.00   Min.   :40.24
##  1st Qu.:0.2727      1st Qu.:0.1845       1st Qu.: 71.00   1st Qu.:70.30
##  Median :0.3636      Median :0.3963       Median : 78.44   Median :75.98
##  Mean   :0.3834      Mean   :0.3831       Mean   : 77.82   Mean   :75.00
##  3rd Qu.:0.5455      3rd Qu.:0.5631       3rd Qu.: 85.00   3rd Qu.:80.38
##  Max.   :1.0000      Max.   :1.0000       Max.   :100.00   Max.   :94.61
##
##  Humidity_lag11  Humidity_lag11w
##  Min.   :42.20   Min.   :40.10
##  1st Qu.:71.19   1st Qu.:70.94
```

```
##   Median :76.14   Median :76.99
##   Mean   :75.48   Mean   :75.84
##   3rd Qu.:80.32   3rd Qu.:81.08
##   Max.   :93.36   Max.   :94.04
##
```

The dataframe is a simple features object with information at the level of the province. The dataframe includes information about the province, including its Autonomous Community (a superior jurisdiction), an identifier, dates, COVID-19 cases and incidence. The period covered is from March 13, 2020 to April 11, 2020. In addition there are some demographic controls, and various climatic variables. Of interest are the lagged variables. The lagged variables are 8-day moving averages calculated using date-minus-12-days to date-minus-5-days, to account for the latency of the infection. More information about the dataset can be obtained by typing `?covid18_spain`.

There are 50 provinces in the dataframe `covid19_spain`:

```r
nlevels(covid19_spain$province)
```

```
## [1] 50
```

The dataset covers 30 days:

```r
T <- max(covid19_spain$Date) - min(covid19_spain$Date) + 1 # To include the starting day
T
```

```
## Time difference of 30 days
```

The order to shelter in place in Spain went into effect on March 16, 2020. March 13 is the first day that every province had at least one reported case of COVID-19.

Convert GDP per capita to thousands of euros:

```r
covid19_spain <- covid19_spain %>%
  mutate(GDPpc = GDPpc/1000)
```

Calculate density variable and join to `covid19_spain`:

```r
covid19_spain <- covid19_spain %>%
  left_join(provinces_spain %>%
              left_join(covid19_spain %>%
                          filter(Date == "2020-03-14") %>%
                          select(ID_INE, Population),
                        by = "ID_INE") %>%
              transmute(ID_INE, Density = Population/units::set_units(st_area(provinces_spain), km^2)) 
              st_drop_geometry(),
            by = "ID_INE")
```

Data exploration

Correlation analysis with Incidence:

```r
covid19_spain %>%
  group_by(Date) %>%
  summarize(correlation_age = cor(Median_Age, Incidence),
            correlation_older = cor(Older, Incidence),
            correlation_m2f = cor(Male2Female, Incidence),
            correlation_density = cor(Density, Incidence),
            correlation_gdppc = cor(GDPpc, Incidence),
            correlation_humidity = cor(Humidity_lag11, Incidence),
            correlation_temp = cor(Mean_Temp_lag11, Incidence),
```

```
            correlation_sunshine = cor(Sunshine_Hours_lag11, Incidence)) %>%
  summary()
```

```
##       Date            correlation_age    correlation_older correlation_m2f
##  Min.   :2020-03-13   Min.   :-0.07549   Min.   :-0.2646   Min.   :-0.088806
##  1st Qu.:2020-03-20   1st Qu.: 0.06498   1st Qu.:-0.2298   1st Qu.:-0.037567
##  Median :2020-03-27   Median : 0.23377   Median :-0.2160   Median : 0.009642
##  Mean   :2020-03-27   Mean   : 0.15994   Mean   :-0.2083   Mean   : 0.013288
##  3rd Qu.:2020-04-03   3rd Qu.: 0.26632   3rd Qu.:-0.1807   3rd Qu.: 0.066967
##  Max.   :2020-04-11   Max.   : 0.27278   Max.   :-0.1204   Max.   : 0.106345
##  correlation_density correlation_gdppc correlation_humidity correlation_temp
##  Min.   :-0.08832    Min.   :0.2745    Min.   :-0.03195     Min.   :-0.6211
##  1st Qu.:-0.04832    1st Qu.:0.3354    1st Qu.: 0.04558     1st Qu.:-0.5997
##  Median : 0.03670    Median :0.4257    Median : 0.14829     Median :-0.5504
##  Mean   : 0.03221    Mean   :0.4035    Mean   : 0.13657     Mean   :-0.5160
##  3rd Qu.: 0.10103    3rd Qu.:0.4672    3rd Qu.: 0.20276     3rd Qu.:-0.4505
##  Max.   : 0.16734    Max.   :0.5052    Max.   : 0.31221     Max.   :-0.2780
##  correlation_sunshine
##  Min.   :-0.25196
##  1st Qu.:-0.12233
##  Median : 0.07528
##  Mean   : 0.02127
##  3rd Qu.: 0.13996
##  Max.   : 0.24925
```

The negative correlation of older people is interesting. Our initial idea was that a greater proportion of older people would be related to higher incidence. However, this research reports the contacts, and older people tend to have lower social contact levels across the board, which would explain why *incidence* might be lower in places with a higher proportion of older adults: they are already isolated or in involuntary forms of social isolation due to immobility.

Correlation analysis with Incidence (log-transformed variables):

```
covid19_spain %>%
  group_by(Date) %>%
  summarize(correlation_age = cor(log(Median_Age), log(Incidence)),
            correlation_older = cor(log(Older), log(Incidence)),
            correlation_m2f = cor(log(Male2Female), log(Incidence)),
            correlation_density = cor(log(Density), log(Incidence)),
            correlation_gdppc = cor(log(GDPpc), log(Incidence)),
            correlation_humidity = cor(log(Humidity_lag11), log(Incidence)),
            correlation_temp = cor(log(Mean_Temp_lag11), log(Incidence)),
            correlation_sunshine = cor(log(Sunshine_Hours_lag11 + 0.1), log(Incidence))) %>%
  summary()
```

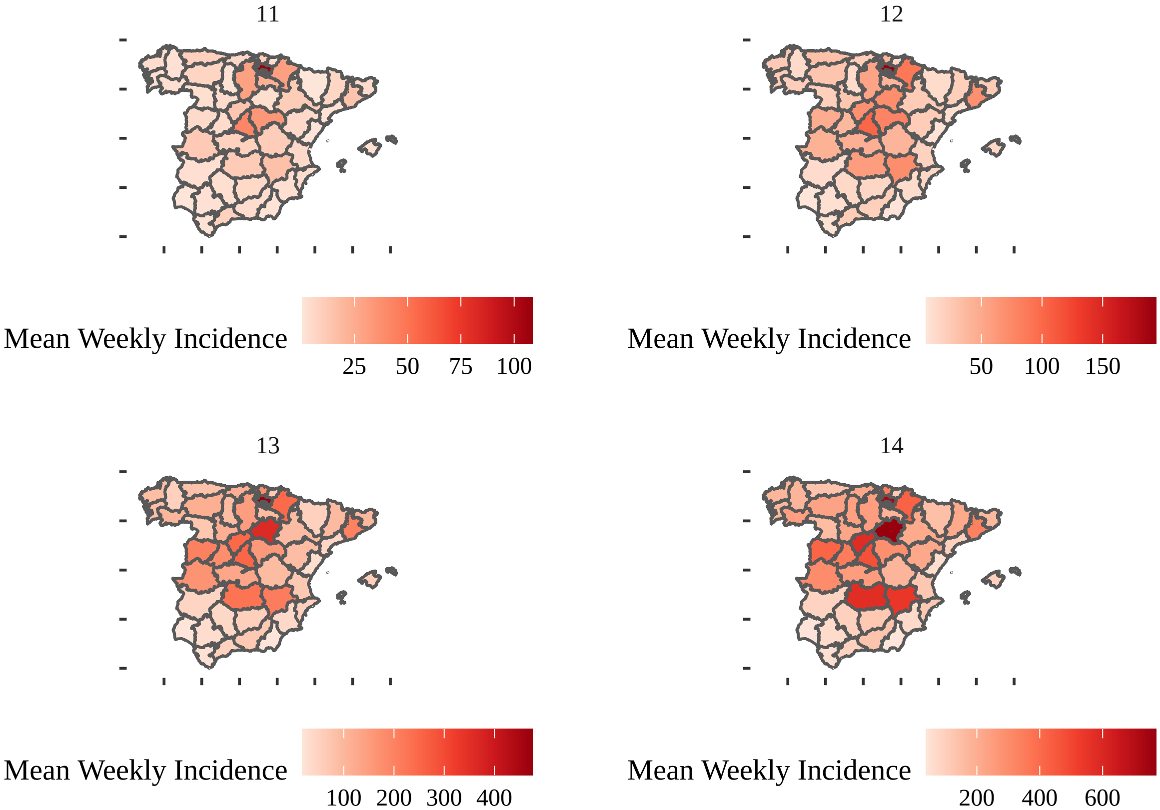
```
##       Date            correlation_age    correlation_older
##  Min.   :2020-03-13   Min.   :-0.05954   Min.   :-0.218157
##  1st Qu.:2020-03-20   1st Qu.: 0.25912   1st Qu.:-0.176906
##  Median :2020-03-27   Median : 0.40458   Median :-0.153385
##  Mean   :2020-03-27   Mean   : 0.32729   Mean   :-0.148579
##  3rd Qu.:2020-04-03   3rd Qu.: 0.44522   3rd Qu.:-0.137772
##  Max.   :2020-04-11   Max.   : 0.45304   Max.   :-0.006352
##  correlation_m2f     correlation_density correlation_gdppc correlation_humidity
##  Min.   :-0.127937   Min.   :-0.37372    Min.   :0.2595    Min.   :-0.056810
##  1st Qu.:-0.072667   1st Qu.:-0.34259    1st Qu.:0.3314    1st Qu.: 0.004894
```

```
##  Median :-0.049076   Median :-0.24061    Median :0.3547    Median : 0.128513
##  Mean   :-0.047487   Mean   :-0.21770    Mean   :0.3541    Mean   : 0.133877
##  3rd Qu.:-0.023532   3rd Qu.:-0.14173    3rd Qu.:0.3800    3rd Qu.: 0.267209
##  Max.   : 0.004793   Max.   : 0.09139    Max.   :0.4123    Max.   : 0.324925
##  correlation_temp  correlation_sunshine
##  Min.   :-0.7454   Min.   :-0.01165
##  1st Qu.:-0.7230   1st Qu.: 0.17008
##  Median :-0.6716   Median : 0.23303
##  Mean   :-0.6133   Mean   : 0.21897
##  3rd Qu.:-0.5388   3rd Qu.: 0.29667
##  Max.   :-0.2716   Max.   : 0.35854
```

There are 30 days in the dataset. We can summarize the incidence by week (excluding Canarias):

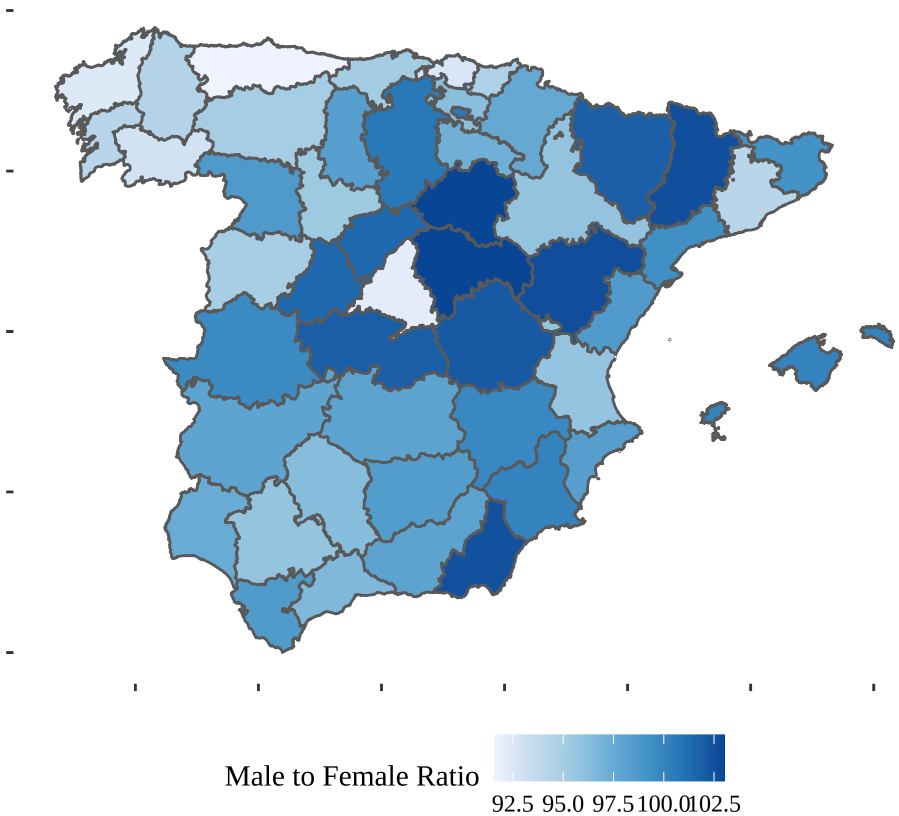
```r
week11.plot <- covid19_spain %>%
  left_join(provinces_spain, by = c("province", "CCAA", "ID_INE")) %>%
  st_as_sf() %>%
  filter(CCAA != "Canarias") %>%
  group_by(province, week = isoweek(Date)) %>%
  summarise(mean_weekly_incidence = mean(Incidence)) %>%
  filter(week == 11) %>%
  ggplot() +
  geom_sf(aes(fill = mean_weekly_incidence)) +
  scale_fill_distiller(name = "Mean Weekly Incidence",
                       palette = "Reds",
                       direction = 1) +
  theme_tufte() +
  theme(axis.text = element_blank(),
        legend.position = "bottom") +
  facet_wrap(~week)

week12.plot <- covid19_spain %>%
  left_join(provinces_spain, by = c("province", "CCAA", "ID_INE")) %>%
  st_as_sf() %>%
  filter(CCAA != "Canarias") %>%
  group_by(province, week = isoweek(Date)) %>%
  summarise(mean_weekly_incidence = mean(Incidence)) %>%
  filter(week == 12) %>%
  ggplot() +
  geom_sf(aes(fill = mean_weekly_incidence)) +
  scale_fill_distiller(name = "Mean Weekly Incidence",
                       palette = "Reds",
                       direction = 1) +
  theme_tufte() +
  theme(axis.text = element_blank(),
        legend.position = "bottom") +
  facet_wrap(~week)

week13.plot <- covid19_spain %>%
  left_join(provinces_spain, by = c("province", "CCAA", "ID_INE")) %>%
  st_as_sf() %>%
  filter(CCAA != "Canarias") %>%
  group_by(province, week = isoweek(Date)) %>%
  summarise(mean_weekly_incidence = mean(Incidence)) %>%
  filter(week == 13) %>%
```

