Extension: Synthetic Control without Piauí

```
#-----------------------------------------------------------------------------------------------#
# Data Subsetting
#-----------------------------------------------------------------------------------------------#

PRIMARY_M <- as.data.frame(filter(DATA_COMPLETE, grade == "P", subject == "math"))
PRIMARY_P <- as.data.frame(filter(DATA_COMPLETE, grade == "P", subject == "port"))
LOWERS_M <- as.data.frame(filter(DATA_COMPLETE, grade == "LS", subject == "math"))
LOWERS_P <- as.data.frame(filter(DATA_COMPLETE, grade == "LS", subject == "port"))

#-----------------------------------------------------------------------------------------------#
# Preparing Data for Synth (Excluding Piauí)
#-----------------------------------------------------------------------------------------------#

prepare_p_ls_PI <- function(data) {
  library(Synth)

  predictors <- c("homicides", "TWh", "ln_pop", "unemployment", "edu_invest_pc")

  DATA <- dataprep(foo = data,
                   predictors = predictors,
                   dependent = "score",
                   unit.variable = "code_state",
                   time.variable = "year",
                   unit.names.variable = "abbr_state",
                   treatment.identifier = 23, # Ceará Code
                   controls.identifier = c(11:17, 21, 24:29, 31:33, 35, 41:43, 50:53),
                   # Exclude Piauí (22) and Ceará (23)
                   time.predictors.prior = seq(1995, 2007, 2),
                   time.optimize.ssr = seq(1995, 2007, 2),
                   time.plot = seq(1995, 2019, 2))

  return(DATA)
}

#-----------------------------------------------------------------------------------------------#
# Execution of Synthetic Control Method
#-----------------------------------------------------------------------------------------------#

DATA_PM <- prepare_p_ls_PI(PRIMARY_M)
SCM_PM <- synth(DATA_PM)
```

```
##
## X1, X0, Z1, Z0 all come directly from dataprep object.
##
##
## ****************
##  searching for synthetic control unit
##
##
## ****************
## ****************
## ****************
```

```
##
## MSPE (LOSS V): 63.48728
##
## solution.v:
##  0.1934857 0.3127029 2.19e-08 0.2126195 0.2811919
##
## solution.w:
##  0.004474852 0.0009300773 0.0007292257 0.0007054601 0.001420396 0.0005013932 0.002673195 0.1163018 0
```

```
DATA_PP <- prepare_p_ls_PI(PRIMARY_P)
SCM_PP <- synth(DATA_PP)
```

```
##
## X1, X0, Z1, Z0 all come directly from dataprep object.
##
##
## ****************
##  searching for synthetic control unit
##
##
## ****************
## ****************
## ****************
##
## MSPE (LOSS V): 46.26716
##
## solution.v:
##  0.3413594 0.4124263 0.01070271 3.33389e-05 0.2354782
##
## solution.w:
##  4.55448e-05 2.50038e-05 7.84002e-05 1.99015e-05 3.23363e-05 2.20135e-05 2.9265e-05 0.0009849393 4.68
```

```
DATA_LSM <- prepare_p_ls_PI(LOWERS_M)
SCM_LSM <- synth(DATA_LSM)
```

```
##
## X1, X0, Z1, Z0 all come directly from dataprep object.
##
##
## ****************
##  searching for synthetic control unit
##
##
## ****************
## ****************
## ****************
##
## MSPE (LOSS V): 10.86386
##
## solution.v:
##  0.19474 0.3147814 1e-09 0.2101793 0.2802993
##
## solution.w:
##  0.004648188 0.0009383975 0.0007193599 0.0007152314 0.001422106 0.0005072035 0.002593207 0.1156682 0
```

```r
DATA_LSP <- prepare_p_ls_PI(LOWERS_P)
SCM_LSP <- synth(DATA_LSP)
```

