Stat 463 Final Project

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Introduction

For decades, the scientific community, policymakers, and global organizations have been grappling with the pressing issue of global warming, aiming to identify, develop, and implement the most effective strategies to mitigate its effects. One of the most critical steps in addressing this challenge is to thoroughly investigate its underlying causes, particularly the factors contributing to the increased concentration of carbon dioxide (co_2) in the atmosphere. As a primary greenhouse gas, co_2 plays a pivotal role in the intensification of the greenhouse effect, which has directly and indirectly led to a steady rise in global average temperatures. Understanding the historical trends and sources of co_2 emissions is crucial to comprehending the broader dynamics of climate change.

This research specifically focuses on analyzing the significant boom in co_2 emissions that occurred during the Second Industrial Revolution, a period marked by rapid industrialization, technological advancements, and fossil fuel exploitation. By evaluating the socio-economic activities and technological developments of this transformative era, we aim to uncover the extent to which these factors contributed to the expansion of greenhouse gas levels and how they set the stage for the modern challenges of global warming. Through this analysis, we hope to provide insights into historical emission trends and their implications for current and future efforts to combat climate change.

Background

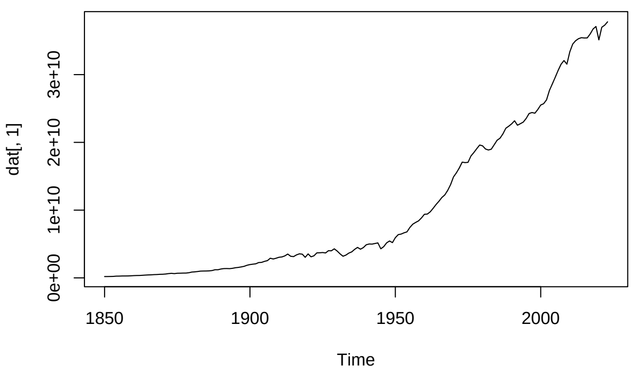
The Intergovernmental Panel on Climate Change (IPCC) issued a report in 1990 utilizing global mean near surface temperature which raised concern on the rate of increasing. (J. Ring et al. 2012). This concern raised the question of further research on greenhouse effect of the change in global temperatures.

This issue has largely driven by the significant increase in greenhouse gas emissions such as carbon dioxide, methane, and nitrous oxide, has far-reaching consequences for urban life and biodiversity. The accumulation of these gases intensifies the greenhouse effect, leading to rising global temperatures and more frequent extreme weather events, including heatwaves, severe storms, and flooding. In urban areas, this exacerbates challenges like the urban heat island effect, worsened air quality, and increased strain on infrastructure. Coastal cities are particularly vulnerable, facing rising sea levels and flooding that can displace populations and result in substantial economic losses. On a broader scale, global warming disrupts ecosystems, causing habitat loss, shifts in climate zones, and resource scarcity that threaten the survival of countless species. These disruptions highlight the critical need for reducing greenhouse gas emissions and adopting sustainable practices to address the growing impacts of global warming on both human systems and the environment.

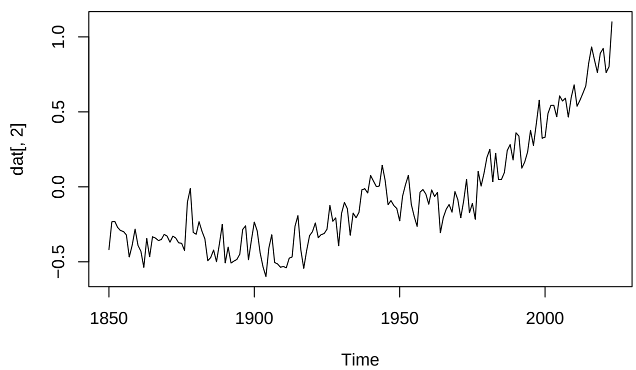
Anthropological contribution on the emission of carbon dioxide that mainly draws from the effect of human activity (Collins et al. 2010) on a large scale acts as the main motive of the extreme spur especially after the second industrial revolution era.(Smith et al. 2008) Predominantly starts from western europe and north america where both regions exceeded 10 ton per capita as from the region report (Ritchie, Rosado, and Roser 2023). A combination of boost in different industries which is facilitated by the second industrial revolution including chemical and transportation domain (Mokyr and Strotz 1998) after the mid 1880s followed by the expansion boom leads to the official start of boosting the aggregate global carbon dioxide emission. This major event placed a major factor on the co_2 emission which reflected on the overall data trend in terms of human intervention.

Method

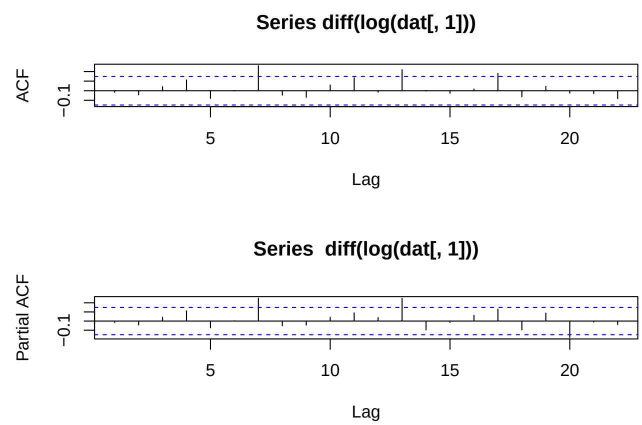
In this study, we determine the effect of co_2 on temperature and compare the trend found through constructing a time series model for forecasting and the Arch-Garch method for taking care of the variance change aspect as time progresses. We use linear regression and Auto-Aggressive-Moving-Average(ARIMA) models for stationary and stochastic respectively. The model takes in consideration the data behavior change due to real world events.