```r
  ggplot() +
  geom_sf(aes(fill = mean_weekly_incidence)) +
  scale_fill_distiller(name = "Mean Weekly Incidence",
                       palette = "Reds",
                       direction = 1) +
  theme_tufte() +
  theme(axis.text = element_blank(),
        legend.position = "bottom") +
  facet_wrap(~week)

week14.plot <- covid19_spain %>%
  left_join(provinces_spain, by = c("province", "CCAA", "ID_INE")) %>%
  st_as_sf() %>%
  filter(CCAA != "Canarias") %>%
  group_by(province, week = isoweek(Date)) %>%
  summarise(mean_weekly_incidence = mean(Incidence)) %>%
  filter(week == 14) %>%
  ggplot() +
  geom_sf(aes(fill = mean_weekly_incidence)) +
  scale_fill_distiller(name = "Mean Weekly Incidence",
                       palette = "Reds",
                       direction = 1) +
  theme_tufte() +
  theme(axis.text = element_blank(),
        legend.position = "bottom") +
  facet_wrap(~week)

grid.arrange(week11.plot, week12.plot, week13.plot, week14.plot, nrow = 2)
```



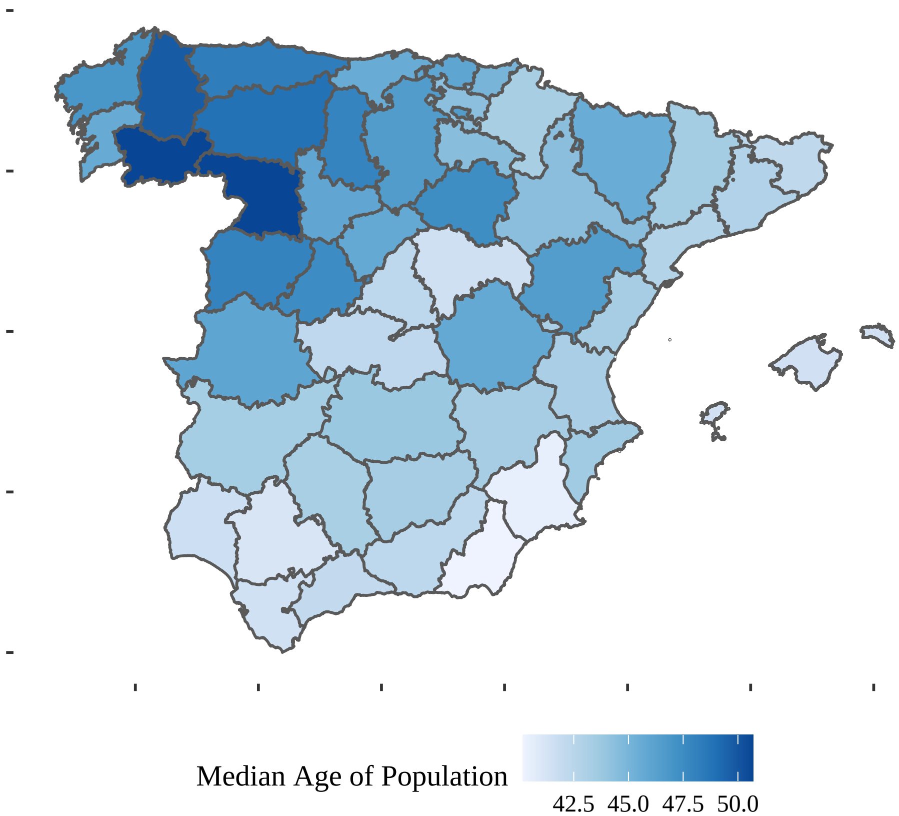
We consider some control variables: ratio of male to female in the province, median age of the population, population density:

```
covid19_spain %>%
  filter(CCAA != "Canarias", Date == "2020-03-13") %>%
  left_join(provinces_spain, by = c("province", "CCAA", "ID_INE")) %>%
  st_as_sf() %>%
  ggplot() +
  geom_sf(aes(fill = Male2Female)) +
  scale_fill_distiller(name = "Male to Female Ratio",
                       palette = "Blues",
                       direction = 1) +
  theme_tufte() +
  theme(axis.text = element_blank(),
        legend.position = "bottom")
```



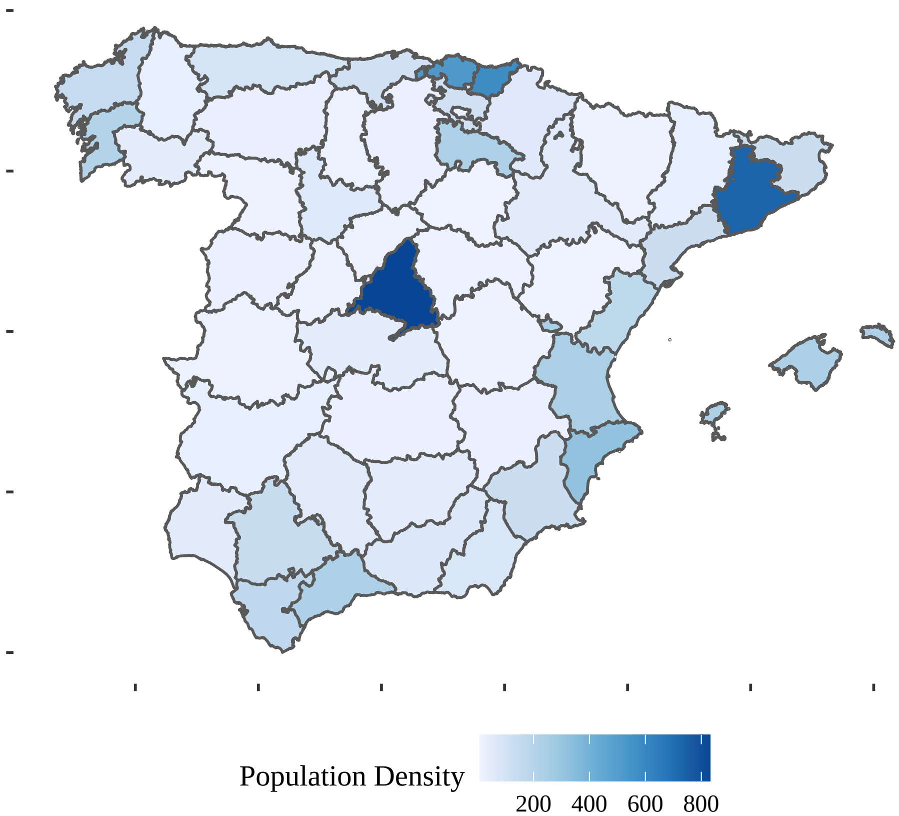
Median age of the population:

```
covid19_spain %>%
  filter(CCAA != "Canarias", Date == "2020-03-13") %>%
  left_join(provinces_spain, by = c("province", "CCAA", "ID_INE")) %>%
  st_as_sf() %>%
  ggplot() +
  geom_sf(aes(fill = Median_Age)) +
  scale_fill_distiller(name = "Median Age of Population",
                       palette = "Blues",
                       direction = 1) +
  theme_tufte() +
  theme(axis.text = element_blank(),
        legend.position = "bottom")
```



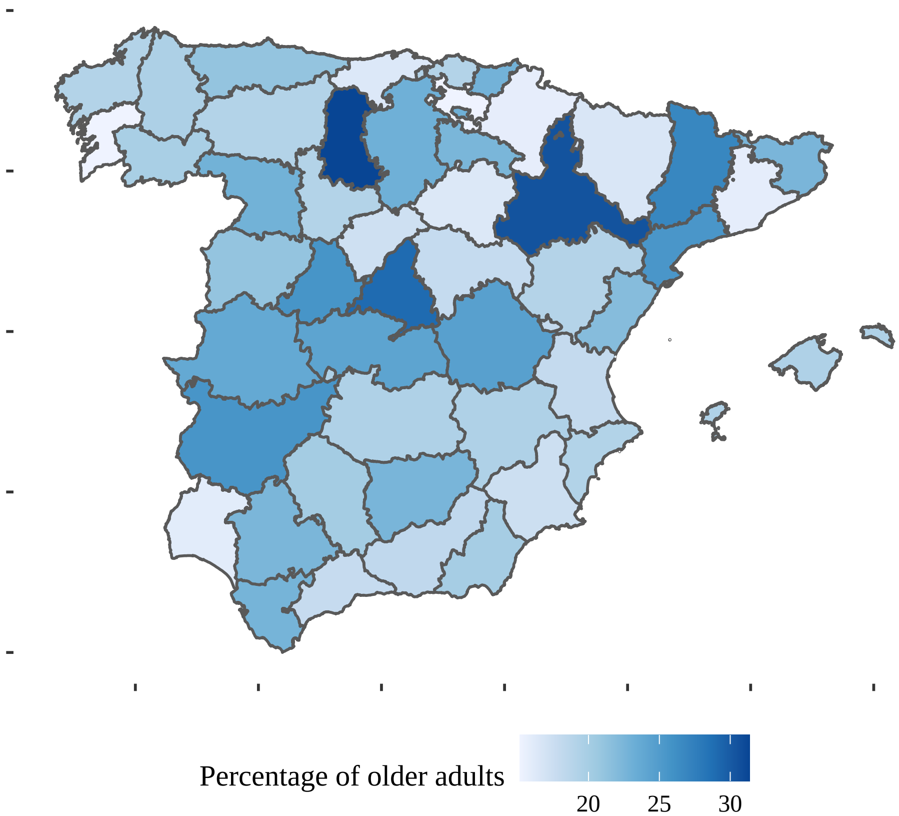
Population density:

```
covid19_spain %>%
  filter(CCAA != "Canarias", Date == "2020-03-13") %>%
  left_join(provinces_spain, by = c("province", "CCAA", "ID_INE")) %>%
  st_as_sf() %>%
  ggplot() +
  geom_sf(aes(fill = as.numeric(Density))) +
  scale_fill_distiller(name = "Population Density",
                       palette = "Blues",
                       direction = 1) +
  theme_tufte() +
  theme(axis.text = element_blank(),
        legend.position = "bottom")
```



Older people:

```
covid19_spain %>%
  filter(CCAA != "Canarias", Date == "2020-03-13") %>%
  left_join(provinces_spain, by = c("province", "CCAA", "ID_INE")) %>%
  st_as_sf() %>%
  ggplot() +
  geom_sf(aes(fill = as.numeric(Older))) +
  scale_fill_distiller(name = "Percentage of older adults",
                       palette = "Blues",
                       direction = 1) +
  theme_tufte() +
  theme(axis.text = element_blank(),
        legend.position = "bottom")
```



We are also interested in the climatic variables. To visualize the distribution of temperature by CCAA, we want to sort the communities by latitude, from north to south:

```
# Autonomous communities
ccaa.sf <-  provinces_spain %>%
  left_join(covid19_spain %>%
              filter(Date == "2020-03-13") %>%
              select(ID_INE, CCAA),
            by = c("CCAA", "ID_INE")) %>%
  drop_na() %>%
  group_by(CCAA) %>%
  summarize(provinces = n())

# Extract coordinates of autonomous communities
ccaa.coords <- ccaa.sf %>%
  st_centroid() %>%
  st_coordinates() %>%
  as.data.frame()
```

```
## Warning in st_centroid.sf(.): st_centroid assumes attributes are constant over
## geometries of x
```

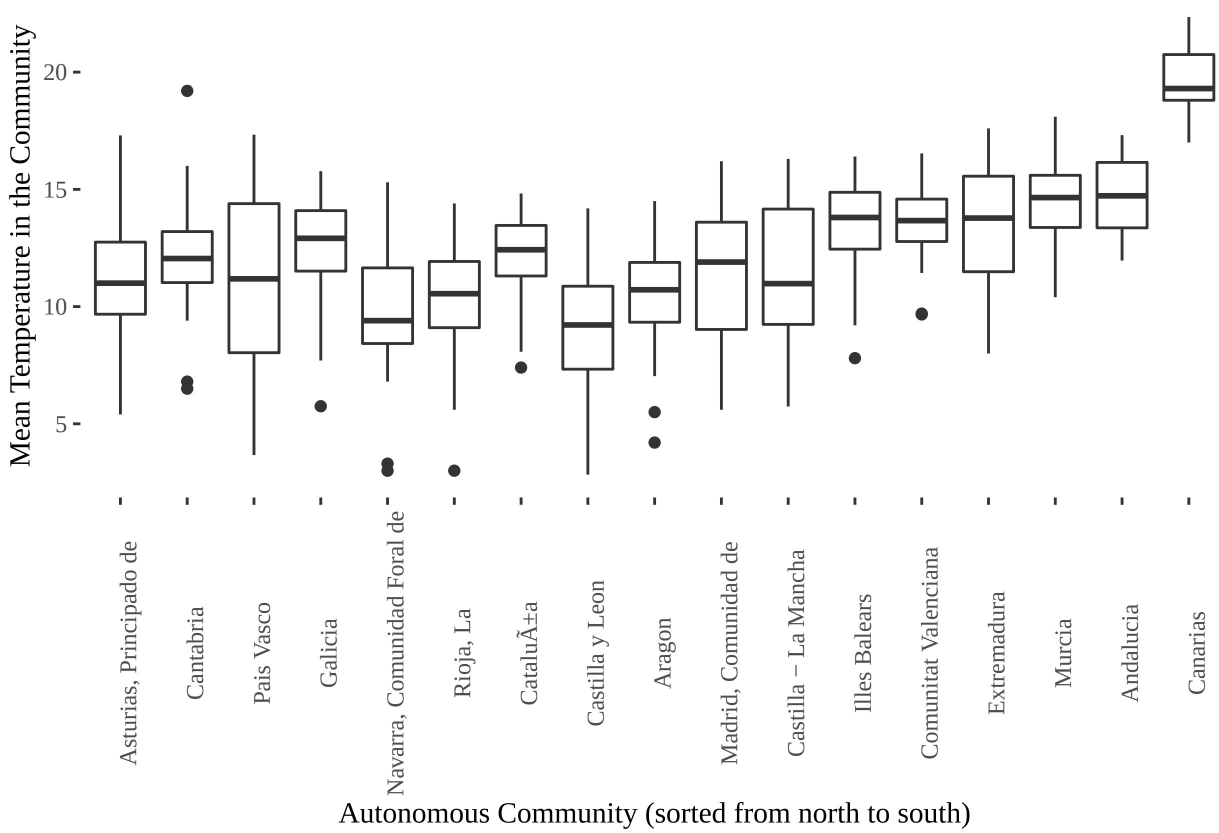
```
## Warning in st_centroid.sfc(st_geometry(x), of_largest_polygon =
## of_largest_polygon): st_centroid does not give correct centroids for longitude/
## latitude data
```

```
# Join Y coordinate to ccaa.sf
ccaa.sf <- ccaa.sf %>%
```

```
  mutate(long = ccaa.coords$Y)

# Sort autonomous communities from north to south
ccaa.levels <- ccaa.sf %>%
  arrange(desc(long)) %>% select(CCAA)

ccaa.levels <- as.character(ccaa.levels$CCAA)

# Relevel autonomous communities
covid19_spain <- covid19_spain %>%
  mutate(CCAA = factor(CCAA, levels = ccaa.levels, ordered = TRUE))
```

The following plot is the distribution of temperature by CCAA, sorted by latitude:

```
# Boxplots of temperatures
covid19_spain %>%
  group_by(CCAA, Date) %>%
  summarize(Mean_Temp = mean(Mean_Temp)) %>%
  ggplot(aes(x = CCAA, y = Mean_Temp)) +
  geom_boxplot() +
  theme_tufte() +
  theme(axis.text.x = element_text(angle = 90)) +
  xlab("Autonomous Community (sorted from north to south)") +
  ylab("Mean Temperature in the Community")
```



Multivariate analysis: comparison of approaches

Panel

1) Panel clásico

2) Panel Clásico o Dinámico

- Debe ser un modelo de efectos fijos para recoger la hetereogeneidad entre las distintas provincias (efectos)
- Debería incluir estructura dinámica ya que la serie tiene una fuerte estrutura temporal
- INCONVENIENTE: considera que la incluencia del dato del día anterior es constante (se estima un coeficiente constante)
- INCONVENIENTE: No se pueden incluir varaibles constantes en T. La hetereogeneidad entre provincias queda en el efecto fijo. No podemos por tanto incluir datos sobre estructura de la poblacion.
- INCONVENIENTE: No podemos incorporar efectos espaciales. El paquete **splm** no incluye estimación de paneles dinámicos con efectos espaciales. Tendriamos que hacerlo en matlab con los códigos de P.Elhorst.

Spatial SUR

2) SUR espacial

- Hay un coeficente para cada variable y cada instante de tiempo. Aunque es posible considerar coeficientes constantes para los periodos temporales que consideremos.
- La hetereoeneidad espacial debemos incorporarla mediante variables explicativas. –> Estructura de la población relacionada con COVID-19.
- Permite incluir varaibles constantes en T.
- la dinámica temporar quedará recogida mediante el término independiente y la estructura de correlaciones en los residuos. EN TODO CASO, ENTIENDO QUE NUESTRO OBJETIVO NO ES EXPLICAR ESA TENEDENCIA TEMPORAL (solo modelizarla para no incurrir en errores)

Prepare data for SUR analysis

*El modelo debe considerar efectos del 'individuo' y del 'tiempo' (para incorporar tendencia temporal)**