```
##
## X1, X0, Z1, Z0 all come directly from dataprep object.
##
##
## ****************
##  searching for synthetic control unit
##
##
## ****************
## ****************
## ****************
##
## MSPE (LOSS V): 13.40889
##
## solution.v:
##  0.1547955 0.2160913 0.0001584944 0.002317496 0.6266372
##
## solution.w:
##  0.004261227 0.001742724 0.002064103 0.001211499 0.002541634 0.001109108 0.003500906 0.1036674 0.0028
```

```r
#-------------------------------------------------------------------------------------------#
# Graphs Generation in ggplot (Excluding Piauí)
#-------------------------------------------------------------------------------------------#

# Generate Plots for Each Category
PM <- plot_scm(PRIMARY_M, synth.tab(dataprep.res = DATA_PM, synth.res = SCM_PM))
```

```
## -- Attaching core tidyverse packages ------------------------ tidyverse 2.0.0 --
## v forcats   1.0.0     v stringr   1.5.1
## v lubridate 1.9.3     v tibble    3.2.1
## v purrr     1.0.2     v tidyr     1.3.0
## v readr     2.1.4
## -- Conflicts ------------------------------------------ tidyverse_conflicts() --
## x dplyr::filter() masks stats::filter()
## x dplyr::lag()    masks stats::lag()
## i Use the conflicted package (<http://conflicted.r-lib.org/>) to force all conflicts to become errors
```

```
## 'data.frame':    5 obs. of  3 variables:
##  $ w.weights   : num  0.116 0.768 0.033 0.012 0.033
##  $ abbr_state  : chr  "MA" "PB" "PE" "SC" ...
##  $ unit.numbers: num  21 25 26 42 51
## 'data.frame':    351 obs. of  14 variables:
##  $ abbr_state   : chr  "AC" "AC" "AC" "AC" ...
##  $ code_state   : num  12 12 12 12 12 27 27 27 27 27 ...
##  $ year         : num  1995 1997 1999 2001 2003 ...
##  $ grade        : chr  "P" "P" "P" "P" ...
##  $ subject      : chr  "math" "math" "math" "math" ...
##  $ score        : num  168 166 162 152 159 ...
##  $ TWh          : num  0.0139 0.0132 0.0137 0.0198 0.0227 ...
##  $ homicides    : num  22.62 19.99 9.66 21.24 22.04 ...
##  $ pop          : num  455242 500185 527937 574355 600595 ...
##  $ ln_pop       : num  13 13.1 13.2 13.3 13.3 ...
```

```
##  $ unemployment : num  9.8 8.89 12.2 8.56 7.45 ...
##  $ gini         : num  0.582 0.574 0.621 0.623 0.578 ...
##  $ edu_invest   : num  3.69e+08 4.34e+08 4.54e+08 6.19e+08 6.26e+08 ...
##  $ edu_invest_pc: num  811 868 860 1077 1042 ...
```

```
PP <- plot_scm(PRIMARY_P, synth.tab(dataprep.res = DATA_PP, synth.res = SCM_PP))
```

```
## 'data.frame':    4 obs. of  3 variables:
##  $ w.weights   : num  0.738 0.028 0.115 0.117
##  $ abbr_state  : chr  "PB" "PE" "BA" "GO"
##  $ unit.numbers: num  25 26 29 52
## 'data.frame':    351 obs. of  14 variables:
##  $ abbr_state   : chr  "AC" "AC" "AC" "AC" ...
##  $ code_state   : num  12 12 12 12 12 27 27 27 27 27 ...
##  $ year         : num  1995 1997 1999 2001 2003 ...
##  $ grade        : chr  "P" "P" "P" "P" ...
##  $ subject      : chr  "port" "port" "port" "port" ...
##  $ score        : num  166 160 154 148 158 ...
##  $ TWh          : num  0.0139 0.0132 0.0137 0.0198 0.0227 ...
##  $ homicides    : num  22.62 19.99 9.66 21.24 22.04 ...
##  $ pop          : num  455242 500185 527937 574355 600595 ...
##  $ ln_pop       : num  13 13.1 13.2 13.3 13.3 ...
##  $ unemployment : num  9.8 8.89 12.2 8.56 7.45 ...
##  $ gini         : num  0.582 0.574 0.621 0.623 0.578 ...
##  $ edu_invest   : num  3.69e+08 4.34e+08 4.54e+08 6.19e+08 6.26e+08 ...
##  $ edu_invest_pc: num  811 868 860 1077 1042 ...
```

```
LSM <- plot_scm(LOWERS_M, synth.tab(dataprep.res = DATA_LSM, synth.res = SCM_LSM))
```