(a) Plot data of Gobal CO2 Emission



(b) Plot data of Gobal Temperature



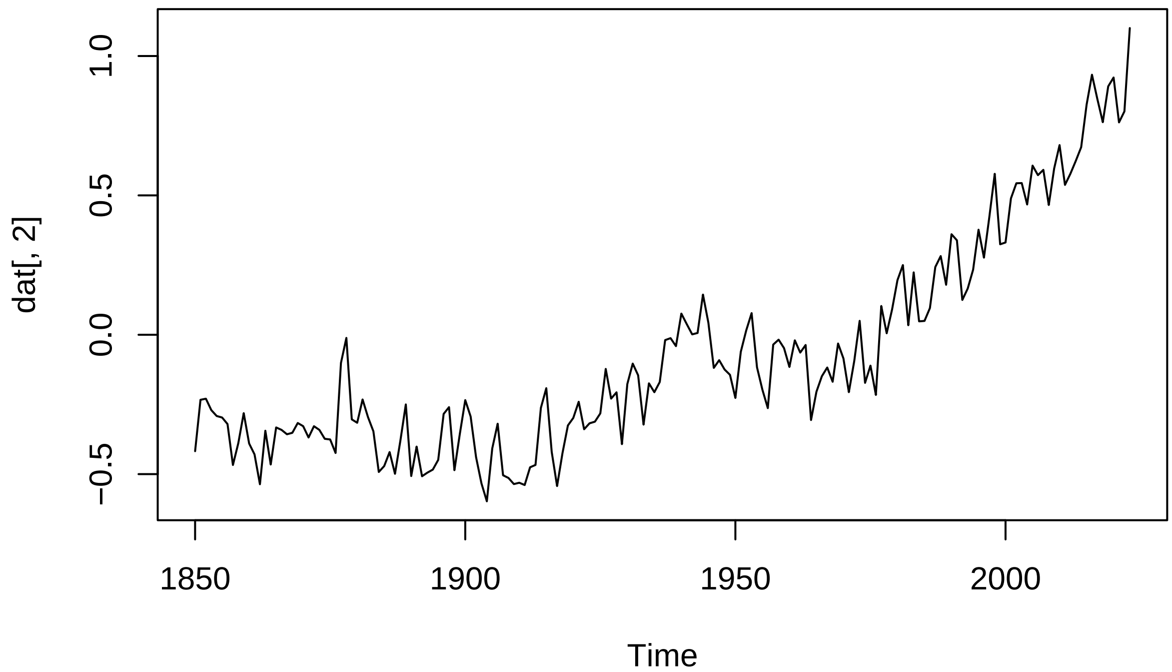
(c) ACF and PACF of CO2 data

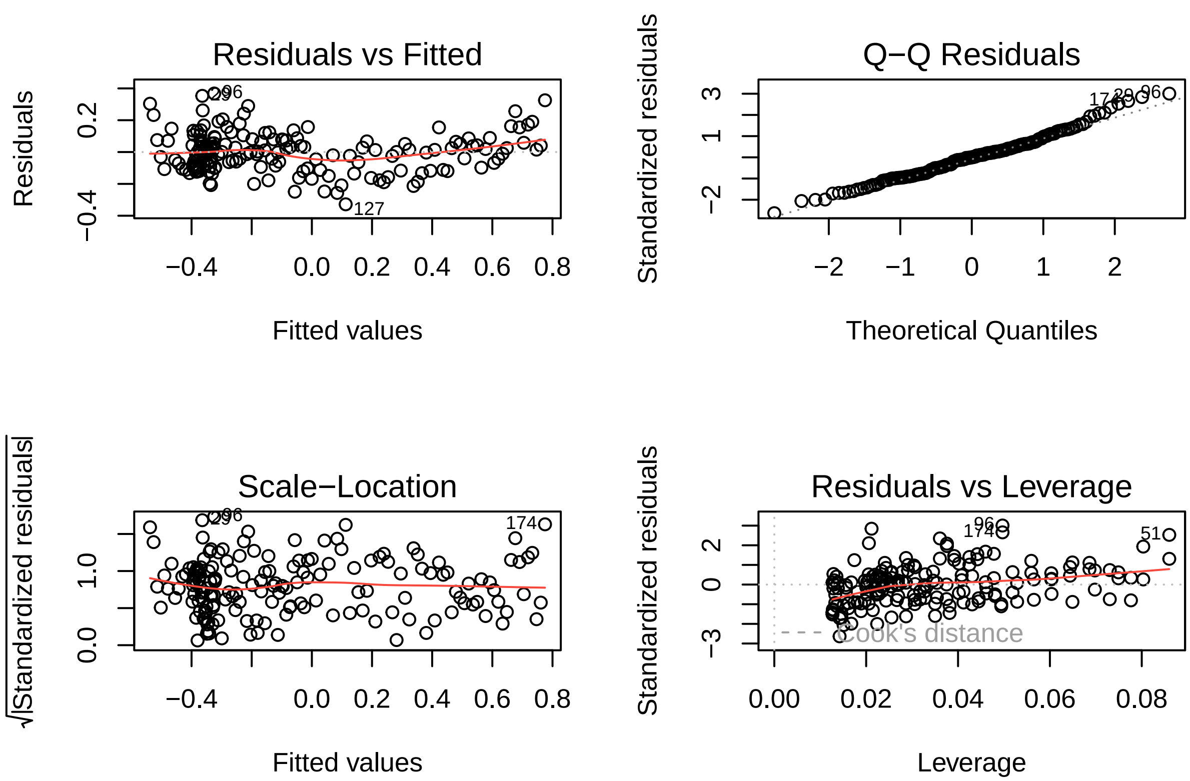
Figure 1: Intial Data Exploration

By looking at both Golbal CO2 emmision and Golbal tempureature, there are insight that we can observe from the plots. Both data are not display stationary feature which requires furthre data processing since, for time series data, stationary assumption needs to be met before modeling the data with either Move Average or Auto Regressive.

Model Deterministic Part.

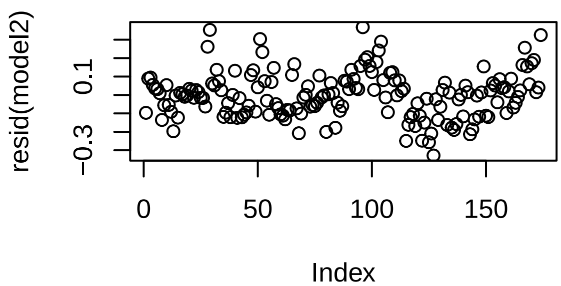
Looking at our plot It seems as if events occurred around 1950, and 1900 start of second industrial revolution and end of World War II.

