The Paris Climate Agreement: CO_2 Emissions Forecasting

Business, Economic, and Financial Data Final Project

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The Paris Climate Agreement

What is the Paris Climate Agreement

A **legally binding** international treaty on climate change that has been adopted by 196 parties.

Temperatures 2100

Limit global warming to **well below 2 degree celsius**, preferably around 1.5, compared to pre-industrial levels.

Finance 2020 - 2025

Rich countries must provide 100 billion USD from 2020, as a "floor". Amount to be updated by 2025

Differentiation

Developed countries must continue to "take the lead" in the reduction of greenhouse gases. Developing nations are encouraged to "enhance their efforts" and move over time to cuts

Emissions Objective 2050

Aim for greenhouse gases emissions to peak "as soon as possible".
From 2050, rapid reductions to achieve a balance between emissions from human activity and the amount that can be captured by "sinks"

Burden Sharing

Developed countries must provide financial resources to help developing countries. Other countries invited to provide support on a voluntary basis.

Review Mechanism 2023

A review every five years. First world review on 2023.
Each review will inform countries in "updating and enhancing" their pledges.

Climate Damage

Vulnerable countries have won recognition of the need for "averting, minimizing, and addressing" losses suffered due to climate change.

How does the Paris Agreement work?

- **5-year cycle** of increasingly ambitious climate action carried out by countries
- By 2020, countries submit **Nationally Determined Contributions (NDCs)** - their plans for climate action.

- Countries **support each other** through:
  - Finance
  - Technology
  - Capacity Building

Progress tracked through: Enhanced Transparency Framework (ETF)

- Under ETF, starting in 2024, countries will r**eport transparently on actions taken and progress in climate change mitigation**, adaptation measures and support provided or received.

2030 CO_2 Emission Goals

- **EU** : 55% below 1990 levels (1,739,471,265 tCO_2e)
- **USA** : 50-52% below 2005 levels (2,946,049,728 tCO_2e)
- **China** : 60% below 2005 levels (2,350,622,120 tCO_2e)
- **South Africa** : 350-420 $MtCO_2e$

** excluding Land Use, Land-Use Change, and Forestry (LULUCF)*

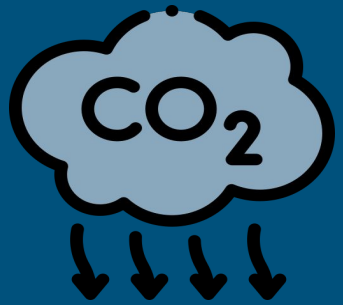
Objectives

- Investigate whether the EU and other top emitting countries will **meet the Paris Climate Agreement emission goals** to reduce CO_2 emissions
- Investigate whether **economic growth has decoupled from CO_2 emissions** - relationship between GDP and CO_2 emissions
- Compare the trends between More Economically Developed Countries (MEDCs) and Newly Industrialised Countries (NICs)

Datasets & Exploratory Analysis

DATASETS

Source: Our World in Data, UN department of Economic and Social Affairs, OECD (2023)



	CO_2 Emission	Population	GDP
Features:	CO_2 emissions (excluding LULUCF)	Population (in millions)	GDP - in millions (USD)

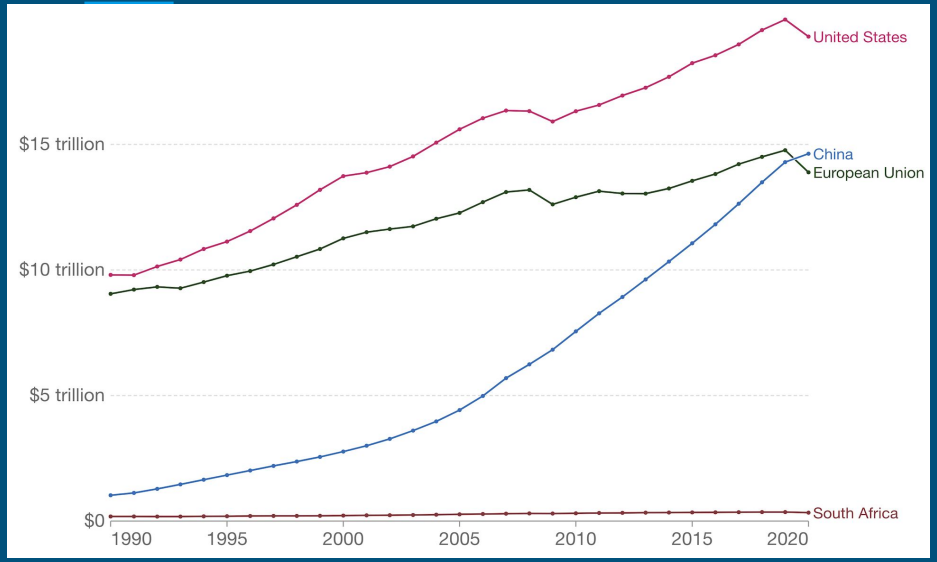
**LULUCF refers to Land use, Land-use change, and forestry*