```
# Definicion del panel para plm
GPanel <- plm::pdata.frame(covid19_spain %>%
                             select(province,
                                    Date,
                                    Incidence,
                                    Median_Age,
                                    Male2Female,
                                    Older,
                                    GDPpc,
                                    Density,
                                    Transit,
                                    Mean_Temp_lag8,
                                    Humidity_lag8,
                                    Sunshine_Hours_lag8,
                                    Mean_Temp_lag11,
                                    Humidity_lag11,
                                    Sunshine_Hours_lag11,
                                    Mean_Temp_lag11w,
                                    Humidity_lag11w,
                                    Sunshine_Hours_lag11w),
                           c("province","Date"))
```

Spatial SUR model

Create connectivity matrix:

```
# Spatial weights matrix:
Wmat <- provinces_spain %>%
  drop_na() %>%
  as("Spatial") %>%
  poly2nb(queen = FALSE) %>%
  nb2mat(zero.policy = TRUE)

Wmat <- (Wmat > 0) * 1

# Join the two provinces in Canarias
Wmat[which(provinces_spain$province == "Palmas(Las)"),
     which(provinces_spain$province == "Santa Cruz de Tenerife")] <- 1
Wmat[which(provinces_spain$province == "Santa Cruz de Tenerife"),
     which(provinces_spain$province == "Palmas(Las)")] <- 1

# 'Paises Catalans'
#n = 8
Wmat[which(provinces_spain$province == "Barcelona"),
     which(provinces_spain$province == "Baleares")] <- 1
Wmat[which(provinces_spain$province == "Baleares"),
     which(provinces_spain$province == "Barcelona")] <- 1
Wmat[which(provinces_spain$province == "Baleares"),
     which(provinces_spain$province == "Castellon/Castello")] <- 1
Wmat[which(provinces_spain$province == "Castellon/Castello"),
     which(provinces_spain$province == "Baleares")] <- 1
Wmat[which(provinces_spain$province == "Baleares"),
     which(provinces_spain$province == "Tarragona")] <- 1
Wmat[which(provinces_spain$province == "Tarragona"),
     which(provinces_spain$province == "Baleares")] <- 1
miW <- Wmat/rowSums(Wmat)

# Convert to listw
listw <- mat2listw(Wmat,style = "W")
```

Define formulas with three different lagged variables:

```
formula_lag8 <- log(Incidence) ~
  log(GDPpc) +
  #log(Male2Female) +
  #log(Median_Age) +
  log(Older) +
  log(Density) +
  Transit +
  log(Humidity_lag8) +
  log(Mean_Temp_lag8)

formula_lag11 <- log(Incidence) ~
  log(GDPpc) +
  #log(Male2Female) +
  #log(Median_Age) +
  log(Older) +
  log(Density) +
```

```
  Transit +
  log(Humidity_lag11) +
  log(Mean_Temp_lag11)

formula_lag11w <- log(Incidence) ~
  log(GDPpc) +
  #log(Male2Female) +
  #log(Median_Age) +
  log(Older) +
  log(Density) +
  Transit +
  log(Humidity_lag11w) +
  log(Mean_Temp_lag11w)
```

Create the terms needed to impose restrictions to the parameters for estimation. In this case we will restrict the two demographic variables and let Density, Transit, and the climatic variables to vary across equations. The rationale is that age and ratio of male to female do not change in the short period of time examined; on the other hand, while density and the presence of transit systems are also constants over the period examined, the behavior changed as a consequence of the lockdown: we expect these variables to be significant early on in the evolution of the pandemic, and become non-significant as the lockdown reduces their importance for the transmission of the virus.

```
# Recall that T is the number of days, i.e., time periods, i.e., equations
k <- 7 # Number of independent variables, including the constant
coef_rest <- 2 # Number of restrictions

# nrow is number of equations (time periods) minus 1, times the number of restrictions
# ncol is number of variables times number of equations
R2 <- matrix(0, nrow = (T - 1) * coef_rest, ncol = k * T)

for (i in 1:(T-1)){
  R2[i, 2] <- 1
  R2[i, (2 + i * k)] <- -1
  R2[(i + T - 1), 3] <- 1
  R2[(i + T - 1), (3 + i * k)] <- -1
  # Use if more restrictions are needed
  #R2[(i + T - 1) * 2, 4] <- 1
  #R2[(i + T - 1) * 2, (4 + i * k)] <- -1
}
b2 <- matrix(0, ncol = 21*coef_rest)
```

Model with a lagged 8-day moving average of climatic variables:

```
sur.slm_lag8 <- spsur::spsurtime(formula = formula_lag8,
                                 data=GPanel,
                                 time = GPanel$Date,
                                 type = "slm",
                                 fit_method = "3sls",
                                 listw=  listw,
                                 R = R2,
                                 b = b2)
```

```
## Time to fit the model:  0.7  seconds
```

```
#summary(sur.slm_lag8)
print(paste("Pooled R^2 = ", sur.slm_lag8$R2[1]))
```

```
## [1] "Pooled R^2 =  0.823487166284304"
```

Model with 11-day moving average of climatic variables:

```r
sur.slm_lag11 <- spsur::spsurtime(formula = formula_lag11,
                                  data=GPanel,
                                  time = GPanel$Date,
                                  type = "slm",
                                  fit_method = "3sls",
                                  listw=  listw,
                                 R = R2,
                                 b = b2)
```

```
## Time to fit the model:  0.79  seconds
```

```r
#summary(sur.slm_lag11)
print(paste("Pooled R^2 = ", sur.slm_lag11$R2[1]))
```

```
## [1] "Pooled R^2 =  0.826867183185423"
```

Model with 11-day weighted moving average of climatic variables:

```r
sur.slm_lag11w <- spsur::spsurtime(formula = formula_lag11w,
                                   data=GPanel,
                                   time = GPanel$Date,
                                   type = "slm",
                                   fit_method = "3sls",
                                   listw=  listw,
                                 R = R2,
                                 b = b2)
```

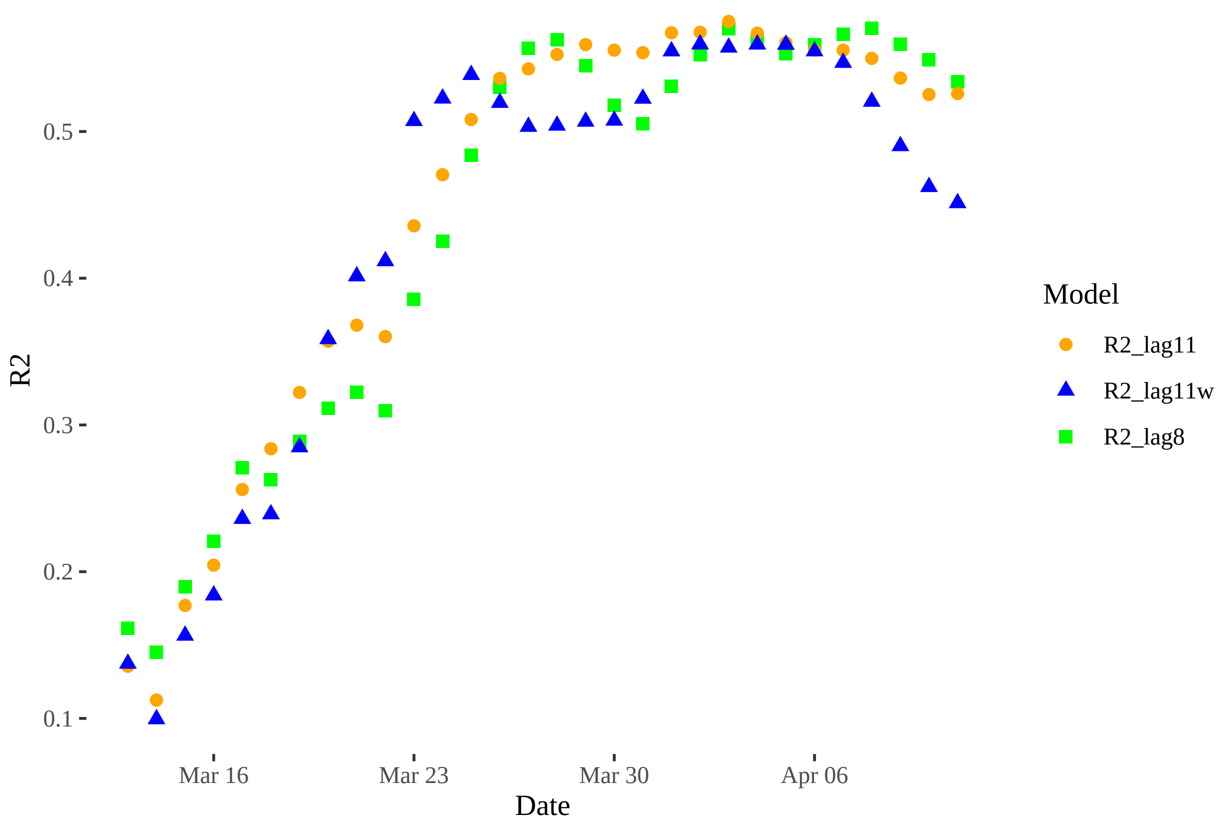
```
## Time to fit the model:  0.8  seconds
```

```r
#summary(sur.slm_lag11w)
print(paste("Pooled R^2 = ", sur.slm_lag11w$R2[1]))
```

```
## [1] "Pooled R^2 =  0.822798823244128"
```

Compare goodness of fit:

```r
data.frame(R2_lag8 = sur.slm_lag8$R2,
           R2_lag11 = sur.slm_lag11$R2,
           R2_lag11w = sur.slm_lag11w$R2) %>%
  slice(2:n()) %>%
  rownames_to_column(var = "Equation") %>%
  mutate(Date = seq(ymd("2020-03-13"),
                    ymd("2020-04-11"),
                    by = "days")) %>%
  pivot_longer(cols = starts_with("R"), names_to = "Model", values_to = "R2") %>%
  ggplot(aes(x = Date, y = R2, color = Model, shape = Model)) +
  geom_point(size = 2) +
  scale_color_manual(values = c("R2_lag11w" = "blue", "R2_lag11" = "orange", "R2_lag8" = "green") ) +
  theme_tufte()
```



Summary of best model

The model with the lagged 11-day moving average of temperature and humidity provides the best fit overall:

```
summary(sur.slm_lag11)
```

```
## Call:
## spsur::spsurtime(formula = formula_lag11, data = GPanel, time = GPanel$Date,
##     listw = listw, type = "slm", fit_method = "3sls", R = R2,
##     b = b2)
##
##
## Spatial SUR model type:  slm
##
## Equation  1
##                         Estimate Std. Error t value  Pr(>|t|)
## (Intercept)_1            9.62813    3.14397  3.0624  0.002265 **
## log(GDPpc)_1             0.51259    0.27332  1.8754  0.061080 .
## log(Older)_1            -0.78338    0.24176 -3.2403  0.001240 **
## log(Density)_1           0.18772    0.16087  1.1669  0.243574
## Transit_1                0.30048    0.58991  0.5094  0.610628
## log(Humidity_lag11)_1   -1.17622    0.51700 -2.2751  0.023147 *
## log(Mean_Temp_lag11)_1  -1.66884    0.52698 -3.1668  0.001596 **
## rho_1                    0.58091    0.14390  4.0370 5.901e-05 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
## R-squared: 0.1355
```

```
##   Equation  2
##                        Estimate Std. Error t value Pr(>|t|)
## (Intercept)_2          8.430032   2.821950  2.9873 0.002895 **
## log(Density)_2         0.086319   0.140790  0.6131 0.539973
## Transit_2              0.418297   0.525970  0.7953 0.426668
## log(Humidity_lag11)_2  -0.801191   0.451640 -1.7740 0.076427 .
## log(Mean_Temp_lag11)_2 -1.455707   0.460288 -3.1626 0.001619 **
## rho_2                  0.419746   0.143884  2.9173 0.003624 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
## R-squared: 0.1125
##   Equation  3
##                        Estimate Std. Error t value  Pr(>|t|)
## (Intercept)_3          8.552628   2.419158  3.5354 0.0004291 ***
## log(Density)_3         0.044792   0.120720  0.3710 0.7107011
## Transit_3              0.406651   0.459631  0.8847 0.3765506
## log(Humidity_lag11)_3  -0.767144   0.382338 -2.0065 0.0451226 *
## log(Mean_Temp_lag11)_3 -1.425833   0.357076 -3.9931 7.084e-05 ***
## rho_3                  0.458573   0.096856  4.7346 2.569e-06 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
## R-squared: 0.177
##   Equation  4
##                        Estimate Std. Error t value  Pr(>|t|)
## (Intercept)_4          7.837546   2.119033  3.6986 0.0002306 ***
## log(Density)_4        -0.021670   0.106286 -0.2039 0.8384905
## Transit_4              0.507415   0.407778  1.2443 0.2137153
## log(Humidity_lag11)_4  -0.559470   0.327388 -1.7089 0.0878352 .
## log(Mean_Temp_lag11)_4 -1.120872   0.277691 -4.0364 5.916e-05 ***
## rho_4                  0.258825   0.099505  2.6011 0.0094529 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
## R-squared: 0.2045
##   Equation  5
##                        Estimate Std. Error t value  Pr(>|t|)
## (Intercept)_5          9.405677   1.999965  4.7029 2.990e-06 ***
## log(Density)_5        -0.050703   0.104830 -0.4837  0.628746
## Transit_5              0.519425   0.404044  1.2856  0.198943
## log(Humidity_lag11)_5  -0.812451   0.303199 -2.6796  0.007513 **
## log(Mean_Temp_lag11)_5 -1.214297   0.248086 -4.8947 1.178e-06 ***
## rho_5                  0.248965   0.088061  2.8272  0.004806 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
## R-squared: 0.256
##   Equation  6
##                        Estimate Std. Error t value  Pr(>|t|)
## (Intercept)_6          7.174949   1.889316  3.7976 0.0001564 ***
## log(Density)_6        -0.092083   0.104839 -0.8783 0.3800112
## Transit_6              0.553666   0.404348  1.3693 0.1712719
## log(Humidity_lag11)_6  -0.267789   0.271649 -0.9858 0.3245155
## log(Mean_Temp_lag11)_6 -1.096782   0.233397 -4.6992 3.044e-06 ***
## rho_6                  0.241557   0.089565  2.6970 0.0071348 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
## R-squared: 0.2838
##   Equation  7
##                        Estimate Std. Error t value  Pr(>|t|)
## (Intercept)_7          8.088878   1.837640  4.4018 1.210e-05 ***
## log(Density)_7        -0.095128   0.097407 -0.9766  0.329041
## Transit_7              0.547569   0.376465  1.4545  0.146175
## log(Humidity_lag11)_7  -0.322333   0.265176 -1.2155  0.224496
## log(Mean_Temp_lag11)_7 -1.285205   0.219572 -5.8532 6.873e-09 ***
## rho_7                  0.245101   0.081014  3.0254  0.002558 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
## R-squared: 0.3222
##   Equation  8
##                        Estimate Std. Error t value  Pr(>|t|)
## (Intercept)_8          7.611175   1.774307  4.2897 1.994e-05 ***
## log(Density)_8        -0.131252   0.089245 -1.4707   0.14175
## Transit_8              0.557633   0.345892  1.6122   0.10730
## log(Humidity_lag11)_8  -0.098606   0.249151 -0.3958   0.69237
## log(Mean_Temp_lag11)_8 -1.220649   0.194833 -6.2651 5.904e-10 ***
## rho_8                  0.169294   0.071384  2.3716   0.01793 *
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
## R-squared: 0.357
##   Equation  9
##                        Estimate Std. Error t value  Pr(>|t|)
## (Intercept)_9         10.012887   1.778095  5.6312 2.429e-08 ***
## log(Density)_9        -0.148110   0.091459 -1.6194  0.105729
## Transit_9              0.587413   0.355362  1.6530  0.098699 .
## log(Humidity_lag11)_9  -0.435034   0.243464 -1.7869  0.074316 .
## log(Mean_Temp_lag11)_9 -1.524788   0.198771 -7.6711 4.652e-14 ***
## rho_9                  0.189202   0.066603  2.8408  0.004608 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
## R-squared: 0.368
##   Equation  10
##                         Estimate Std. Error t value  Pr(>|t|)
## (Intercept)_10          9.890754   1.849244  5.3485 1.140e-07 ***
## log(Density)_10        -0.104128   0.089863 -1.1587   0.24688
## Transit_10              0.552313   0.348867  1.5832   0.11375
## log(Humidity_lag11)_10  -0.397202   0.260507 -1.5247   0.12770
## log(Mean_Temp_lag11)_10 -1.513470   0.205270 -7.3731 3.946e-13 ***
## rho_10                  0.146974   0.074949  1.9610   0.05021 .
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
## R-squared: 0.3602
##   Equation  11
##                         Estimate Std. Error t value  Pr(>|t|)
## (Intercept)_11          9.041622   1.743143  5.1870 2.672e-07 ***
## log(Density)_11        -0.047066   0.078451 -0.5999    0.5487
## Transit_11              0.484483   0.302991  1.5990    0.1102
## log(Humidity_lag11)_11  -0.062984   0.231907 -0.2716    0.7860
## log(Mean_Temp_lag11)_11 -1.717164   0.176683 -9.7189 < 2.2e-16 ***
## rho_11                  0.106474   0.069511  1.5318    0.1260
## ---
```