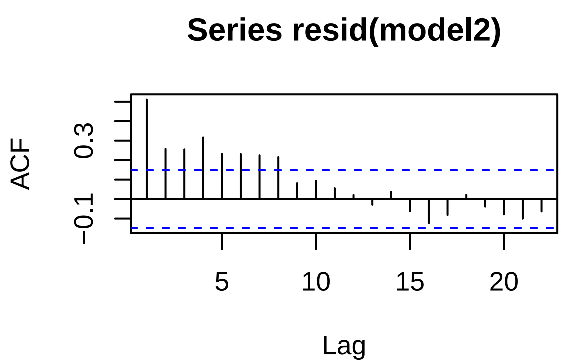


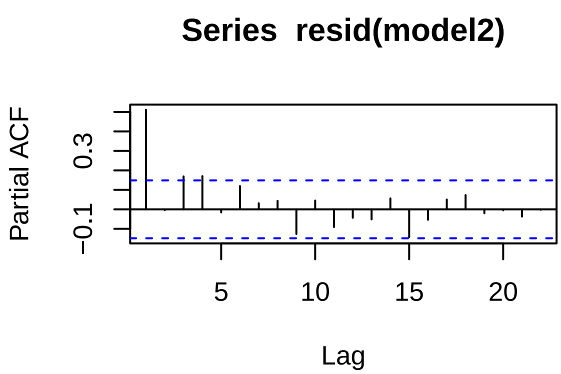


##

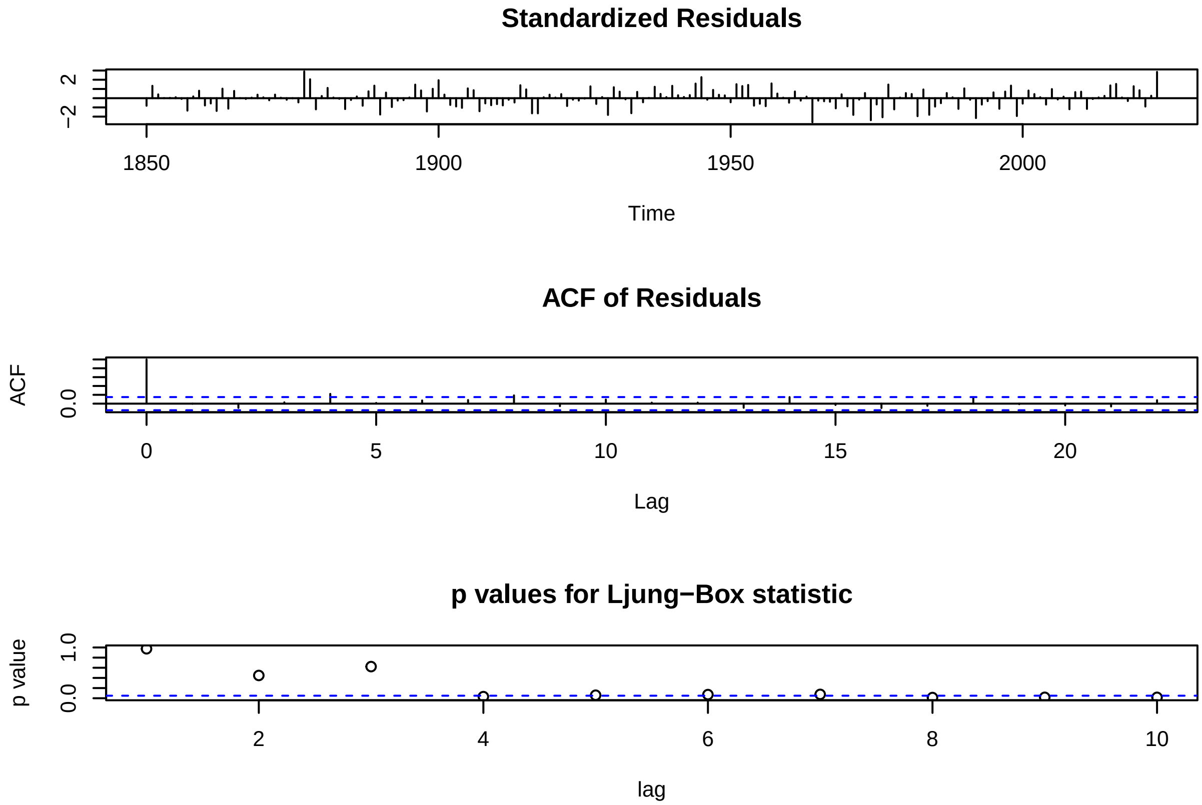
```
## Call:
## lm(formula = dat[, 2] ~ time(dat) + time(dat) * Afterww2 + time(dat) *
##     IndustryRev, data = dat)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -0.32823 -0.09304  0.00055  0.06970  0.36771
##
## Coefficients:
##                          Estimate Std. Error t value Pr(>|t|)
## (Intercept)              2.551782   2.306113   1.107    0.270
## time(dat)               -0.001553   0.001230  -1.262    0.209
## Afterww2                -4.543077   3.029908  -1.499    0.136
## IndustryRev            -25.753919   3.603931  -7.146 2.60e-11 ***
## time(dat):Afterww2       0.002170   0.001568   1.383    0.168
## time(dat):IndustryRev    0.013481   0.001895   7.115 3.08e-11 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.1255 on 168 degrees of freedom
## Multiple R-squared:  0.8936, Adjusted R-squared:  0.8904
## F-statistic: 282.1 on 5 and 168 DF,  p-value: < 2.2e-16
```