```
## 'data.frame':    5 obs. of  3 variables:
##  $ w.weights   : num  0.116 0.769 0.033 0.012 0.032
##  $ abbr_state  : chr  "MA" "PB" "PE" "SC" ...
##  $ unit.numbers: num  21 25 26 42 51
## 'data.frame':    351 obs. of  14 variables:
##  $ abbr_state   : chr  "AC" "AC" "AC" "AC" ...
##  $ code_state   : num  12 12 12 12 12 27 27 27 27 27 ...
##  $ year         : num  1995 1997 1999 2001 2003 ...
##  $ grade        : chr  "LS" "LS" "LS" "LS" ...
##  $ subject      : chr  "math" "math" "math" "math" ...
##  $ score        : num  223 220 223 219 225 ...
##  $ TWh          : num  0.0139 0.0132 0.0137 0.0198 0.0227 ...
##  $ homicides    : num  22.62 19.99 9.66 21.24 22.04 ...
##  $ pop          : num  455242 500185 527937 574355 600595 ...
##  $ ln_pop       : num  13 13.1 13.2 13.3 13.3 ...
##  $ unemployment : num  9.8 8.89 12.2 8.56 7.45 ...
##  $ gini         : num  0.582 0.574 0.621 0.623 0.578 ...
##  $ edu_invest   : num  3.69e+08 4.34e+08 4.54e+08 6.19e+08 6.26e+08 ...
##  $ edu_invest_pc: num  811 868 860 1077 1042 ...
```

```
LSP <- plot_scm(LOWERS_P, synth.tab(dataprep.res = DATA_LSP, synth.res = SCM_LSP))
```

```
## 'data.frame':    3 obs. of  3 variables:
##  $ w.weights   : num  0.104 0.785 0.039
##  $ abbr_state  : chr  "MA" "PB" "PE"
##  $ unit.numbers: num  21 25 26
## 'data.frame':    351 obs. of  14 variables:
```