```
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
## R-squared: 0.4357
##   Equation  12
##                          Estimate Std. Error  t value  Pr(>|t|)
## (Intercept)_12          10.553116   1.642439   6.4253 2.186e-10 ***
## log(Density)_12         -0.053535   0.076803  -0.6970   0.48597
## Transit_12               0.526863   0.295615   1.7823   0.07506 .
## log(Humidity_lag11)_12  -0.350787   0.212538  -1.6505   0.09922 .
## log(Mean_Temp_lag11)_12 -1.742167   0.160251 -10.8715 < 2.2e-16 ***
## rho_12                   0.100180   0.064360   1.5565   0.11995
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
## R-squared: 0.4706
##   Equation  13
##                          Estimate Std. Error  t value  Pr(>|t|)
## (Intercept)_13          10.272152   1.547408   6.6383 5.641e-11 ***
## log(Density)_13         -0.040756   0.074586  -0.5464   0.58492
## Transit_13               0.514282   0.285119   1.8037   0.07162 .
## log(Humidity_lag11)_13  -0.259085   0.195706  -1.3238   0.18591
## log(Mean_Temp_lag11)_13 -1.747029   0.147648 -11.8324 < 2.2e-16 ***
## rho_13                   0.092876   0.060496   1.5352   0.12510
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
## R-squared: 0.5082
##   Equation  14
##                          Estimate Std. Error  t value  Pr(>|t|)
## (Intercept)_14          10.677779   1.631934   6.5430 1.039e-10 ***
## log(Density)_14         -0.012814   0.072922  -0.1757   0.86056
## Transit_14               0.498220   0.276077   1.8046   0.07148 .
## log(Humidity_lag11)_14  -0.212106   0.218020  -0.9729   0.33089
## log(Mean_Temp_lag11)_14 -1.897131   0.157356 -12.0563 < 2.2e-16 ***
## rho_14                   0.043771   0.065757   0.6657   0.50581
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
## R-squared: 0.5362
##   Equation  15
##                          Estimate Std. Error  t value  Pr(>|t|)
## (Intercept)_15          12.363863   1.552998   7.9613 5.419e-15 ***
## log(Density)_15         -0.014269   0.073153  -0.1951  0.845391
## Transit_15               0.471397   0.276621   1.7041  0.088722 .
## log(Humidity_lag11)_15  -0.499375   0.192017  -2.6007  0.009465 **
## log(Mean_Temp_lag11)_15 -2.048119   0.157302 -13.0203 < 2.2e-16 ***
## rho_15                   0.058221   0.067710   0.8599  0.390110
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
## R-squared: 0.5427
##   Equation  16
##                           Estimate Std. Error  t value  Pr(>|t|)
## (Intercept)_16          13.3619316  1.4239213   9.3839 < 2.2e-16 ***
## log(Density)_16         -0.0532339  0.0714743  -0.7448   0.45660
## Transit_16               0.5310789  0.2717992   1.9539   0.05103 .
## log(Humidity_lag11)_16  -0.7077959  0.1632945  -4.3345 1.635e-05 ***
## log(Mean_Temp_lag11)_16 -1.8610247  0.1298837 -14.3284 < 2.2e-16 ***
## rho_16                  -0.0069609  0.0629344  -0.1106   0.91195
```

```
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
## R-squared: 0.5525
##   Equation  17
##                         Estimate Std. Error  t value  Pr(>|t|)
## (Intercept)_17         13.845006   1.422100   9.7356 < 2.2e-16 ***
## log(Density)_17        -0.072773   0.069570  -1.0460   0.29584
## Transit_17              0.511603   0.265577   1.9264   0.05439 .
## log(Humidity_lag11)_17  -0.808325   0.156116  -5.1777 2.803e-07 ***
## log(Mean_Temp_lag11)_17 -1.854032   0.121677 -15.2373 < 2.2e-16 ***
## rho_17                  0.016545   0.059619   0.2775   0.78145
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
## R-squared: 0.5592
##   Equation  18
##                         Estimate Std. Error  t value  Pr(>|t|)
## (Intercept)_18         13.580912   1.387280   9.7896 < 2.2e-16 ***
## log(Density)_18        -0.089104   0.067944  -1.3114   0.19006
## Transit_18              0.481452   0.259069   1.8584   0.06346 .
## log(Humidity_lag11)_18  -0.808806   0.146486  -5.5214 4.465e-08 ***
## log(Mean_Temp_lag11)_18 -1.681588   0.115031 -14.6186 < 2.2e-16 ***
## rho_18                  0.016228   0.057799   0.2808   0.77896
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
## R-squared: 0.5554
##   Equation  19
##                         Estimate Std. Error  t value  Pr(>|t|)
## (Intercept)_19         13.091684   1.321251   9.9086 < 2.2e-16 ***
## log(Density)_19        -0.096334   0.067762  -1.4216   0.15549
## Transit_19              0.490048   0.259137   1.8911   0.05895 .
## log(Humidity_lag11)_19  -0.761422   0.133018  -5.7242 1.439e-08 ***
## log(Mean_Temp_lag11)_19 -1.593348   0.105226 -15.1421 < 2.2e-16 ***
## rho_19                  0.044852   0.053014   0.8460   0.39777
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
## R-squared: 0.5538
##   Equation  20
##                         Estimate Std. Error  t value  Pr(>|t|)
## (Intercept)_20         11.500576   1.236071   9.3041 < 2.2e-16 ***
## log(Density)_20        -0.117067   0.066878  -1.7504   0.08040 .
## Transit_20              0.494178   0.256515   1.9265   0.05437 .
## log(Humidity_lag11)_20  -0.527359   0.111395  -4.7341 2.575e-06 ***
## log(Mean_Temp_lag11)_20 -1.380257   0.086156 -16.0204 < 2.2e-16 ***
## rho_20                  0.078000   0.047115   1.6555   0.09819 .
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
## R-squared: 0.5673
##   Equation  21
##                         Estimate Std. Error  t value  Pr(>|t|)
## (Intercept)_21         10.112143   1.215491   8.3194 3.483e-16 ***
## log(Density)_21        -0.136009   0.065842  -2.0657   0.03916 *
## Transit_21              0.533919   0.252998   2.1104   0.03512 *
## log(Humidity_lag11)_21  -0.247910   0.107393  -2.3084   0.02121 *
## log(Mean_Temp_lag11)_21 -1.202712   0.074203 -16.2084 < 2.2e-16 ***
```

```
## rho_21                   0.049755   0.043869   1.1342   0.25704
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
## R-squared: 0.5676
##   Equation  22
##                          Estimate Std. Error  t value  Pr(>|t|)
## (Intercept)_22           9.669712   1.209799   7.9928 4.273e-15 ***
## log(Density)_22         -0.149862   0.065332  -2.2939   0.02204 *
## Transit_22               0.544729   0.251556   2.1654   0.03063 *
## log(Humidity_lag11)_22  -0.142980   0.102714  -1.3920   0.16428
## log(Mean_Temp_lag11)_22 -1.178958   0.069086 -17.0650 < 2.2e-16 ***
## rho_22                   0.058932   0.039521   1.4911   0.13630
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
## R-squared: 0.575
##   Equation  23
##                          Estimate Std. Error  t value  Pr(>|t|)
## (Intercept)_23           9.412759   1.206185   7.8037 1.756e-14 ***
## log(Density)_23         -0.167489   0.066005  -2.5375   0.01134 *
## Transit_23               0.552479   0.254631   2.1697   0.03030 *
## log(Humidity_lag11)_23  -0.091730   0.101869  -0.9005   0.36812
## log(Mean_Temp_lag11)_23 -1.087327   0.064933 -16.7453 < 2.2e-16 ***
## rho_23                   0.048918   0.038557   1.2687   0.20490
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
## R-squared: 0.567
##   Equation  24
##                          Estimate Std. Error  t value  Pr(>|t|)
## (Intercept)_24           9.477033   1.215601   7.7962 1.857e-14 ***
## log(Density)_24         -0.183175   0.066982  -2.7347  0.006374 **
## Transit_24               0.558080   0.258778   2.1566  0.031316 *
## log(Humidity_lag11)_24  -0.109744   0.107721  -1.0188  0.308598
## log(Mean_Temp_lag11)_24 -1.021792   0.063302 -16.1416 < 2.2e-16 ***
## rho_24                   0.040908   0.037027   1.1048  0.269558
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
## R-squared: 0.5605
##   Equation  25
##                          Estimate Std. Error  t value  Pr(>|t|)
## (Intercept)_25           9.611339   1.205539   7.9726 4.975e-15 ***
## log(Density)_25         -0.192266   0.067566  -2.8456  0.004539 **
## Transit_25               0.556351   0.261294   2.1292  0.033522 *
## log(Humidity_lag11)_25  -0.145809   0.100349  -1.4530  0.146586
## log(Mean_Temp_lag11)_25 -0.988734   0.062353 -15.8571 < 2.2e-16 ***
## rho_25                   0.044503   0.037204   1.1962  0.231952
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
## R-squared: 0.5555
##   Equation  26
##                          Estimate Std. Error  t value  Pr(>|t|)
## (Intercept)_26           9.563464   1.219679   7.8410 1.332e-14 ***
## log(Density)_26         -0.184896   0.068474  -2.7002  0.007066 **
## Transit_26               0.550643   0.264897   2.0787  0.037943 *
## log(Humidity_lag11)_26  -0.110766   0.110621  -1.0013  0.316958
```

```
## log(Mean_Temp_lag11)_26 -1.067575   0.065827 -16.2179 < 2.2e-16 ***
## rho_26                   0.064616   0.037279   1.7333  0.083402 .
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
## R-squared: 0.5555
##   Equation  27
##                          Estimate Std. Error  t value  Pr(>|t|)
## (Intercept)_27           9.276573   1.236498   7.5023 1.576e-13 ***
## log(Density)_27         -0.184504   0.069386  -2.6591  0.007982 **
## Transit_27               0.529660   0.268633   1.9717  0.048968 *
## log(Humidity_lag11)_27  -0.013092   0.117726  -0.1112  0.911478
## log(Mean_Temp_lag11)_27 -1.197443   0.074341 -16.1074 < 2.2e-16 ***
## rho_27                   0.110690   0.036863   3.0027  0.002754 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
## R-squared: 0.5499
##   Equation  28
##                          Estimate Std. Error  t value  Pr(>|t|)
## (Intercept)_28          10.209675   1.319968   7.7348 2.919e-14 ***
## log(Density)_28         -0.203611   0.071187  -2.8602  0.004337 **
## Transit_28               0.572373   0.275893   2.0746  0.038321 *
## log(Humidity_lag11)_28  -0.136907   0.149951  -0.9130  0.361494
## log(Mean_Temp_lag11)_28 -1.290847   0.088610 -14.5678 < 2.2e-16 ***
## rho_28                   0.112413   0.040124   2.8017  0.005199 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
## R-squared: 0.5364
##   Equation  29
##                          Estimate Std. Error  t value  Pr(>|t|)
## (Intercept)_29           9.285914   1.397654   6.6439 5.439e-11 ***
## log(Density)_29         -0.217382   0.072403  -3.0024  0.002757 **
## Transit_29               0.581366   0.280886   2.0698  0.038776 *
## log(Humidity_lag11)_29   0.144756   0.176356   0.8208  0.411978
## log(Mean_Temp_lag11)_29 -1.375721   0.102242 -13.4556 < 2.2e-16 ***
## rho_29                   0.121945   0.043979   2.7728  0.005679 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
## R-squared: 0.5252
##   Equation  30
##                          Estimate Std. Error  t value  Pr(>|t|)
## (Intercept)_30           8.685899   1.499058   5.7942 9.652e-09 ***
## log(Density)_30         -0.208568   0.073513  -2.8371   0.00466 **
## Transit_30               0.594559   0.284420   2.0904   0.03687 *
## log(Humidity_lag11)_30   0.342200   0.207831   1.6465   0.10002
## log(Mean_Temp_lag11)_30 -1.476302   0.120965 -12.2044 < 2.2e-16 ***
## rho_30                   0.124626   0.049555   2.5149   0.01209 *
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
## R-squared: 0.5259
##
## Variance-Covariance Matrix of inter-equation residuals:
##  1.1743351 0.9845782 0.8484755 0.7157808 0.6893094 0.6504312 0.5860227
##  0.9845782 0.9356792 0.7757446 0.6568113 0.6196064 0.6010151 0.5560345
##  0.8484755 0.7757446 0.7155399 0.6050589 0.5867769 0.5637152 0.5118237
```

```
##   0.7157808 0.6568113 0.6050589 0.5631327 0.5463620 0.5258625 0.4800013
##   0.6893094 0.6196064 0.5867769 0.5463620 0.5527119 0.5349140 0.4889751
##   0.6504312 0.6010151 0.5637152 0.5258625 0.5349140 0.5544452 0.5086733
##   0.5860227 0.5560345 0.5118237 0.4800013 0.4889751 0.5086733 0.4793202
##   0.5222648 0.4949815 0.4636514 0.4323580 0.4421922 0.4551111 0.4322950
##   0.5199123 0.4995427 0.4624256 0.4350647 0.4455092 0.4578929 0.4363055
##   0.4980127 0.4778795 0.4407681 0.4161385 0.4262484 0.4369273 0.4174421
##   0.4157791 0.3954887 0.3696758 0.3356395 0.3489905 0.3656777 0.3524505
##   0.3937882 0.3658327 0.3450793 0.3243990 0.3393347 0.3482374 0.3358996
##   0.3739610 0.3460180 0.3283830 0.3105006 0.3245016 0.3262757 0.3151575
##   0.3245135 0.2992725 0.2913454 0.2721487 0.2840346 0.2799987 0.2745595
##   0.3110393 0.2791457 0.2771828 0.2534828 0.2640236 0.2584430 0.2532007
##   0.2953762 0.2689979 0.2723038 0.2468195 0.2524245 0.2477462 0.2421799
##   0.2879181 0.2649456 0.2712552 0.2449988 0.2490068 0.2465591 0.2402710
##   0.2667768 0.2572452 0.2611897 0.2358732 0.2365585 0.2360252 0.2303959
##   0.2632233 0.2536639 0.2585125 0.2351783 0.2370464 0.2351794 0.2305271
##   0.2584684 0.2506709 0.2531571 0.2358933 0.2394911 0.2388397 0.2348104
##   0.2732020 0.2604405 0.2562275 0.2387826 0.2439325 0.2455459 0.2421114
##   0.2690788 0.2581422 0.2559212 0.2387717 0.2456236 0.2467033 0.2437294
##   0.2720970 0.2626725 0.2614268 0.2446128 0.2510219 0.2527500 0.2490297
##   0.2755611 0.2684007 0.2670723 0.2493951 0.2559357 0.2597518 0.2550699
##   0.2709340 0.2667514 0.2655854 0.2498892 0.2569775 0.2610276 0.2562907
##   0.2758177 0.2720868 0.2700236 0.2535411 0.2596097 0.2627112 0.2581158
##   0.2845186 0.2821297 0.2764137 0.2575175 0.2637432 0.2669409 0.2636278
##   0.2901134 0.2905320 0.2843311 0.2638063 0.2702869 0.2734182 0.2708034
##   0.2971065 0.2971756 0.2908401 0.2664812 0.2738670 0.2779554 0.2755673
##   0.3016243 0.3034114 0.2943518 0.2664577 0.2737199 0.2779529 0.2753138
##
##   0.5222648 0.5199123 0.4980127 0.4157791 0.3937882 0.3739610 0.3245135
##   0.4949815 0.4995427 0.4778795 0.3954887 0.3658327 0.3460180 0.2992725
##   0.4636514 0.4624256 0.4407681 0.3696758 0.3450793 0.3283830 0.2913454
##   0.4323580 0.4350647 0.4161385 0.3356395 0.3243990 0.3105006 0.2721487
##   0.4421922 0.4455092 0.4262484 0.3489905 0.3393347 0.3245016 0.2840346
##   0.4551111 0.4578929 0.4369273 0.3656777 0.3482374 0.3262757 0.2799987
##   0.4322950 0.4363055 0.4174421 0.3524505 0.3358996 0.3151575 0.2745595
##   0.4037341 0.4087270 0.3903770 0.3325038 0.3180174 0.2973992 0.2624761
##   0.4087270 0.4261309 0.4117400 0.3479996 0.3352958 0.3136915 0.2800876
##   0.3903770 0.4117400 0.4106560 0.3441891 0.3349299 0.3155046 0.2861410
##   0.3325038 0.3479996 0.3441891 0.3084608 0.2945369 0.2749729 0.2509342
##   0.3180174 0.3352958 0.3349299 0.2945369 0.2932987 0.2785151 0.2576517
##   0.2973992 0.3136915 0.3155046 0.2749729 0.2785151 0.2727143 0.2561852
##   0.2624761 0.2800876 0.2861410 0.2509342 0.2576517 0.2561852 0.2549200
##   0.2425073 0.2621762 0.2718344 0.2399284 0.2463518 0.2466840 0.2507042
##   0.2331507 0.2521500 0.2597073 0.2277640 0.2320248 0.2321874 0.2374248
##   0.2323323 0.2512143 0.2554036 0.2241419 0.2262925 0.2241903 0.2280054
##   0.2220687 0.2400863 0.2459753 0.2141095 0.2153809 0.2142240 0.2170179
##   0.2218825 0.2392138 0.2452320 0.2146626 0.2161752 0.2156325 0.2172352
##   0.2251137 0.2417694 0.2471570 0.2160810 0.2181138 0.2176574 0.2154268
##   0.2327378 0.2484692 0.2506715 0.2214384 0.2221093 0.2191487 0.2134088
##   0.2356130 0.2509650 0.2516939 0.2224780 0.2220920 0.2183549 0.2102538
##   0.2415086 0.2561127 0.2565147 0.2252640 0.2244097 0.2195252 0.2093616
##   0.2467304 0.2607350 0.2603014 0.2290375 0.2269858 0.2211295 0.2092564
##   0.2489586 0.2631574 0.2621184 0.2304398 0.2283000 0.2218357 0.2090950
##   0.2522672 0.2666573 0.2657942 0.2334613 0.2317400 0.2253278 0.2130473
```