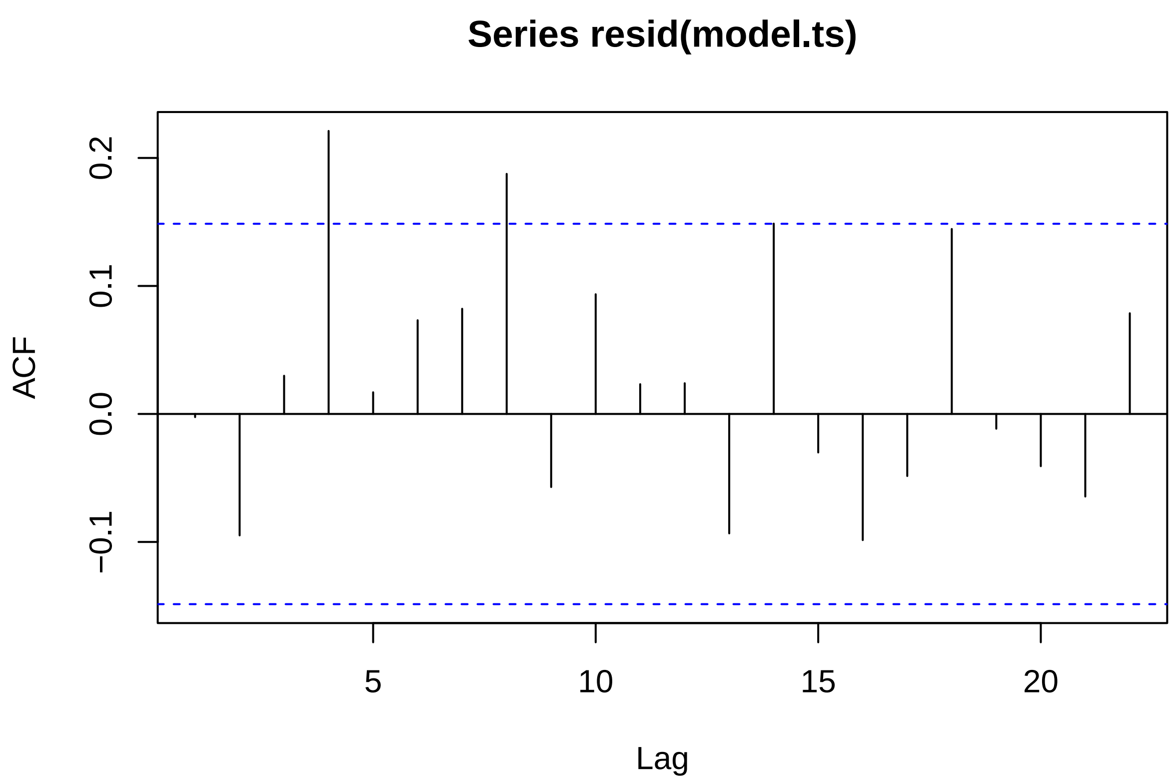


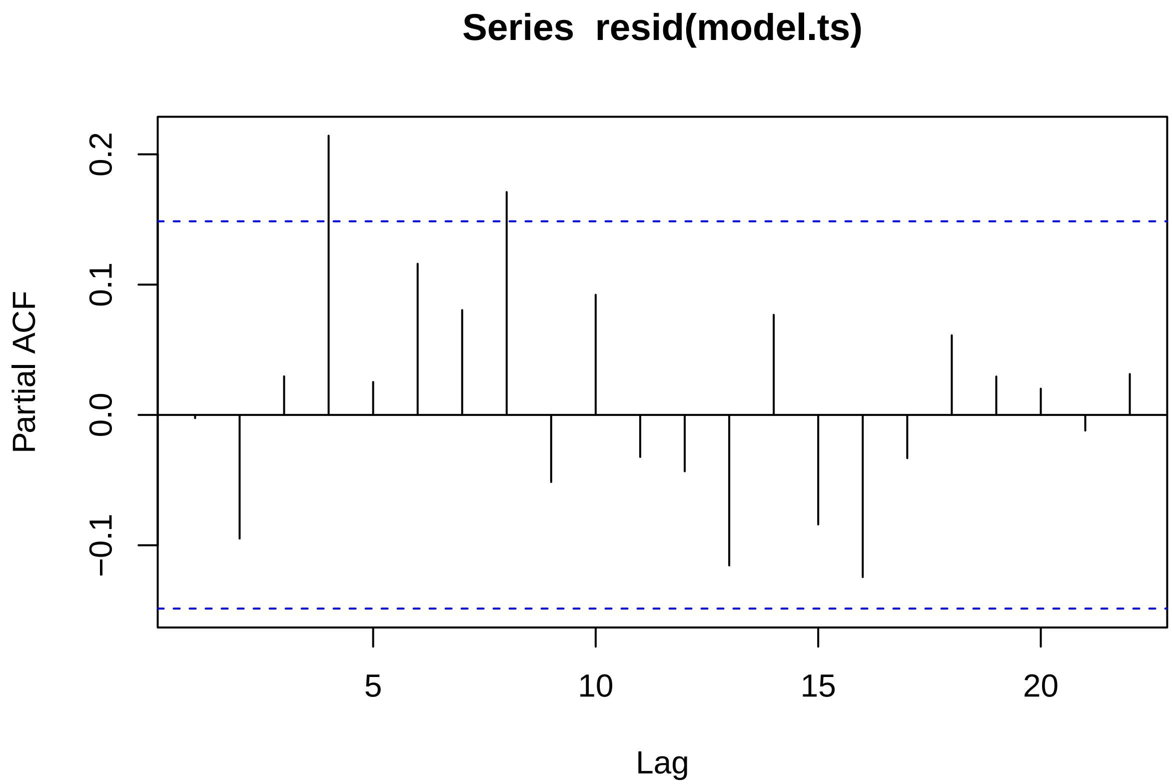




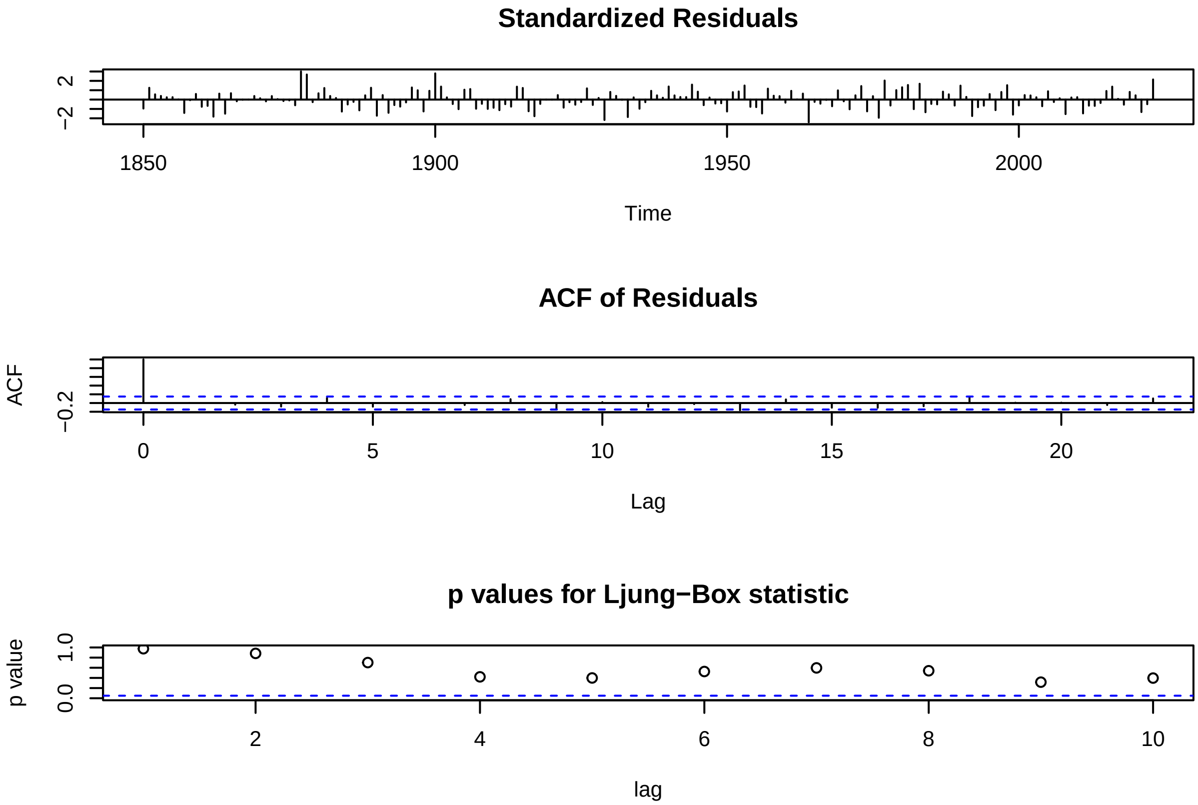
ACF tails off or cuts off after lag 2. PACF cuts off after lag 1. I Will fit an arima(1,0,0) and arima(2,0,2) to see which fits better.

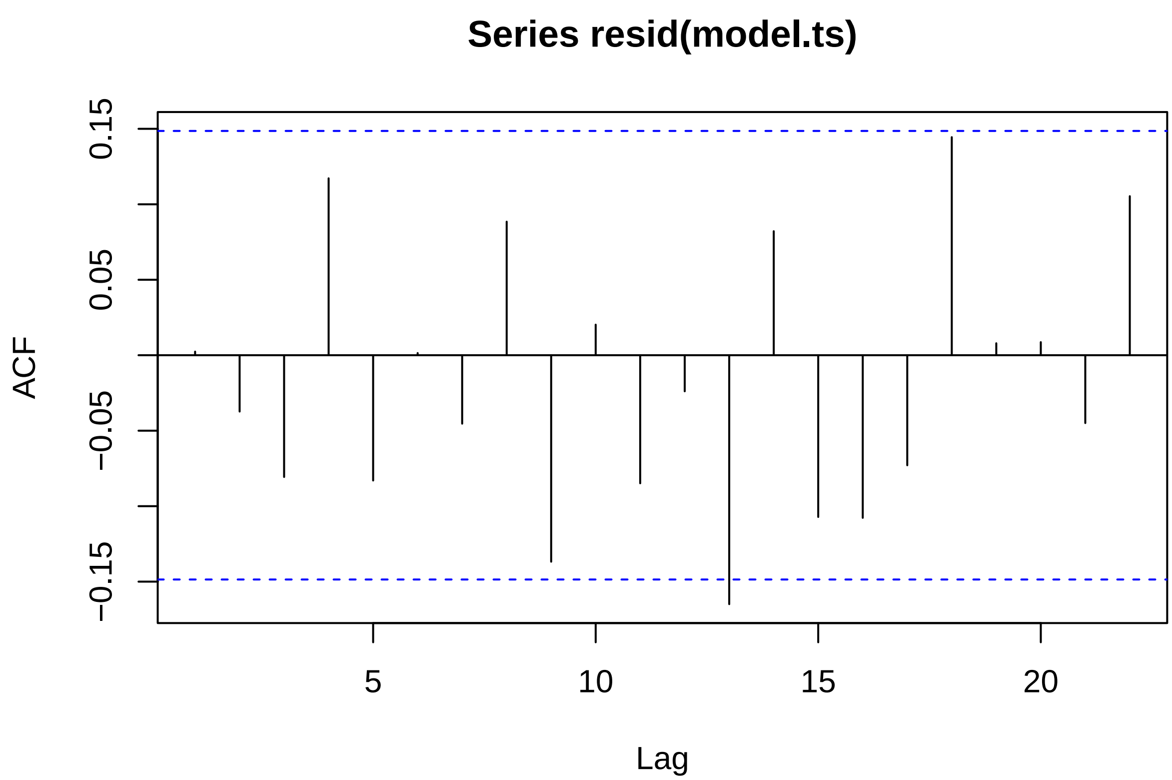

Standardized Residuals
−2
2
1850
1900
1950
2000
Time
ACF of Residuals
ACF
0.0
0
5
10
15
20
Lag
p values for Ljung−Box statistic
p value
0.0
1.0
2
4
6
8
10
lag