Data Range

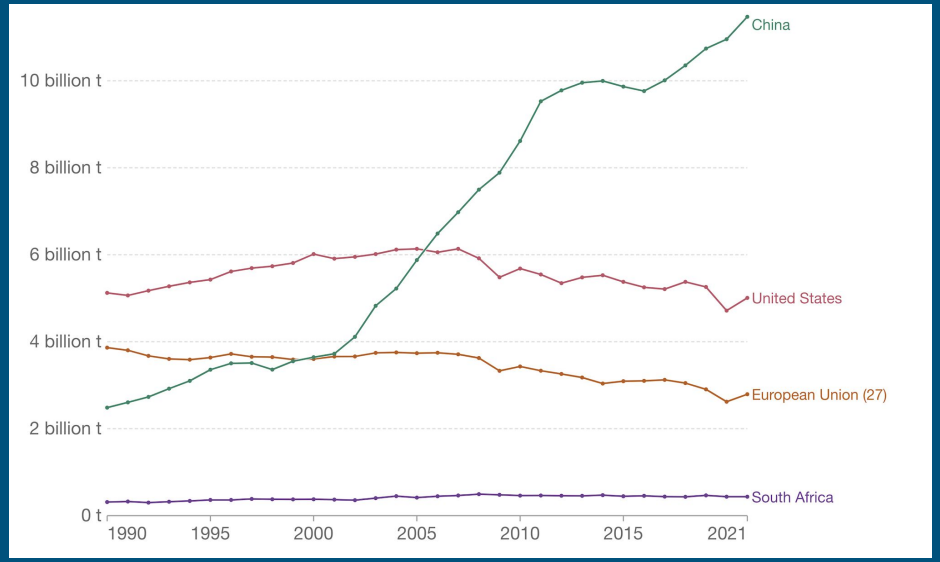
1990 — **2021**

Exploratory Data Analysis (EDA)