```
##   0.2575406 0.2722685 0.2707594 0.2396347 0.2371262 0.2302901 0.2178305
##   0.2655783 0.2806142 0.2782259 0.2468318 0.2438680 0.2362524 0.2229985
##   0.2704037 0.2860579 0.2832621 0.2533595 0.2487511 0.2404044 0.2275425
##   0.2708462 0.2863477 0.2844161 0.2535837 0.2486156 0.2415978 0.2298777
##
##   0.3110393 0.2953762 0.2879181 0.2667768 0.2632233 0.2584684 0.2732020
##   0.2791457 0.2689979 0.2649456 0.2572452 0.2536639 0.2506709 0.2604405
##   0.2771828 0.2723038 0.2712552 0.2611897 0.2585125 0.2531571 0.2562275
##   0.2534828 0.2468195 0.2449988 0.2358732 0.2351783 0.2358933 0.2387826
##   0.2640236 0.2524245 0.2490068 0.2365585 0.2370464 0.2394911 0.2439325
##   0.2584430 0.2477462 0.2465591 0.2360252 0.2351794 0.2388397 0.2455459
##   0.2532007 0.2421799 0.2402710 0.2303959 0.2305271 0.2348104 0.2421114
##   0.2425073 0.2331507 0.2323323 0.2220687 0.2218825 0.2251137 0.2327378
##   0.2621762 0.2521500 0.2512143 0.2400863 0.2392138 0.2417694 0.2484692
##   0.2718344 0.2597073 0.2554036 0.2459753 0.2452320 0.2471570 0.2506715
##   0.2399284 0.2277640 0.2241419 0.2141095 0.2146626 0.2160810 0.2214384
##   0.2463518 0.2320248 0.2262925 0.2153809 0.2161752 0.2181138 0.2221093
##   0.2466840 0.2321874 0.2241903 0.2142240 0.2156325 0.2176574 0.2191487
##   0.2507042 0.2374248 0.2280054 0.2170179 0.2172352 0.2154268 0.2134088
##   0.2561414 0.2460030 0.2349888 0.2254880 0.2250733 0.2208516 0.2159875
##   0.2460030 0.2473430 0.2390570 0.2305216 0.2291338 0.2235084 0.2173889
##   0.2349888 0.2390570 0.2360305 0.2274159 0.2256182 0.2195815 0.2141509
##   0.2254880 0.2305216 0.2274159 0.2248237 0.2239298 0.2180610 0.2108527
##   0.2250733 0.2291338 0.2256182 0.2239298 0.2251807 0.2208019 0.2140141
##   0.2208516 0.2235084 0.2195815 0.2180610 0.2208019 0.2207395 0.2157599
##   0.2159875 0.2173889 0.2141509 0.2108527 0.2140141 0.2157599 0.2146745
##   0.2105962 0.2122028 0.2096606 0.2061762 0.2097075 0.2123854 0.2123892
##   0.2088120 0.2114477 0.2089401 0.2063946 0.2101328 0.2128362 0.2132105
##   0.2075046 0.2100723 0.2077336 0.2063035 0.2106286 0.2139794 0.2144752
##   0.2062007 0.2087268 0.2065162 0.2056242 0.2102791 0.2136618 0.2144958
##   0.2096655 0.2121042 0.2093694 0.2081243 0.2124894 0.2154594 0.2163679
##   0.2138927 0.2153658 0.2122398 0.2102324 0.2146629 0.2174367 0.2189145
##   0.2180510 0.2187773 0.2158590 0.2135523 0.2175686 0.2195106 0.2211623
##   0.2234006 0.2234153 0.2200508 0.2167839 0.2201922 0.2214043 0.2233709
##   0.2266768 0.2262821 0.2211104 0.2179232 0.2208013 0.2216997 0.2233648
##
##   0.2690788 0.2720970 0.2755611 0.2709340 0.2758177 0.2845186 0.2901134
##   0.2581422 0.2626725 0.2684007 0.2667514 0.2720868 0.2821297 0.2905320
##   0.2559212 0.2614268 0.2670723 0.2655854 0.2700236 0.2764137 0.2843311
##   0.2387717 0.2446128 0.2493951 0.2498892 0.2535411 0.2575175 0.2638063
##   0.2456236 0.2510219 0.2559357 0.2569775 0.2596097 0.2637432 0.2702869
##   0.2467033 0.2527500 0.2597518 0.2610276 0.2627112 0.2669409 0.2734182
##   0.2437294 0.2490297 0.2550699 0.2562907 0.2581158 0.2636278 0.2708034
##   0.2356130 0.2415086 0.2467304 0.2489586 0.2522672 0.2575406 0.2655783
##   0.2509650 0.2561127 0.2607350 0.2631574 0.2666573 0.2722685 0.2806142
##   0.2516939 0.2565147 0.2603014 0.2621184 0.2657942 0.2707594 0.2782259
##   0.2224780 0.2252640 0.2290375 0.2304398 0.2334613 0.2396347 0.2468318
##   0.2220920 0.2244097 0.2269858 0.2283000 0.2317400 0.2371262 0.2438680
##   0.2183549 0.2195252 0.2211295 0.2218357 0.2253278 0.2302901 0.2362524
##   0.2102538 0.2093616 0.2092564 0.2090950 0.2130473 0.2178305 0.2229985
##   0.2105962 0.2088120 0.2075046 0.2062007 0.2096655 0.2138927 0.2180510
##   0.2122028 0.2114477 0.2100723 0.2087268 0.2121042 0.2153658 0.2187773
##   0.2096606 0.2089401 0.2077336 0.2065162 0.2093694 0.2122398 0.2158590
##   0.2061762 0.2063946 0.2063035 0.2056242 0.2081243 0.2102324 0.2135523
```

```
##  0.2097075 0.2101328 0.2106286 0.2102791 0.2124894 0.2146629 0.2175686
##  0.2123854 0.2128362 0.2139794 0.2136618 0.2154594 0.2174367 0.2195106
##  0.2123892 0.2132105 0.2144752 0.2144958 0.2163679 0.2189145 0.2211623
##  0.2123388 0.2140499 0.2159412 0.2165662 0.2184793 0.2214111 0.2244626
##  0.2140499 0.2176773 0.2202233 0.2215445 0.2237336 0.2262428 0.2299931
##  0.2159412 0.2202233 0.2249048 0.2265023 0.2286911 0.2309202 0.2348148
##  0.2165662 0.2215445 0.2265023 0.2293206 0.2320150 0.2342387 0.2387130
##  0.2184793 0.2237336 0.2286911 0.2320150 0.2356785 0.2382016 0.2431516
##  0.2214111 0.2262428 0.2309202 0.2342387 0.2382016 0.2423413 0.2479358
##  0.2244626 0.2299931 0.2348148 0.2387130 0.2431516 0.2479358 0.2556095
##  0.2266844 0.2321545 0.2368205 0.2405387 0.2453041 0.2506912 0.2591993
##  0.2263779 0.2317123 0.2357089 0.2396069 0.2452564 0.2512101 0.2596702
##
##  0.2971065 0.3016243
##  0.2971756 0.3034114
##  0.2908401 0.2943518
##  0.2664812 0.2664577
##  0.2738670 0.2737199
##  0.2779554 0.2779529
##  0.2755673 0.2753138
##  0.2704037 0.2708462
##  0.2860579 0.2863477
##  0.2832621 0.2844161
##  0.2533595 0.2535837
##  0.2487511 0.2486156
##  0.2404044 0.2415978
##  0.2275425 0.2298777
##  0.2234006 0.2266768
##  0.2234153 0.2262821
##  0.2200508 0.2211104
##  0.2167839 0.2179232
##  0.2201922 0.2208013
##  0.2214043 0.2216997
##  0.2233709 0.2233648
##  0.2266844 0.2263779
##  0.2321545 0.2317123
##  0.2368205 0.2357089
##  0.2405387 0.2396069
##  0.2453041 0.2452564
##  0.2506912 0.2512101
##  0.2591993 0.2596702
##  0.2647691 0.2661682
##  0.2661682 0.2710592
## Correlation Matrix of inter-equation residuals:
##  1.0000000 0.9332656 0.9228574 0.8892605 0.8522097 0.8088110 0.7863670
##  0.9332656 1.0000000 0.9514402 0.9140260 0.8659168 0.8415803 0.8401184
##  0.9228574 0.9514402 1.0000000 0.9571306 0.9329766 0.9001294 0.8836049
##  0.8892605 0.9140260 0.9571306 1.0000000 0.9791154 0.9413395 0.9242238
##  0.8522097 0.8659168 0.9329766 0.9791154 1.0000000 0.9661290 0.9498951
##  0.8088110 0.8415803 0.9001294 0.9413395 0.9661290 1.0000000 0.9866341
##  0.7863670 0.8401184 0.8836049 0.9242238 0.9498951 0.9866341 1.0000000
##  0.7681338 0.8169185 0.8724088 0.9048431 0.9363520 0.9622158 0.9827034
##  0.7423434 0.8040254 0.8479150 0.8860219 0.9170235 0.9417072 0.9661790
##  0.7302956 0.7936899 0.8295175 0.8670219 0.8981824 0.9222768 0.9494244
```

```
## 0.6960428 0.7575790 0.8022119 0.8059359 0.8496328 0.8950442 0.9304074
## 0.6914899 0.7310045 0.7823191 0.8102596 0.8594730 0.8884727 0.9219279
## 0.6815950 0.7187415 0.7770677 0.8112347 0.8625869 0.8790384 0.9125505
## 0.6248239 0.6652268 0.7343426 0.7566758 0.8067983 0.8135232 0.8566804
## 0.6033672 0.6308865 0.7047777 0.7146271 0.7631584 0.7686456 0.8106556
## 0.5930855 0.6280206 0.7035979 0.7082540 0.7464389 0.7545503 0.7953798
## 0.5969486 0.6337404 0.7127320 0.7129008 0.7486171 0.7607996 0.8012916
## 0.5718300 0.6313390 0.7027723 0.6993844 0.7284230 0.7470296 0.7891892
## 0.5667376 0.6239106 0.6977255 0.6971858 0.7291088 0.7440787 0.7888411
## 0.5529756 0.6095227 0.6818425 0.6938854 0.7300315 0.7469863 0.7940526
## 0.5755119 0.6241048 0.6886542 0.7026389 0.7412334 0.7623458 0.8105745
## 0.5664357 0.6187538 0.6869377 0.7016577 0.7440163 0.7633718 0.8131266
## 0.5658656 0.6201299 0.6897731 0.7056357 0.7462302 0.7665582 0.8147612
## 0.5659936 0.6227271 0.6932167 0.7086898 0.7487625 0.7723146 0.8182009
## 0.5546524 0.6161869 0.6846366 0.7035264 0.7432476 0.7667534 0.8129122
## 0.5589950 0.6191472 0.6874508 0.7045981 0.7420994 0.7631497 0.8097986
## 0.5679441 0.6283925 0.6943677 0.7070859 0.7452680 0.7660506 0.8151389
## 0.5653948 0.6280282 0.6936107 0.7044799 0.7423242 0.7621600 0.8122662
## 0.5649631 0.6258089 0.6935943 0.6998769 0.7388825 0.7592925 0.8096142
## 0.5662090 0.6285378 0.6960349 0.6970601 0.7359775 0.7557798 0.8050650
##
## 0.7681338 0.7423434 0.7302956 0.6960428 0.6914899 0.6815950 0.6248239
## 0.8169185 0.8040254 0.7936899 0.7575790 0.7310045 0.7187415 0.6652268
## 0.8724088 0.8479150 0.8295175 0.8022119 0.7823191 0.7770677 0.7343426
## 0.9048431 0.8860219 0.8670219 0.8059359 0.8102596 0.8112347 0.7566758
## 0.9363520 0.9170235 0.8981824 0.8496328 0.8594730 0.8625869 0.8067983
## 0.9622158 0.9417072 0.9222768 0.8950442 0.8884727 0.8790384 0.8135232
## 0.9827034 0.9661790 0.9494244 0.9304074 0.9219279 0.9125505 0.8566804
## 1.0000000 0.9869157 0.9657301 0.9539330 0.9488027 0.9359962 0.8873653
## 0.9869157 1.0000000 0.9863801 0.9671491 0.9652976 0.9518515 0.9092888
## 0.9657301 0.9863801 1.0000000 0.9688411 0.9732926 0.9631611 0.9261899
## 0.9539330 0.9671491 0.9688411 1.0000000 0.9823907 0.9620905 0.9291929
## 0.9488027 0.9652976 0.9732926 0.9823907 1.0000000 0.9898405 0.9623653
## 0.9359962 0.9518515 0.9631611 0.9620905 0.9898405 1.0000000 0.9799594
## 0.8873653 0.9092888 0.9261899 0.9291929 0.9623653 0.9799594 1.0000000
## 0.8409243 0.8688260 0.8930905 0.9021053 0.9338311 0.9546510 0.9862933
## 0.8280803 0.8590272 0.8772365 0.8828475 0.9076387 0.9262839 0.9595752
## 0.8377073 0.8688370 0.8772179 0.8868236 0.9068122 0.9219788 0.9522505
## 0.8227569 0.8532538 0.8679352 0.8746734 0.8910091 0.9087425 0.9367962
## 0.8214855 0.8488045 0.8639715 0.8735928 0.8911637 0.9119153 0.9361253
## 0.8256006 0.8508362 0.8662064 0.8747239 0.8958135 0.9194616 0.9352696
## 0.8459886 0.8691744 0.8776442 0.8927903 0.9115666 0.9288308 0.9369361
## 0.8528205 0.8754312 0.8814119 0.8971992 0.9135327 0.9294217 0.9324833
## 0.8567669 0.8774809 0.8839618 0.8960035 0.9120366 0.9248327 0.9227977
## 0.8585746 0.8769921 0.8823934 0.8954623 0.9090674 0.9205611 0.9154045
## 0.8556566 0.8738171 0.8777763 0.8907383 0.9046569 0.9150396 0.9084827
## 0.8557182 0.8738246 0.8783226 0.8903260 0.9056408 0.9155221 0.9100271
## 0.8615518 0.8788117 0.8822649 0.8986815 0.9118755 0.9200760 0.9137771
## 0.8611398 0.8776979 0.8793501 0.8976618 0.9103006 0.9171882 0.9099072
## 0.8592624 0.8764139 0.8775294 0.9019818 0.9118769 0.9169248 0.9114831
## 0.8561027 0.8732243 0.8762586 0.8982228 0.9080646 0.9142942 0.9117616
##
## 0.6033672 0.5930855 0.5969486 0.5718300 0.5667376 0.5529756 0.5755119
## 0.6308865 0.6280206 0.6337404 0.6313390 0.6239106 0.6095227 0.6241048
```