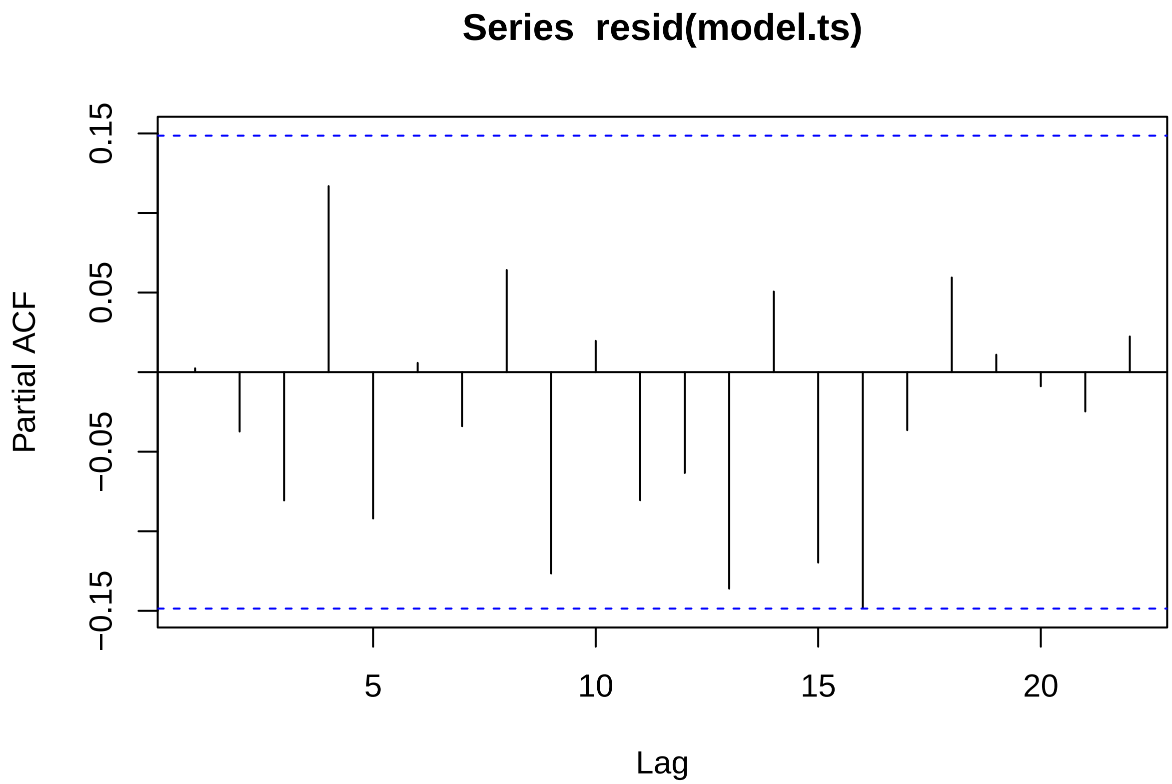

Series resid(model.ts)
ACF
−0.1
0.0
0.1
0.2
5
10
15
20
Lag



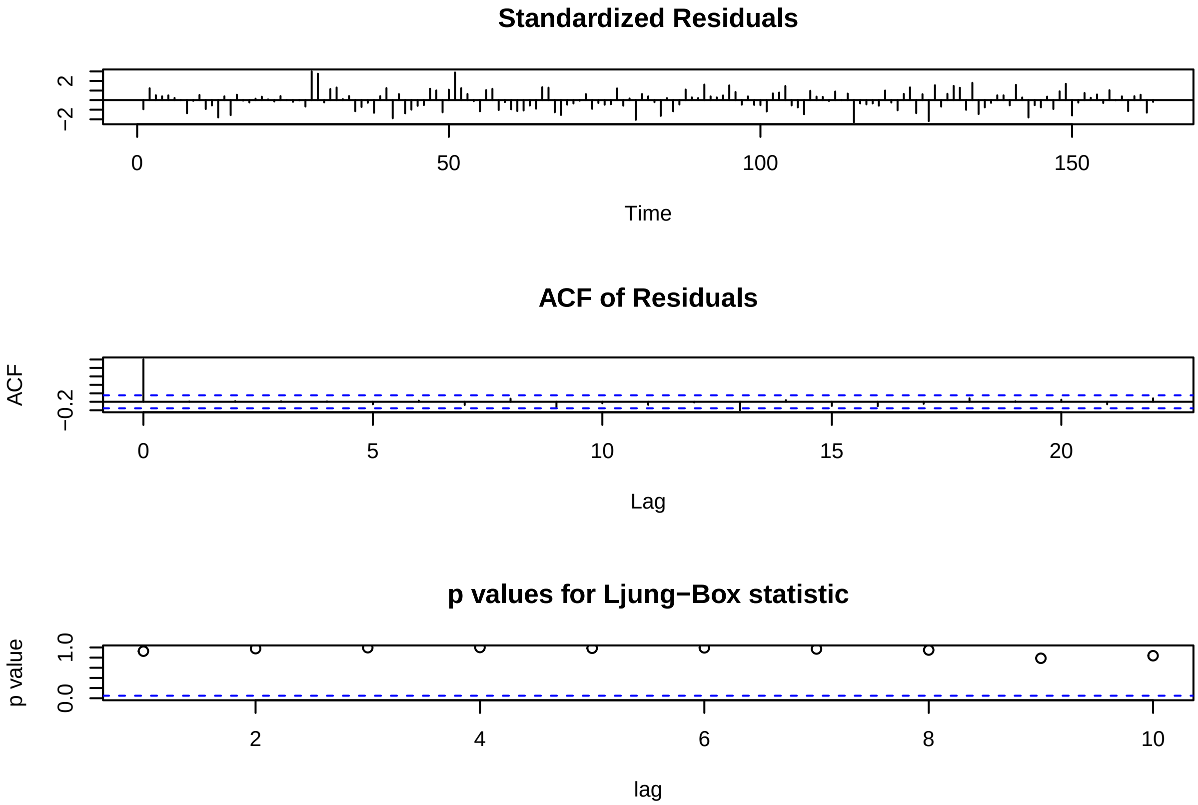

```
##
## z test of coefficients:
##
##                          Estimate  Std. Error z value  Pr(>|z|)
## ar1                     0.5561333   0.0801484  6.9388 3.955e-12 ***
## intercept               4.0105058   3.9954799  1.0038 0.3154940
## time(dat)              -0.0023375   0.0021384 -1.0931 0.2743316
## Afterww2               -9.4970649   5.4416527 -1.7453 0.0809407 .