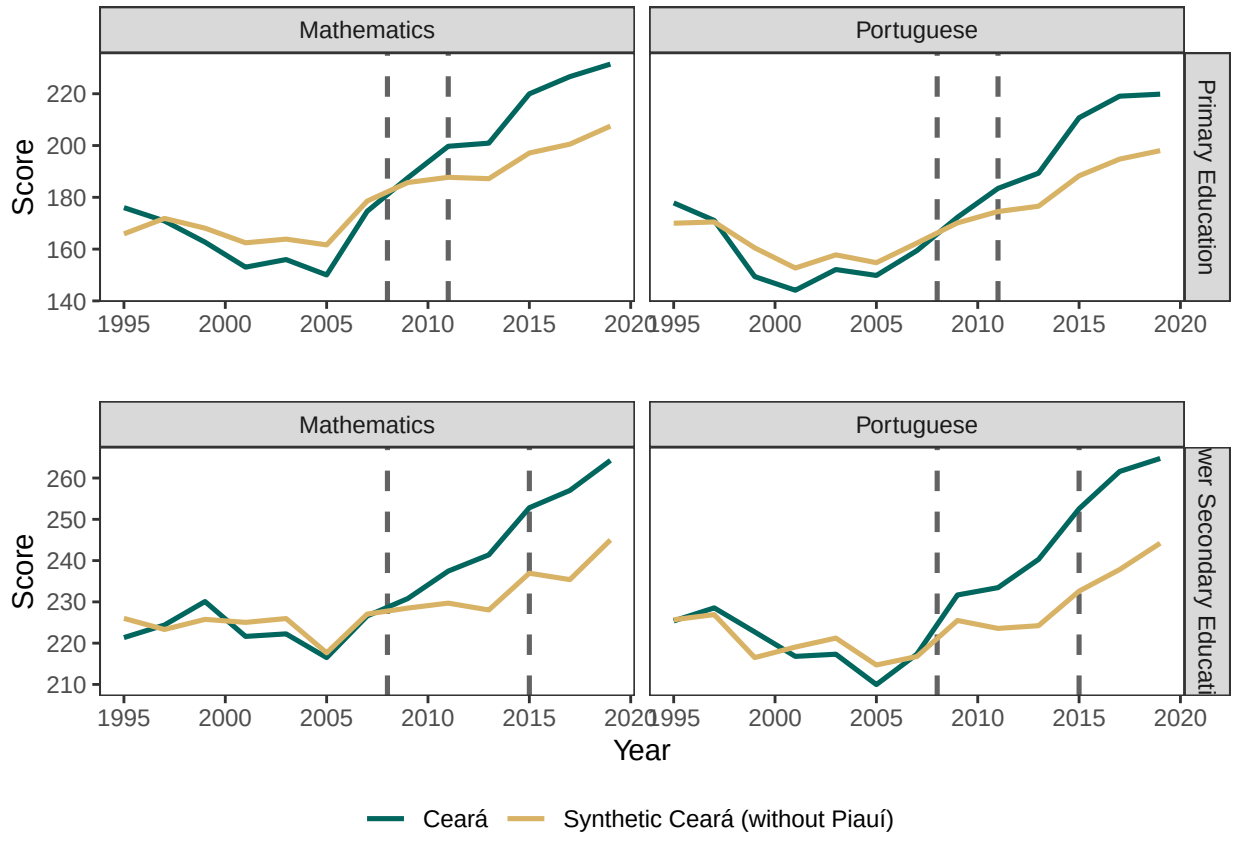
```
##  $ abbr_state   : chr  "AC" "AC" "AC" "AC" ...
##  $ code_state   : num  12 12 12 12 12 27 27 27 27 27 ...
##  $ year         : num  1995 1997 1999 2001 2003 ...
##  $ grade        : chr  "LS" "LS" "LS" "LS" ...
##  $ subject      : chr  "port" "port" "port" "port" ...
##  $ score        : num  227 223 217 218 223 ...
##  $ TWh          : num  0.0139 0.0132 0.0137 0.0198 0.0227 ...
##  $ homicides    : num  22.62 19.99 9.66 21.24 22.04 ...
##  $ pop          : num  455242 500185 527937 574355 600595 ...
##  $ ln_pop       : num  13 13.1 13.2 13.3 13.3 ...
##  $ unemployment : num  9.8 8.89 12.2 8.56 7.45 ...
##  $ gini         : num  0.582 0.574 0.621 0.623 0.578 ...
##  $ edu_invest   : num  3.69e+08 4.34e+08 4.54e+08 6.19e+08 6.26e+08 ...
##  $ edu_invest_pc: num  811 868 860 1077 1042 ...
```

```r
#-------------------------------------------------------------------------------------------#
# Combining Data for Graphs and Plot Adjustments
#-------------------------------------------------------------------------------------------#

# Combine the Synthetic Control Graph Data
DATA_GRAPH <- rbind(PM[[1]], PP[[1]], LSM[[1]], LSP[[1]])

# Adjust the Labels and Factors
DATA_GRAPH$grade[DATA_GRAPH$grade=="P"] <- "Primary Education"
DATA_GRAPH$grade[DATA_GRAPH$grade=="LS"] <- "Lower Secondary Education"
DATA_GRAPH$grade[DATA_GRAPH$grade=="US"] <- "Upper Secondary Education"
DATA_GRAPH$grade <- factor(DATA_GRAPH$grade, levels = c("Primary Education",
                                                        "Lower Secondary Education"))

DATA_GRAPH$subject[DATA_GRAPH$subject=="math"] <- "Mathematics"
DATA_GRAPH$subject[DATA_GRAPH$subject=="port"] <- "Portuguese"
DATA_GRAPH$subject <- factor(DATA_GRAPH$subject, levels = c("Mathematics", "Portuguese"))

#-------------------------------------------------------------------------------------------#
# Final Plotting and Saving
#-------------------------------------------------------------------------------------------#

# Assuming DATA_GRAPH and DATA_GAP are your combined datasets

# Figure for Primary Education
a_without_PI <- ggplot(data = filter(DATA_GRAPH, grade == "Primary Education"), aes(x = year, y = score
  geom_vline(xintercept = 2008, color = "#636363", linetype = "dashed", size = 0.9) +
  geom_vline(xintercept = 2011, color = "#636363", linetype = "dashed", size = 0.9) +
  geom_line(size = 0.9) +
  scale_color_manual(values = c("#01665e", "#d8b365"), labels = c("Ceará", "Synthetic Ceará (without Pi
  ylab("Score") +
  xlab("") +
  theme_bw() +
  theme(panel.grid.major = element_blank(), panel.grid.minor = element_blank(), legend.position = "botto
  facet_grid(vars(grade), vars(subject))
```

```
## Warning: Using `size` aesthetic for lines was deprecated in ggplot2 3.4.0.
## i Please use `linewidth` instead.
## This warning is displayed once every 8 hours.
## Call `lifecycle::last_lifecycle_warnings()` to see where this warning was
```

generated.

```
# Figure for Lower Secondary Education
b_without_PI <- ggplot(data = filter(DATA_GRAPH, grade == "Lower Secondary Education"), aes(x = year, y
  geom_vline(xintercept = 2008, color = "#636363", linetype = "dashed", size = 0.9) +
  geom_vline(xintercept = 2015, color = "#636363", linetype = "dashed", size = 0.9) +
  geom_line(size = 0.9) +
  scale_color_manual(values = c("#01665e", "#d8b365"), labels = c("Ceará", "Synthetic Ceará (without Pia
  ylab("Score") +
  xlab("Year") +
  theme_bw() +
  theme(panel.grid.major = element_blank(), panel.grid.minor = element_blank(), legend.position = "botto
  facet_grid(vars(grade), vars(subject))

# Arrange and Save the Plots
ggarrange(a_without_PI, b_without_PI, ncol = 1, nrow = 2, common.legend = TRUE, legend = "bottom")
```




```
ggsave(filename = "figures_without_PI.png", path = "plots", width = 21, height = 15, units = "cm")
```