```
##   0.7047777 0.7035979 0.7127320 0.7027723 0.6977255 0.6818425 0.6886542
##   0.7146271 0.7082540 0.7129008 0.6993844 0.6971858 0.6938854 0.7026389
##   0.7631584 0.7464389 0.7486171 0.7284230 0.7291088 0.7300315 0.7412334
##   0.7686456 0.7545503 0.7607996 0.7470296 0.7440787 0.7469863 0.7623458
##   0.8106556 0.7953798 0.8012916 0.7891892 0.7888411 0.7940526 0.8105745
##   0.8409243 0.8280803 0.8377073 0.8227569 0.8214855 0.8256006 0.8459886
##   0.8688260 0.8590272 0.8688370 0.8532538 0.8488045 0.8508362 0.8691744
##   0.8930905 0.8772365 0.8772179 0.8679352 0.8639715 0.8662064 0.8776442
##   0.9021053 0.8828475 0.8868236 0.8746734 0.8735928 0.8747239 0.8927903
##   0.9338311 0.9076387 0.9068122 0.8910091 0.8911637 0.8958135 0.9115666
##   0.9546510 0.9262839 0.9219788 0.9087425 0.9119153 0.9194616 0.9288308
##   0.9862933 0.9595752 0.9522505 0.9367962 0.9361253 0.9352696 0.9369361
##   1.0000000 0.9817741 0.9688145 0.9605656 0.9591757 0.9544235 0.9500951
##   0.9817741 1.0000000 0.9935808 0.9878379 0.9815051 0.9713150 0.9652575
##   0.9688145 0.9935808 1.0000000 0.9902831 0.9828889 0.9720295 0.9693869
##   0.9605656 0.9878379 0.9902831 1.0000000 0.9961085 0.9860357 0.9780550
##   0.9591757 0.9815051 0.9828889 0.9961085 1.0000000 0.9944168 0.9866767
##   0.9544235 0.9713150 0.9720295 0.9860357 0.9944168 1.0000000 0.9948793
##   0.9500951 0.9652575 0.9693869 0.9780550 0.9866767 0.9948793 1.0000000
##   0.9402297 0.9563811 0.9618254 0.9703007 0.9801198 0.9900394 0.9970754
##   0.9276021 0.9458732 0.9509626 0.9625643 0.9733870 0.9827621 0.9911068
##   0.9163980 0.9331396 0.9374622 0.9520204 0.9646719 0.9753968 0.9836738
##   0.9063058 0.9237251 0.9283070 0.9439520 0.9576219 0.9679359 0.9772655
##   0.9063830 0.9231984 0.9275614 0.9418490 0.9551171 0.9643954 0.9737511
##   0.9086067 0.9227847 0.9274470 0.9396250 0.9531264 0.9616792 0.9719415
##   0.9018247 0.9150078 0.9198812 0.9310867 0.9439077 0.9509381 0.9618606
##   0.9047243 0.9166994 0.9219319 0.9309048 0.9426007 0.9480099 0.9597170
##   0.9065790 0.9181580 0.9216538 0.9308188 0.9414577 0.9461751 0.9564931
##
##   0.5664357 0.5658656 0.5659936 0.5546524 0.5589950 0.5679441 0.5653948
##   0.6187538 0.6201299 0.6227271 0.6161869 0.6191472 0.6283925 0.6280282
##   0.6869377 0.6897731 0.6932167 0.6846366 0.6874508 0.6943677 0.6936107
##   0.7016577 0.7056357 0.7086898 0.7035264 0.7045981 0.7070859 0.7044799
##   0.7440163 0.7462302 0.7487625 0.7432476 0.7420994 0.7452680 0.7423242
##   0.7633718 0.7665582 0.7723146 0.7667534 0.7631497 0.7660506 0.7621600
##   0.8131266 0.8147612 0.8182009 0.8129122 0.8097986 0.8151389 0.8122662
##   0.8528205 0.8567669 0.8585746 0.8556566 0.8557182 0.8615518 0.8611398
##   0.8754312 0.8774809 0.8769921 0.8738171 0.8738246 0.8788117 0.8776979
##   0.8814119 0.8839618 0.8823934 0.8777763 0.8783226 0.8822649 0.8793501
##   0.8971992 0.8960035 0.8954623 0.8907383 0.8903260 0.8986815 0.8976618
##   0.9135327 0.9120366 0.9090674 0.9046569 0.9056408 0.9118755 0.9103006
##   0.9294217 0.9248327 0.9205611 0.9150396 0.9155221 0.9200760 0.9171882
##   0.9324833 0.9227977 0.9154045 0.9084827 0.9100271 0.9137771 0.9099072
##   0.9402297 0.9276021 0.9163980 0.9063058 0.9063830 0.9086067 0.9018247
##   0.9563811 0.9458732 0.9331396 0.9237251 0.9231984 0.9227847 0.9150078
##   0.9618254 0.9509626 0.9374622 0.9283070 0.9275614 0.9274470 0.9198812
##   0.9703007 0.9625643 0.9520204 0.9439520 0.9418490 0.9396250 0.9310867
##   0.9801198 0.9733870 0.9646719 0.9576219 0.9551171 0.9531264 0.9439077
##   0.9900394 0.9827621 0.9753968 0.9679359 0.9643954 0.9616792 0.9509381
##   0.9970754 0.9911068 0.9836738 0.9772655 0.9737511 0.9719415 0.9618606
##   1.0000000 0.9970342 0.9917668 0.9873075 0.9843522 0.9834240 0.9754585
##   0.9970342 1.0000000 0.9967009 0.9945476 0.9922696 0.9903967 0.9841978
##   0.9917668 0.9967009 1.0000000 0.9983056 0.9960812 0.9935323 0.9875918
##   0.9873075 0.9945476 0.9983056 1.0000000 0.9989313 0.9966084 0.9923131
```

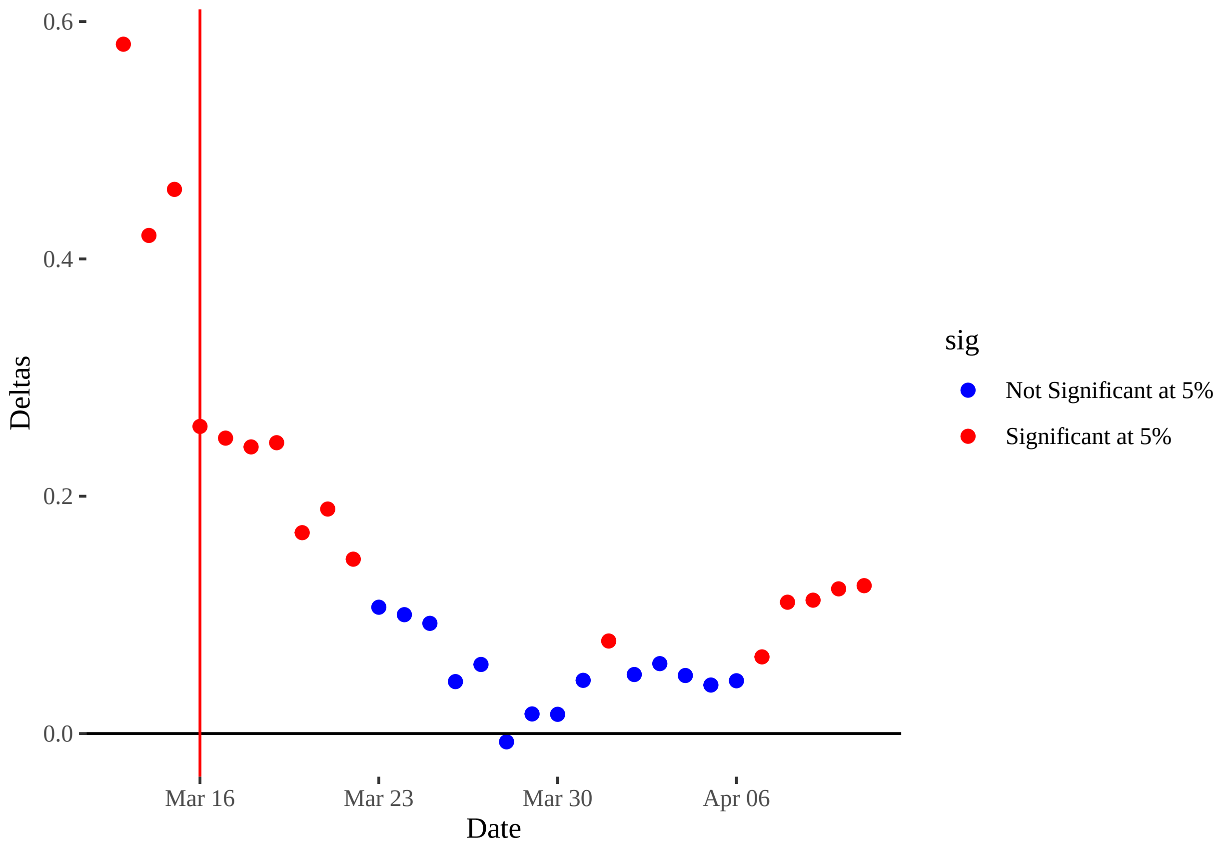
```
## 0.9843522 0.9922696 0.9960812 0.9989313 1.0000000 0.9984648 0.9956137
## 0.9834240 0.9903967 0.9935323 0.9966084 0.9984648 1.0000000 0.9983945
## 0.9754585 0.9841978 0.9875918 0.9923131 0.9956137 0.9983945 1.0000000
## 0.9732597 0.9814483 0.9840818 0.9882399 0.9921406 0.9959955 0.9985713
## 0.9696351 0.9772833 0.9786546 0.9832313 0.9884865 0.9931138 0.9956512
##
## 0.5649631 0.5662090
## 0.6258089 0.6285378
## 0.6935943 0.6960349
## 0.6998769 0.6970601
## 0.7388825 0.7359775
## 0.7592925 0.7557798
## 0.8096142 0.8050650
## 0.8592624 0.8561027
## 0.8764139 0.8732243
## 0.8775294 0.8762586
## 0.9019818 0.8982228
## 0.9118769 0.9080646
## 0.9169248 0.9142942
## 0.9114831 0.9117616
## 0.9047243 0.9065790
## 0.9166994 0.9181580
## 0.9219319 0.9216538
## 0.9309048 0.9308188
## 0.9426007 0.9414577
## 0.9480099 0.9461751
## 0.9597170 0.9564931
## 0.9732597 0.9696351
## 0.9814483 0.9772833
## 0.9840818 0.9786546
## 0.9882399 0.9832313
## 0.9921406 0.9884865
## 0.9959955 0.9931138
## 0.9985713 0.9956512
## 1.0000000 0.9976157
## 0.9976157 1.0000000
##
## R-sq. pooled: 0.8269
## Breusch-Pagan: 1.53e+04  p-value: (   0)
```

Spatial evolution of spatial residual autocorrelation

Plot the evolution of the spatial autocorrelation parameter:

```
data.frame(Date = seq(ymd("2020-03-13"),
                      ymd("2020-04-11"),
                      by = "days"),
           Deltas = sur.slm_lag11$deltas,
           tvalue = sur.slm_lag11$deltas/sur.slm_lag11$deltas.se) %>%
  mutate(sig = ifelse(abs(tvalue) > 1.64, "Significant at 5%", "Not Significant at 5%")) %>%
  ggplot(aes(x = Date, y = Deltas, color = sig)) +
  geom_point(size = 2) +
  scale_color_manual(values = c("Significant at 5%" = "red", "Not Significant at 5%" = "blue")) +
  geom_hline(yintercept = 0) +
```

```r
  geom_vline(xintercept = as_date("2020-03-16"), color = "red") +
  theme_tufte()
```



Analisis of autocorrelated residuals

Identify all equations with significant autocorrelation parameters:

```r
deltas.sig <- data.frame(Date = seq(ymd("2020-03-13"),
                       ymd("2020-04-11"),
                       by = "days"),
           Deltas = sur.slm_lag11$deltas,
           tvalue = sur.slm_lag11$deltas/sur.slm_lag11$deltas.se) %>%
  mutate(sig = abs(tvalue) > 1.64)
```

Extract all residuals and calculate the spatially autocorrelated residuals:

```r
all_residuals <- data.frame(matrix(unlist(residuals(sur.slm_lag11)),
                                   ncol = length(residuals(sur.slm_lag11)),
                                   byrow = FALSE))

# Spatially lagged residuals
for(i in 1:ncol(all_residuals)){
  all_residuals[,i] <- deltas.sig$Deltas[i] * lag.listw(listw, all_residuals[,i])
}

# Pivot table
```

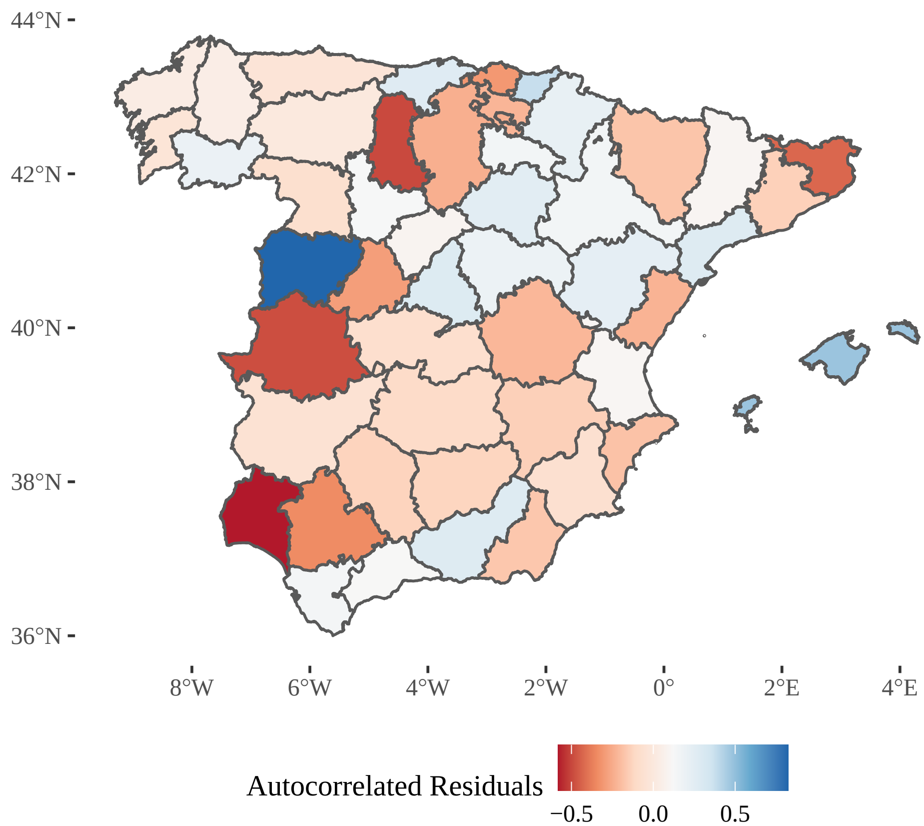
```r
all_residuals <- all_residuals %>%
  pivot_longer(everything(),
               names_to = "Date",
               values_to = "Spatially_Autocorrelated_Residuals")%>%
  mutate(Date = rep(seq(dmy("13-03-2020"),
                        dmy("11-04-2020"),
                        by = "days"),
                    50),
         ID_INE = rep(c(1:50),
                    each = 30))
```

Join to `covid19_spain`:

```r
covid19_spain <- covid19_spain %>%
  left_join(all_residuals, by = c("Date", "ID_INE"))
```

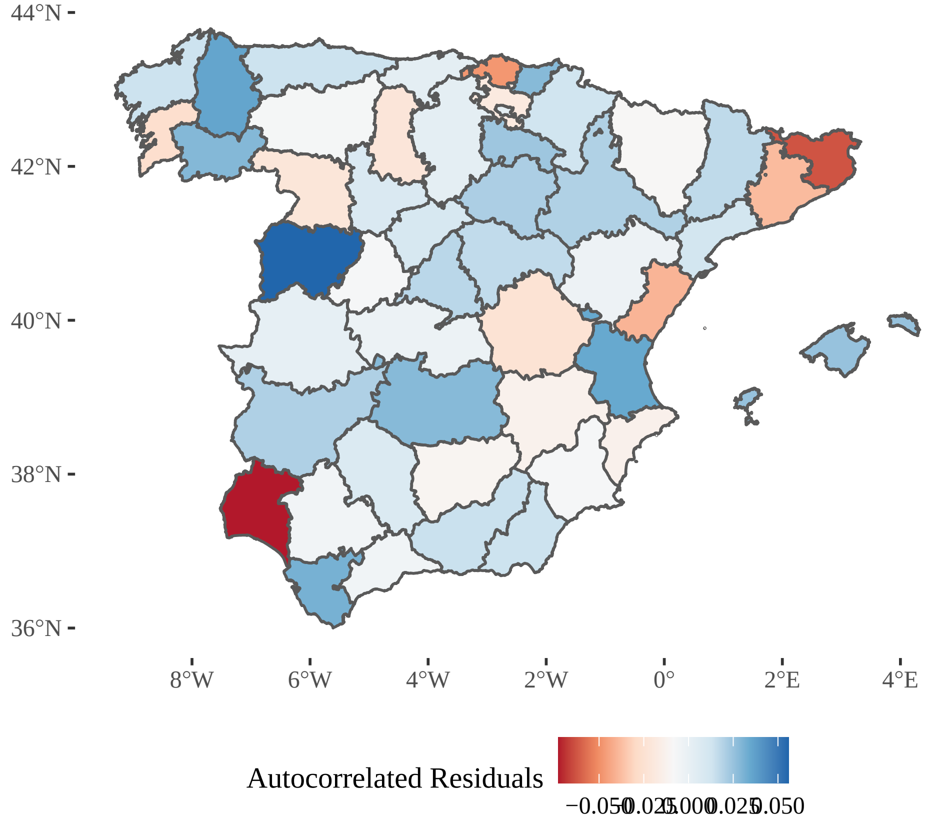
Plot residuals on March 13 (positive autocorrelation):

```r
covid19_spain %>% filter(Date == "2020-03-13") %>%
  filter(CCAA != "Canarias") %>%
  left_join(provinces_spain, by = c("province", "ID_INE")) %>%
  st_as_sf() %>%  ggplot() +
  geom_sf(aes(fill = Spatially_Autocorrelated_Residuals)) +
  scale_fill_distiller(name = "Autocorrelated Residuals", palette = "RdBu", direction = 1) +
  theme_tufte() +
  theme(legend.position = "bottom")
```



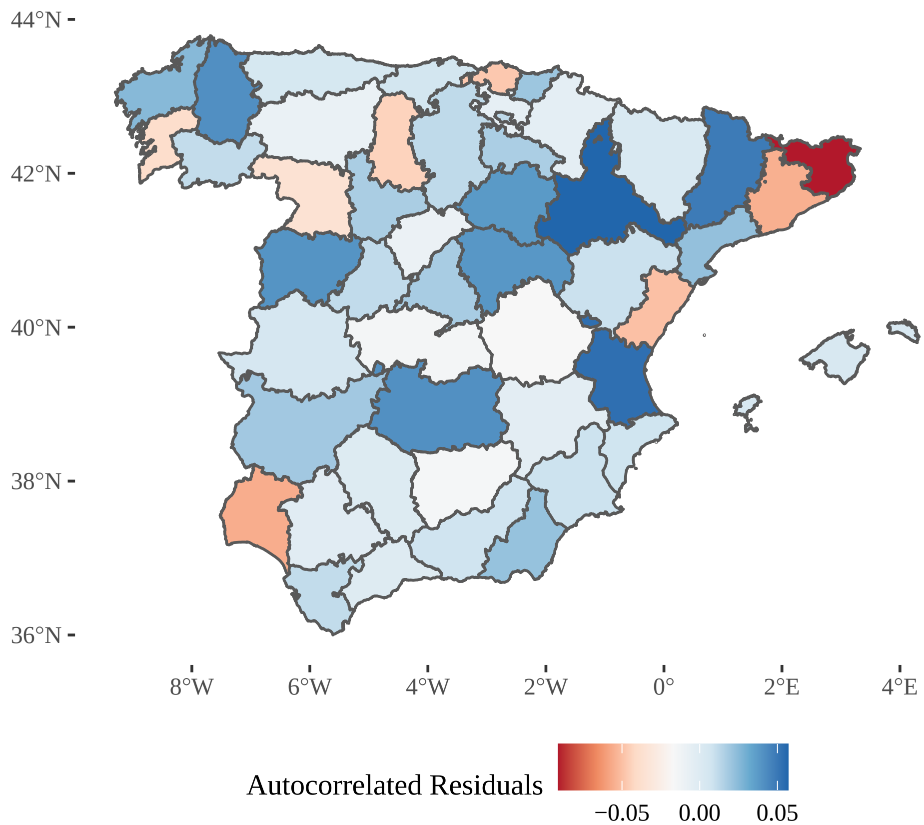
Plot residuals on March 24 (positive autocorrelation):

```r
covid19_spain %>% filter(Date == "2020-03-24") %>%
  filter(CCAA != "Canarias") %>%
  left_join(provinces_spain, by = c("province", "ID_INE")) %>%
  st_as_sf() %>%
  ggplot() +
  geom_sf(aes(fill = Spatially_Autocorrelated_Residuals)) +
  scale_fill_distiller(name = "Autocorrelated Residuals", palette = "RdBu", direction = 1) +
  theme_tufte() +
  theme(legend.position = "bottom")
```



Plot residuals on April 11:

```r
covid19_spain %>% filter(Date == "2020-04-11") %>%
  filter(CCAA != "Canarias") %>%
  left_join(provinces_spain, by = c("province", "ID_INE")) %>%
  st_as_sf() %>%
  ggplot() +
  geom_sf(aes(fill = Spatially_Autocorrelated_Residuals)) +
  scale_fill_distiller(name = "Autocorrelated Residuals", palette = "RdBu", direction = 1) +
  theme_tufte() +
  theme(legend.position = "bottom")
```



Are these spatially autocorrelated residuals correlated with any other potential control variables? Check the correlations:

```
covid19_spain %>%
  group_by(Date) %>%
  summarize(correlation_m2f = cor(log(Male2Female), Spatially_Autocorrelated_Residuals),
            correlation_age = cor(log(Median_Age), Spatially_Autocorrelated_Residuals),
            correlation_sunshine = cor(log(Sunshine_Hours_lag11 + 0.1), Spatially_Autocorrelated_Residu
  summary()
```

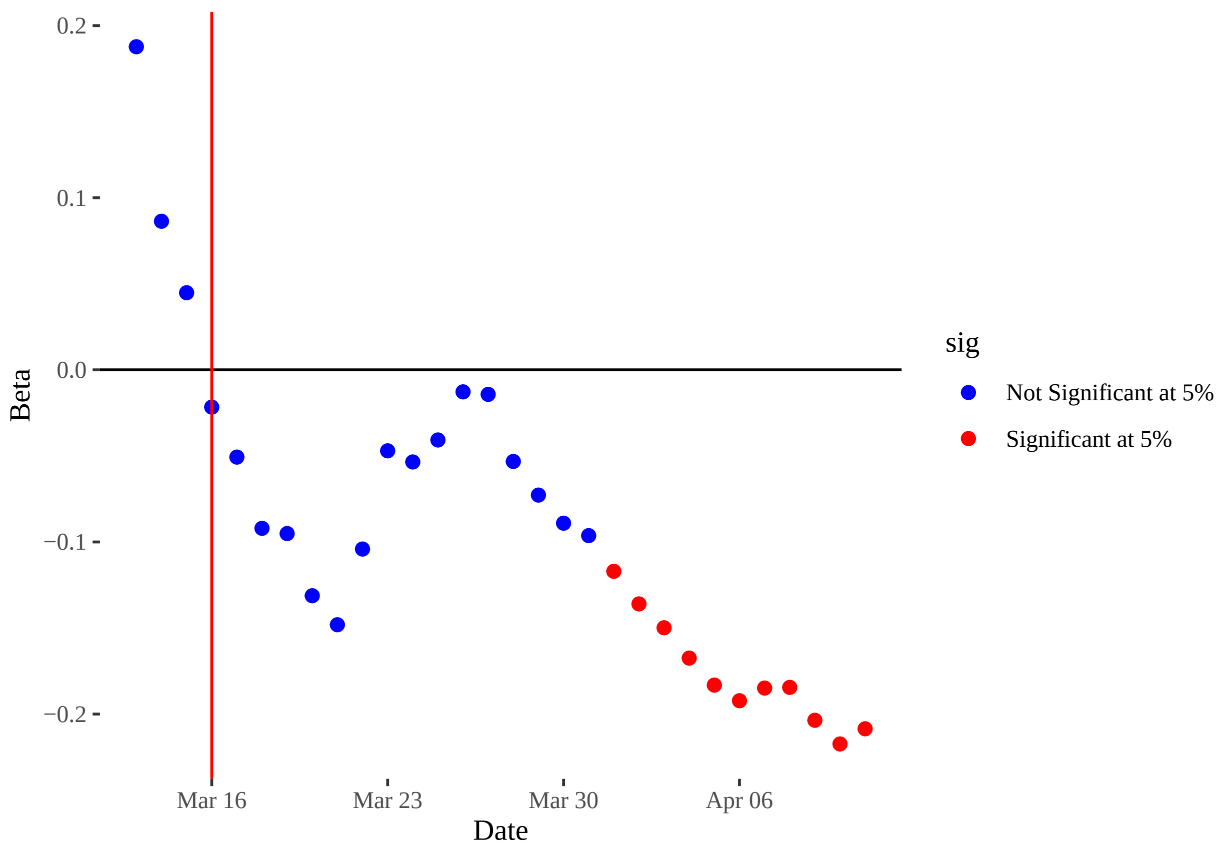
```
##       Date            correlation_m2f    correlation_age
##  Min.   :2020-03-13   Min.   :-0.19569   Min.   :-0.07781
##  1st Qu.:2020-03-20   1st Qu.:-0.12597   1st Qu.: 0.02784
##  Median :2020-03-27   Median :-0.02297   Median : 0.09341
##  Mean   :2020-03-27   Mean   :-0.03760   Mean   : 0.07036
##  3rd Qu.:2020-04-03   3rd Qu.: 0.05934   3rd Qu.: 0.11023
##  Max.   :2020-04-11   Max.   : 0.07991   Max.   : 0.16724
##  correlation_sunshine
##  Min.   :-0.12881
##  1st Qu.:-0.08907
##  Median :-0.05657
##  Mean   :-0.04859
##  3rd Qu.:-0.01693
##  Max.   : 0.13181
```

These three variables are only weakly and inconsistently correlated with the residuals.

Temporal variation of coefficients for density and transit

Density:

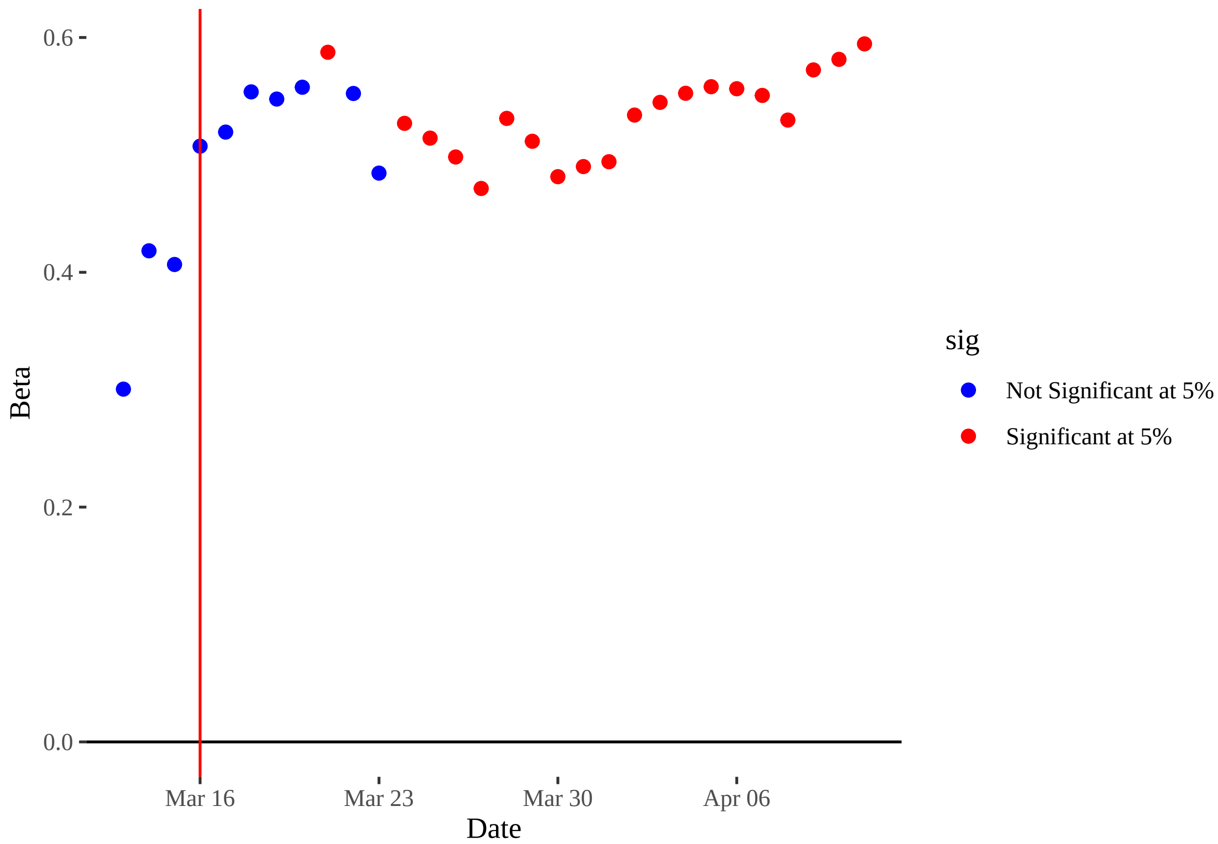
```
n = 2
data.frame(Date = seq(ymd("2020-03-13"),
                      ymd("2020-04-11"),
                      by = "days"),
           Beta = matrix(sur.slm_lag11$coefficients[-c(2,3)],ncol = T)[n,],
           tvalue = matrix(sur.slm_lag11$coefficients[-c(2,3)]/sur.slm_lag11$rest.se[-c(2,3)], ncol = T)
  mutate(sig = ifelse(abs(tvalue) > 1.64, "Significant at 5%", "Not Significant at 5%")) %>%
  ggplot(aes(x = Date, y = Beta, color = sig)) +
  geom_point(size = 2) +
  scale_color_manual(values = c("Significant at 5%" = "red", "Not Significant at 5%" = "blue")) +
  geom_hline(yintercept = 0) +
  geom_vline(xintercept = as_date("2020-03-16"), color = "red") +
  theme_tufte()
```



Transit:

```
n = 3
data.frame(Date = seq(ymd("2020-03-13"),
                      ymd("2020-04-11"),
                      by = "days"),
           Beta = matrix(sur.slm_lag11$coefficients[-c(2,3)],ncol = T)[n,],
           tvalue = matrix(sur.slm_lag11$coefficients[-c(2,3)]/sur.slm_lag11$rest.se[-c(2,3)], ncol = T)
  mutate(sig = ifelse(abs(tvalue) > 1.64, "Significant at 5%", "Not Significant at 5%")) %>%
  ggplot(aes(x = Date, y = Beta, color = sig)) +
```

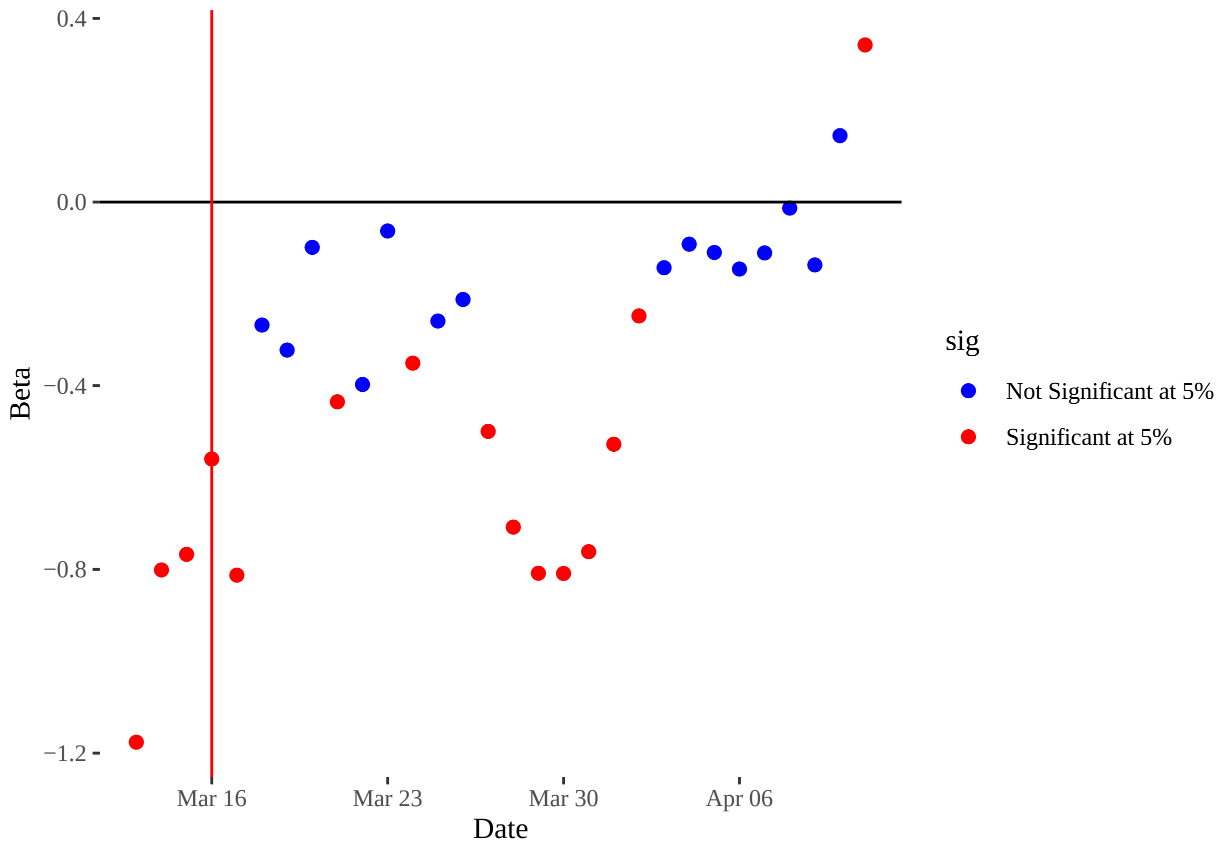
```r
  geom_point(size = 2) +
  scale_color_manual(values = c("Significant at 5%" = "red", "Not Significant at 5%" = "blue")) +
  geom_hline(yintercept = 0) +
  geom_vline(xintercept = as_date("2020-03-16"), color = "red") +
  theme_tufte()
```



Temporal variation of coefficients of climatic variables

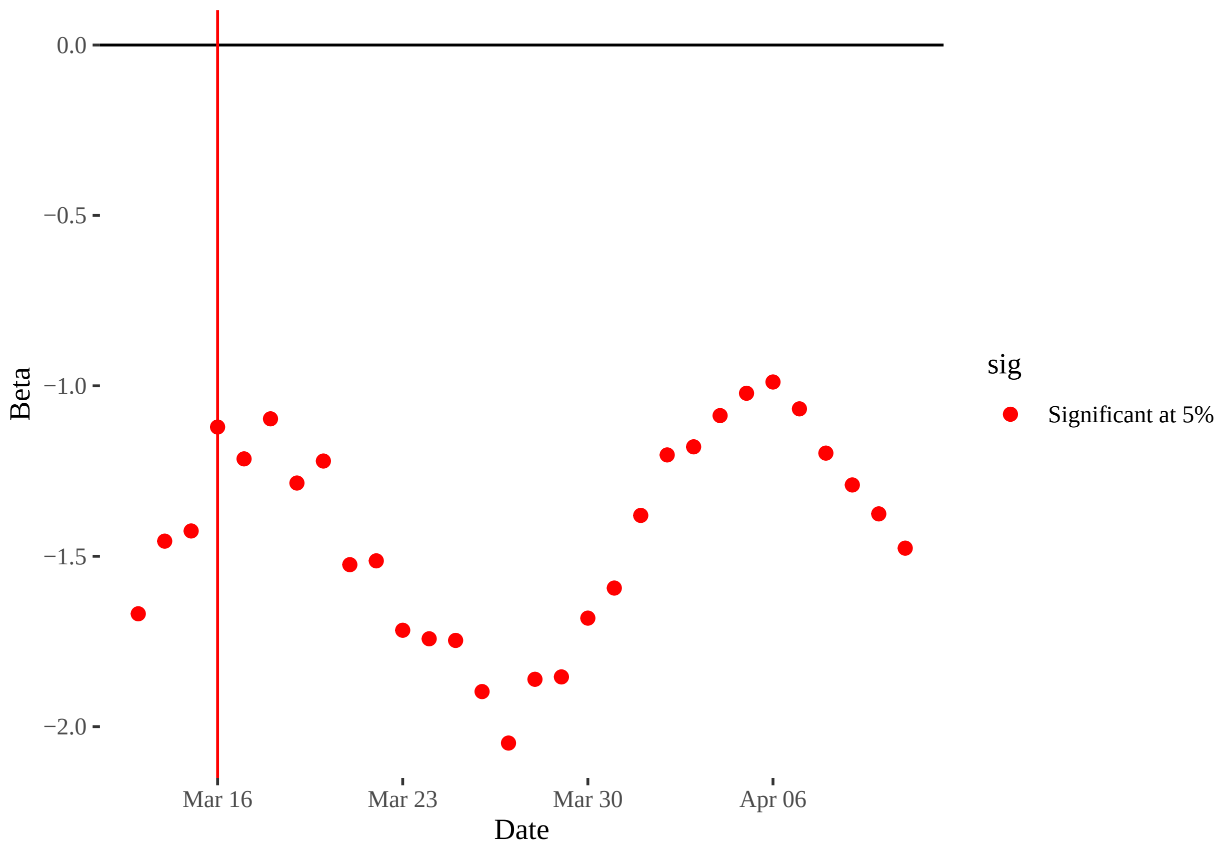
Humidity:

```r
n = 4
data.frame(Date = seq(ymd("2020-03-13"),
                      ymd("2020-04-11"),
                      by = "days"),
           Beta = matrix(sur.slm_lag11$coefficients[-c(2,3)],ncol = T)[n,],
           tvalue = matrix(sur.slm_lag11$coefficients[-c(2,3)]/sur.slm_lag11$rest.se[-c(2,3)], ncol = T)
  mutate(sig = ifelse(abs(tvalue) > 1.64, "Significant at 5%", "Not Significant at 5%")) %>%
  ggplot(aes(x = Date, y = Beta, color = sig)) +
  geom_point(size = 2) +
  scale_color_manual(values = c("Significant at 5%" = "red", "Not Significant at 5%" = "blue")) +
  geom_hline(yintercept = 0) +
  geom_vline(xintercept = as_date("2020-03-16"), color = "red") +
  theme_tufte()
```



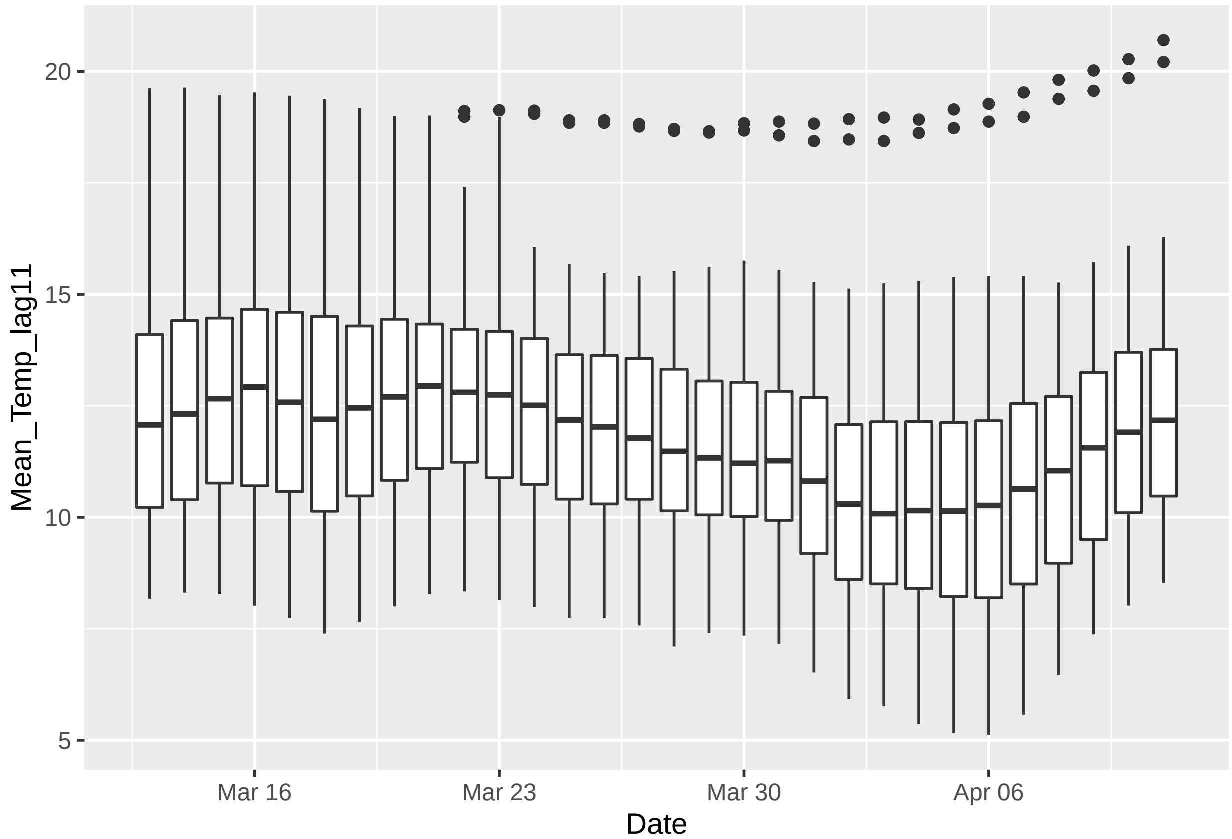
Temperature:

```
n = 5
data.frame(Date = seq(ymd("2020-03-13"),
                      ymd("2020-04-11"),
                      by = "days"),
           Beta = matrix(sur.slm_lag11$coefficients[-c(2,3)],ncol = T)[n,],
           tvalue = matrix(sur.slm_lag11$coefficients[-c(2,3)]/sur.slm_lag11$rest.se[-c(2,3)], ncol = T)
  mutate(sig = ifelse(abs(tvalue) > 1.64, "Significant at 5%", "Not Significant at 5%")) %>%
  ggplot(aes(x = Date, y = Beta, color = sig)) +
  geom_point(size = 2) +
  scale_color_manual(values = c("Significant at 5%" = "red", "Not Significant at 5%" = "blue")) +
  geom_hline(yintercept = 0) +
  geom_vline(xintercept = as_date("2020-03-16"), color = "red") +
  theme_tufte()
```



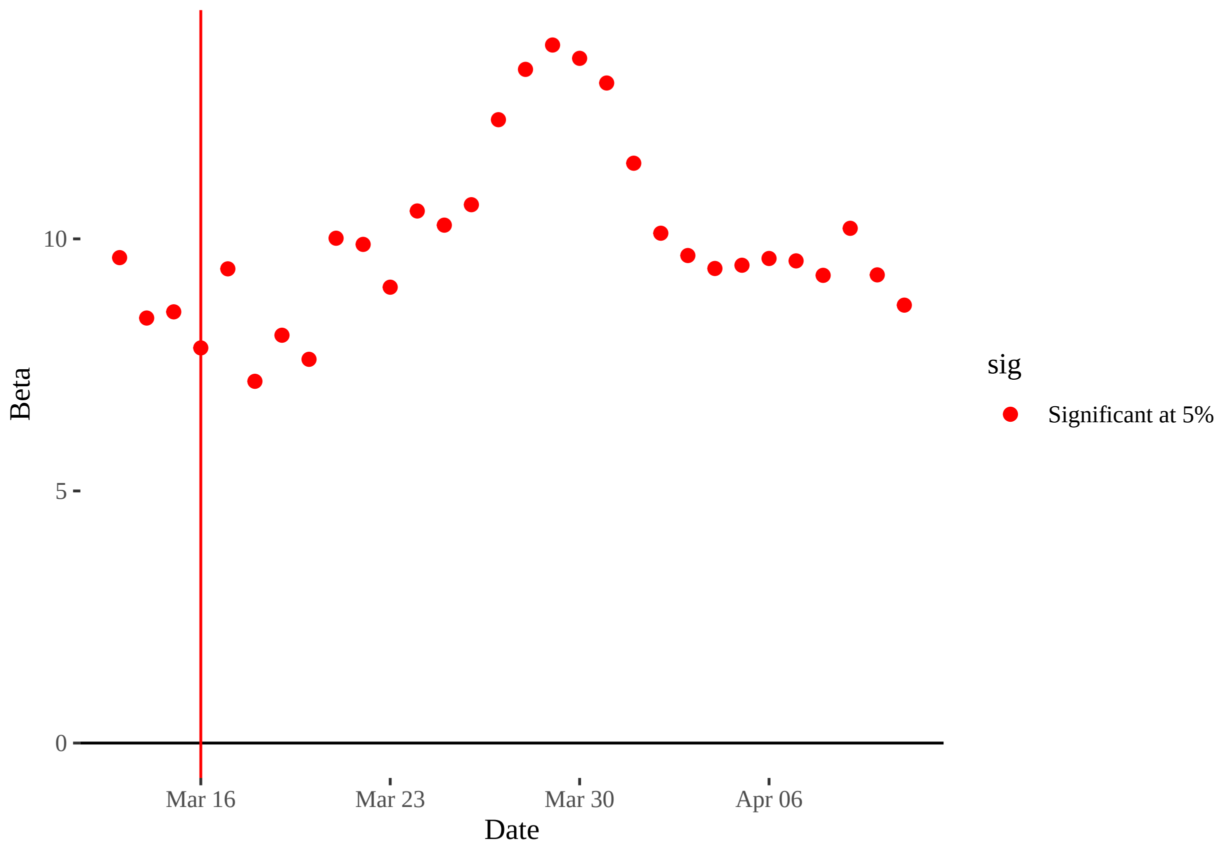
Boxplot of temperatures by date

```
ggplot(data = covid19_spain, aes(x = Date, y = Mean_Temp_lag11, group = Date)) +
  geom_boxplot()
```



Intercept

```
n = 1
data.frame(Date = seq(ymd("2020-03-13"),
                      ymd("2020-04-11"),
                      by = "days"),
           Beta = matrix(sur.slm_lag11$coefficients[-c(2,3)],ncol = T)[n,],
           tvalue = matrix(sur.slm_lag11$coefficients[-c(2,3)]/sur.slm_lag11$rest.se[-c(2,3)], ncol = T)
  mutate(sig = ifelse(abs(tvalue) > 1.64, "Significant at 5%", "Not Significant at 5%")) %>%
  ggplot(aes(x = Date, y = Beta, color = sig)) +
  geom_point(size = 2) +
  scale_color_manual(values = c("Significant at 5%" = "red", "Not Significant at 5%" = "blue")) +
  geom_hline(yintercept = 0) +
  geom_vline(xintercept = as_date("2020-03-16"), color = "red") +
  theme_tufte()
```



Beta
10
5
0
Mar 16
Mar 23
Mar 30
Apr 06
Date
sig
Significant at 5%