## IndustryRev           -22.2203007   6.4850219 -3.4264 0.0006116 ***
## time(dat):Afterww2      0.0047519   0.0028103  1.6909 0.0908609 .
## time(dat):IndustryRev   0.0116694   0.0034080  3.4241 0.0006168 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

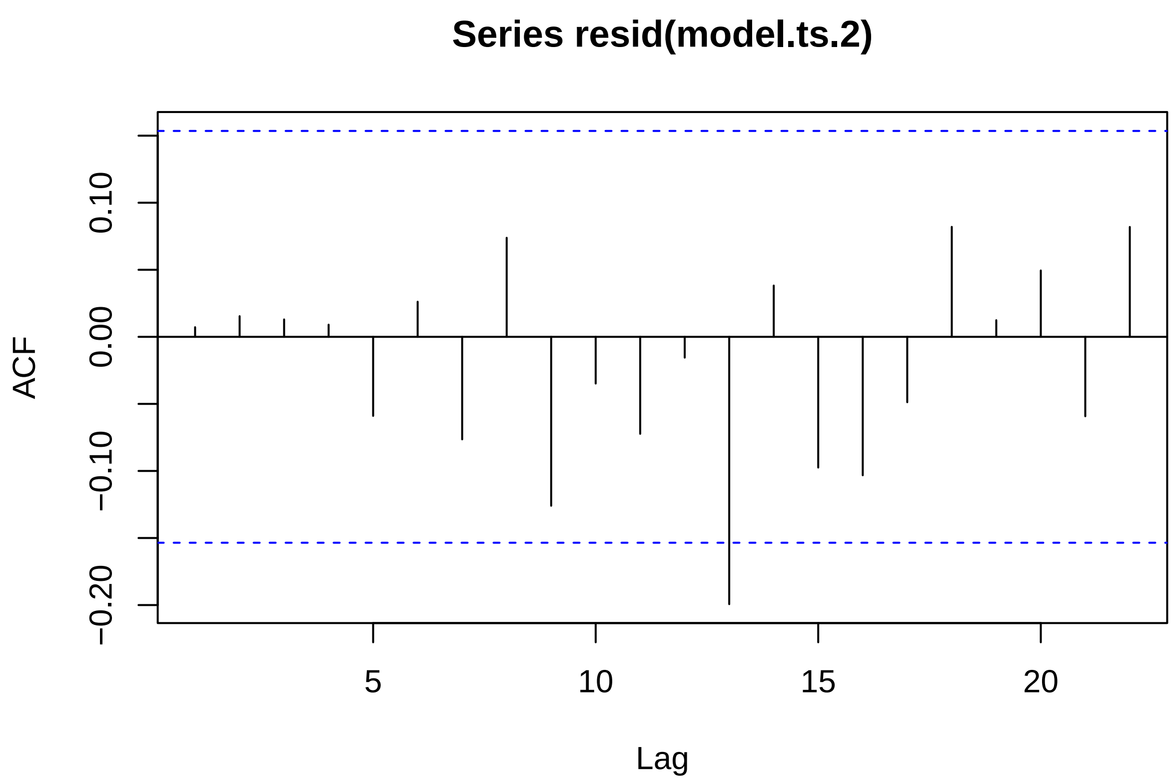

Standardized Residuals
2
−2
1850
1900
1950
2000
Time
ACF of Residuals
ACF
−0.2
0
5
10
15
20
Lag
p values for Ljung−Box statistic
p value
1.0
0.0
2
4
6
8
10
lag

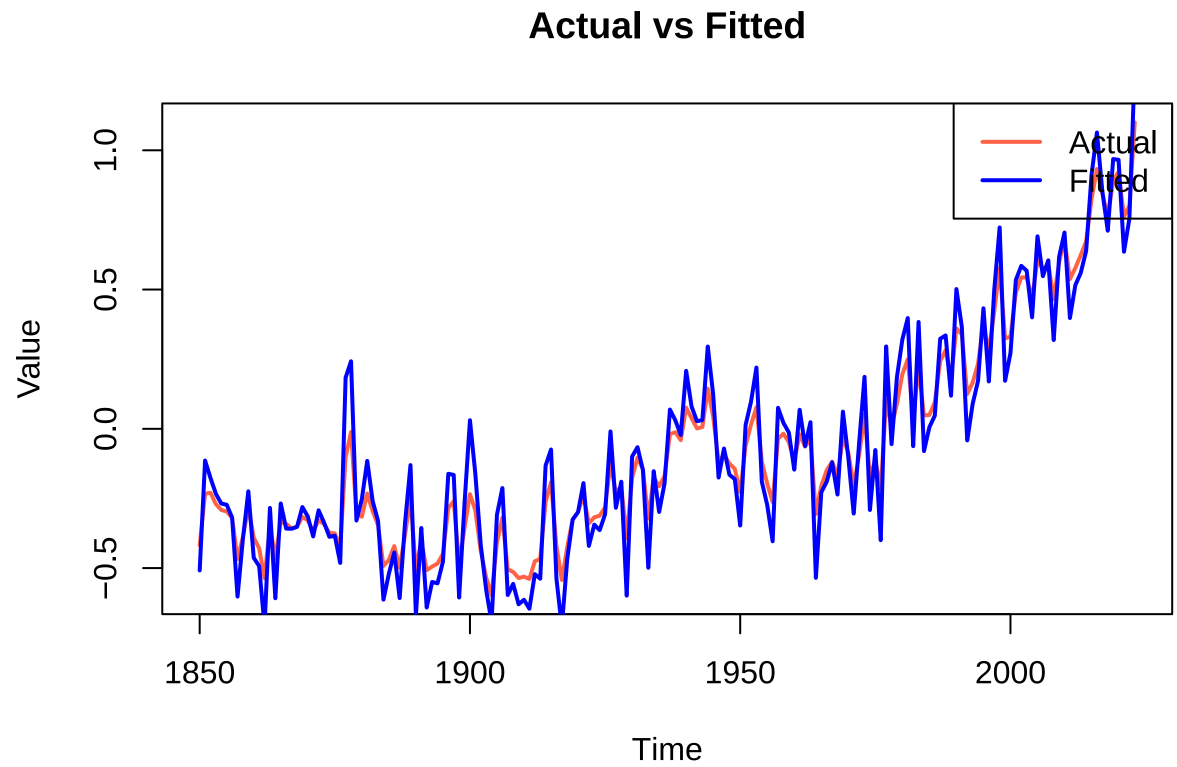

Series resid(model.ts)
ACF
0.15
0.05
−0.05
−0.15
5
10
15
20
Lag



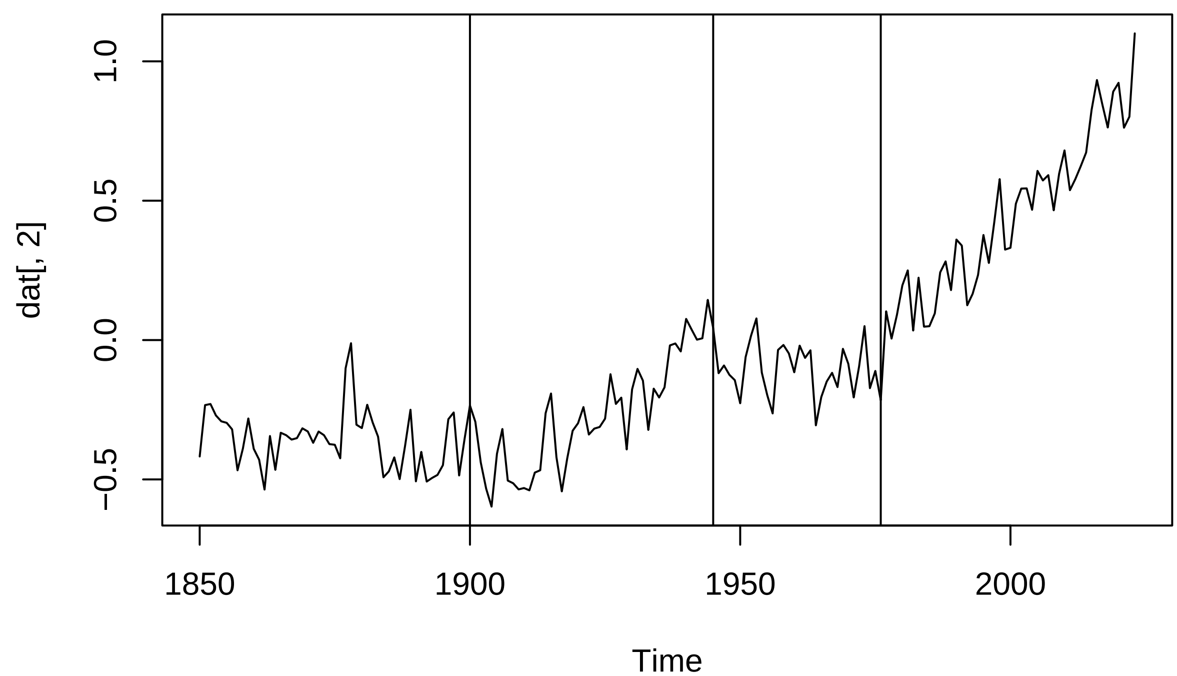

```
##
## z test of coefficients:
##
##                          Estimate  Std. Error z value  Pr(>|z|)
## ma1                     0.3577942   0.0699044  5.1183 3.082e-07 ***
## intercept               2.6897378   2.3217003  1.1585    0.2467
## time(dat)              -0.0016276   0.0012435 -1.3090    0.1905
## Afterww2               23.4711228   5.7243811  4.1002 4.128e-05 ***
## IndustryRev           -25.4781150   3.6554503 -6.9699 3.172e-12 ***
## I1976                 -40.9890374   5.6387633 -7.2692 3.617e-13 ***
## time(dat):Afterww2     -0.0121119   0.0029390 -4.1211 3.770e-05 ***
## time(dat):IndustryRev   0.0133418   0.0019239  6.9347 4.072e-12 ***
## time(dat):I1976         0.0207733   0.0028617  7.2591 3.896e-13 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```


Standardized Residuals
Time
ACF of Residuals
ACF
Lag
p values for Ljung−Box statistic
p value
lag


Series resid(model.ts.2)
ACF
Lag

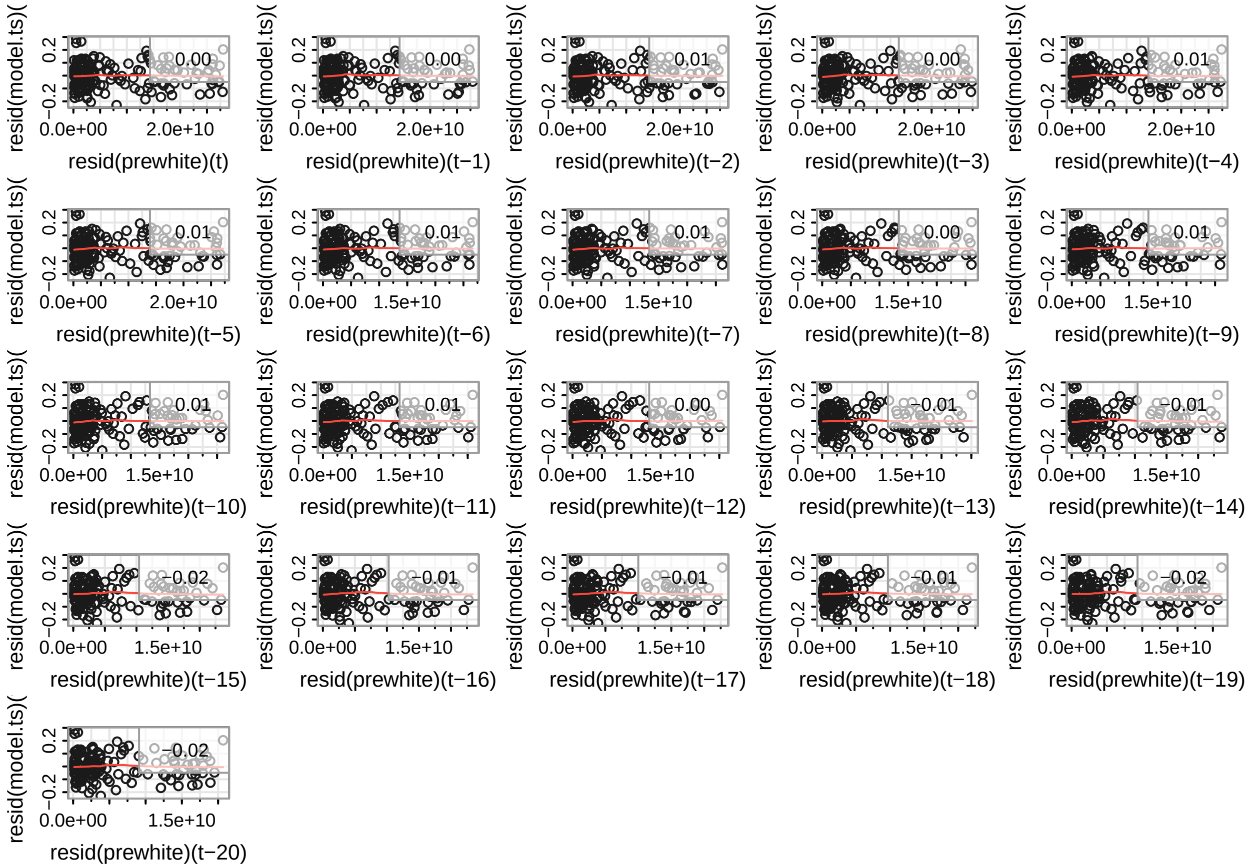


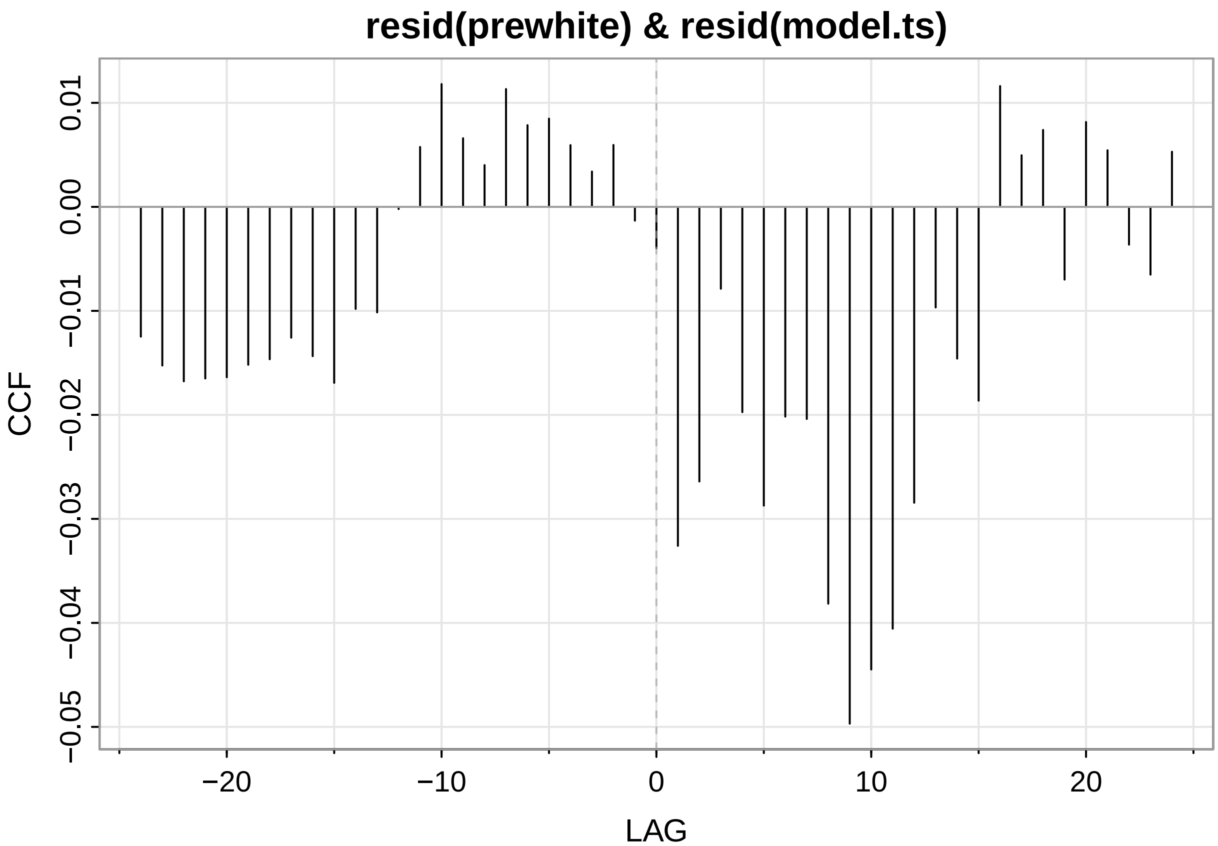
Actual vs Fitted
Actual
Fitted
Value
1.0
0.5
0.0
−0.5
1850
1900
1950
2000
Time



dat[, 2]
1.0
0.5
0.0
−0.5
1850
1900
1950
2000
Time

usuing c02 to predict





Everything from c02 is captured in our model for tempature.

Code Appendix

```
# Setting Document Options ----
knitr::opts_chunk$set(
  echo = FALSE,
  warning = FALSE,
  message = FALSE,
  fig.align = "center"
)


library(TSA)
library(forecast)
library(astsa)
library(dplyr)
library(rugarch)
library(tseries)
library(lmtest)
library(jsonlite)





# Fetch the data
co2Data <- read.csv("https://ourworldindata.org/grapher/annual-co2-emissions-per-country.csv?v=1&csvType


YearlyTemp <- read.csv("Yearly.csv")
YearlyTemp <- YearlyTemp[YearlyTemp$Source == "gcag", ] # keep source constant.
c02_TS <- co2Data[, c("Year", "Annual.CO..emissions")]
c02_TS <- c02_TS[order(c02_TS$Year), ]
c02_TS <- ts(c02_TS$Annual.CO..emissions,
                   start = min(c02_TS$Year),
                   end = max(c02_TS$Year),
                   frequency = 1)

temp_TS <- YearlyTemp[, c("Year", "Mean")]
temp_TS <- temp_TS[order(temp_TS$Year), ]
temp_TS <- ts(temp_TS$Mean,
                   start = min(temp_TS$Year),
                   end = max(temp_TS$Year),
                   frequency = 1)

dat <- ts.intersect(c02_TS, temp_TS)

plot(dat[,1])
plot(dat[,2])

par(mfrow = c(2,1))
acf(diff(log(dat[,1])))
pacf(diff(log(dat[,1])))
plot(dat[,2])
```

```r
Afterww2 <- as.numeric(time(dat)>= 1945)
IndustryRev <- as.numeric(time(dat)>= 1900)
I1976 <- as.numeric(time(dat)>= 1976)

model2 <- lm(dat[,2] ~ time(dat)+time(dat)*Afterww2+ time(dat)*IndustryRev, data = dat)
#plot(model2)
par(mfrow=c(2,2))
plot(model2, whixh = 1:4)
summary(model2)
plot(resid(model2))

acf(resid(model2))
pacf(resid(model2))
model.matrix = model.matrix(object= ~ time(dat)+time(dat)*Afterww2+ time(dat)*IndustryRev-1)

model.ts <- arima(x = dat[,2], order = c(1,0,0),  xreg = model.matrix, method = "ML")

tsdiag(model.ts)

acf(resid(model.ts))
pacf(resid(model.ts))
coeftest(model.ts)
#model.matrix = model.matrix(object= ~ time(tmp)+time(tmp)*Afterww2+ time(tmp)*IndustryRev-1)



model.matrix = model.matrix(object= ~ time(dat)+time(dat)*Afterww2+ time(dat)*IndustryRev + I1976*time(

model.ts <- arima(x = dat[,2], order = c(0,0,1),  xreg = model.matrix, method = "ML")

tsdiag(model.ts)

acf(resid(model.ts))

pacf(resid(model.ts))

coeftest(model.ts)
#model.matrix = model.matrix(object= ~ time(tmp)+time(tmp)*Afterww2+ time(tmp)*IndustryRev-1)

tmp <- dat[,2][1:163]

Afterww2.2<-Afterww2[1:163]
IndustryRev.2<- IndustryRev[1:163]
I1976.2 <- I1976[1:163]
model.matrix.2 = model.matrix(object= ~ time(tmp)+time(tmp)*Afterww2.2+ time(tmp)*IndustryRev.2+ time(tm

model.ts.2 <- arima(x = tmp, order = c(2,0,2),  xreg = model.matrix.2, method = "ML")

tsdiag(model.ts.2)

acf(resid(model.ts.2))
#pacf(resid(model.ts.2))
```

```r
#coeftest(model.ts.2)
fitted_values <- resid(model.ts) + dat[,2]
plot(dat[, 2], type = "l", col = "tomato", lwd = 2, main = "Actual vs Fitted", ylab = "Value")
lines(fitted_values, col = "blue", lwd = 2)
legend("topright", legend = c("Actual", "Fitted"), col = c("tomato", "blue"), lty = 1, lwd = 2)
plot(dat[,2])
abline(v=1900)
abline(v = 1945)
abline(v = 1976)

prewhite <- Arima(dat[,1], model = model.ts, xreg = model.matrix)


lag2.plot(resid(prewhite), resid(model.ts),max.lag = 20)

ccf2(resid(prewhite), resid(model.ts))
```


Collins, Mat, Soon-Il An, Wenju Cai, Alexandre Ganachaud, Eric Guilyardi, Fei-Fei Jin, Markus Jochum, et al. 2010. "The Impact of Global Warming on the Tropical Pacific Ocean and El Niño." *Nature Geoscience* 3 (May): 391–97. https://doi.org/10.1038/ngeo868.

J. Ring, Michael, Daniela Lindner, Emily F. Cross, and Michael E. Schlesinger. 2012. "Causes of the Global Warming Observed Since the 19th Century." *Atmospheric and Climate Sciences* 02: 401–15. https://doi.org/10.4236/acs.2012.24035.

Mokyr, Joel, and Robert Strotz. 1998. "The Second Industrial Revolution, 1870-1914." https://bpb-us-e1.wpmucdn.com/sites.northwestern.edu/dist/3/1222/files/2016/06/The-Second-Industrial-Revolution-1870-1914-Aug-1998-1ubah7s.pdf.

Ritchie, Hannah, Pablo Rosado, and Max Roser. 2023. "CO and Greenhouse Gas Emissions." *Our World in Data*. https://ourworldindata.org/co2-and-greenhouse-gas-emissions.

Smith, Pete, Changming Fang, Julian J. C. Dawson, and John B. Moncrieff. 2008. "Impact of Global Warming on Soil Organic Carbon." *Advances in Agronomy*, 1–43. https://doi.org/10.1016/s0065-2113(07)00001-6.