GDP

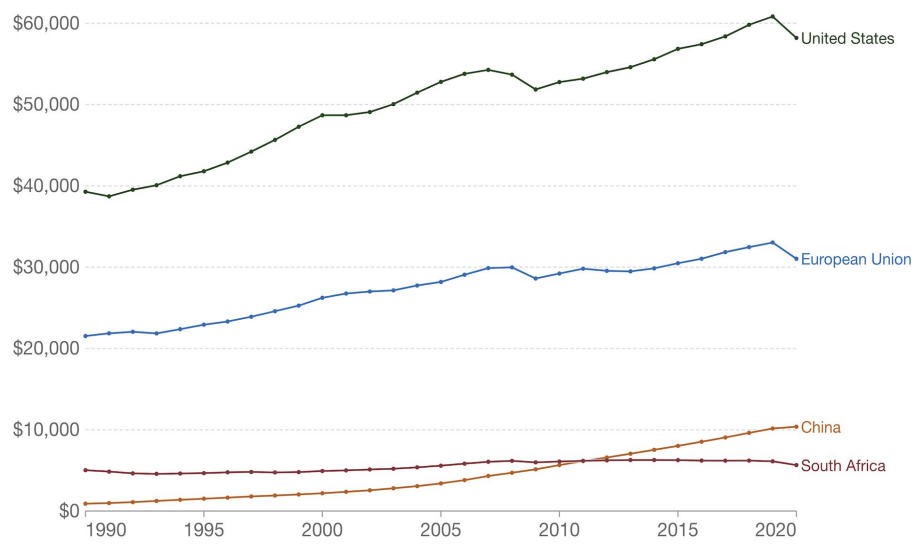


Annual CO_2 emissions

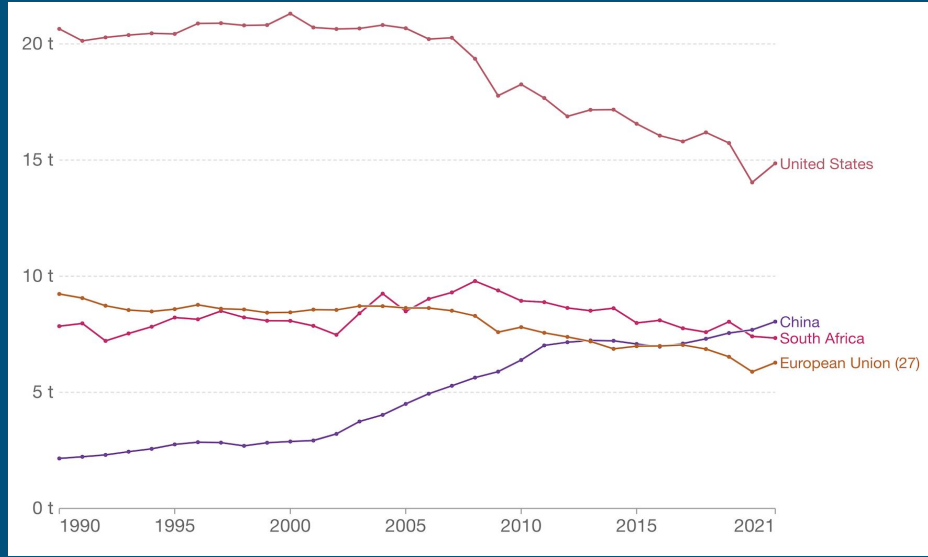


EDA

GDP per capita

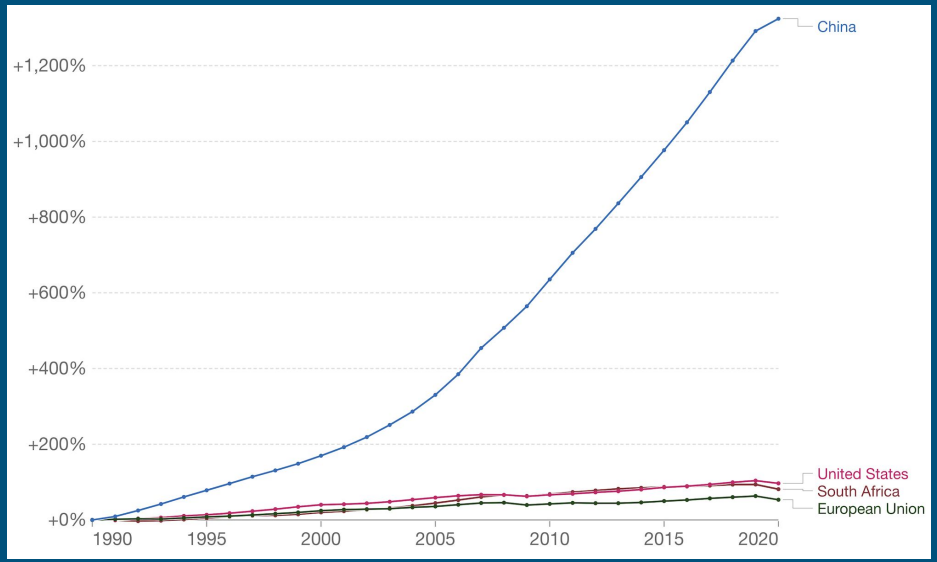


Annual CO_2 per capita emissions

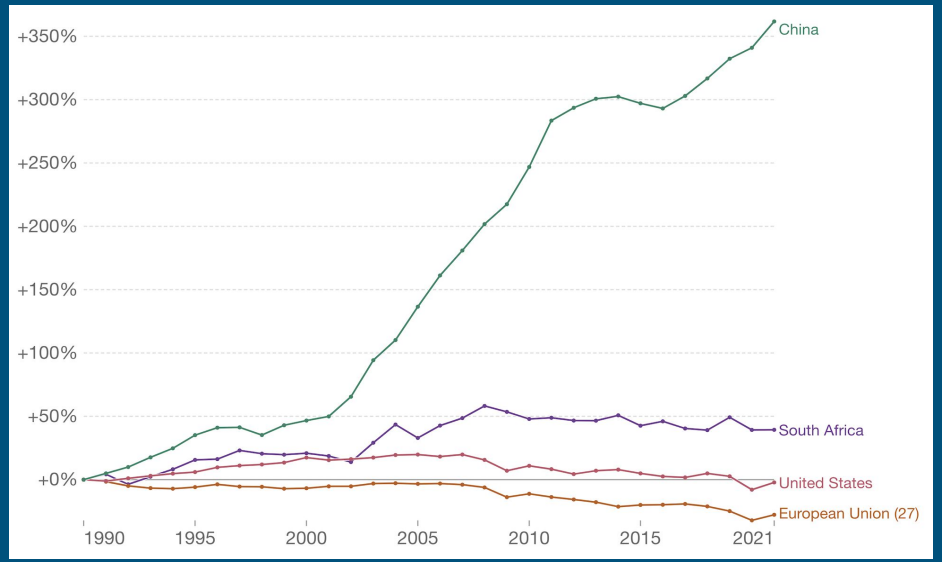


EDA

GDP - Relative change from 1990 (%)

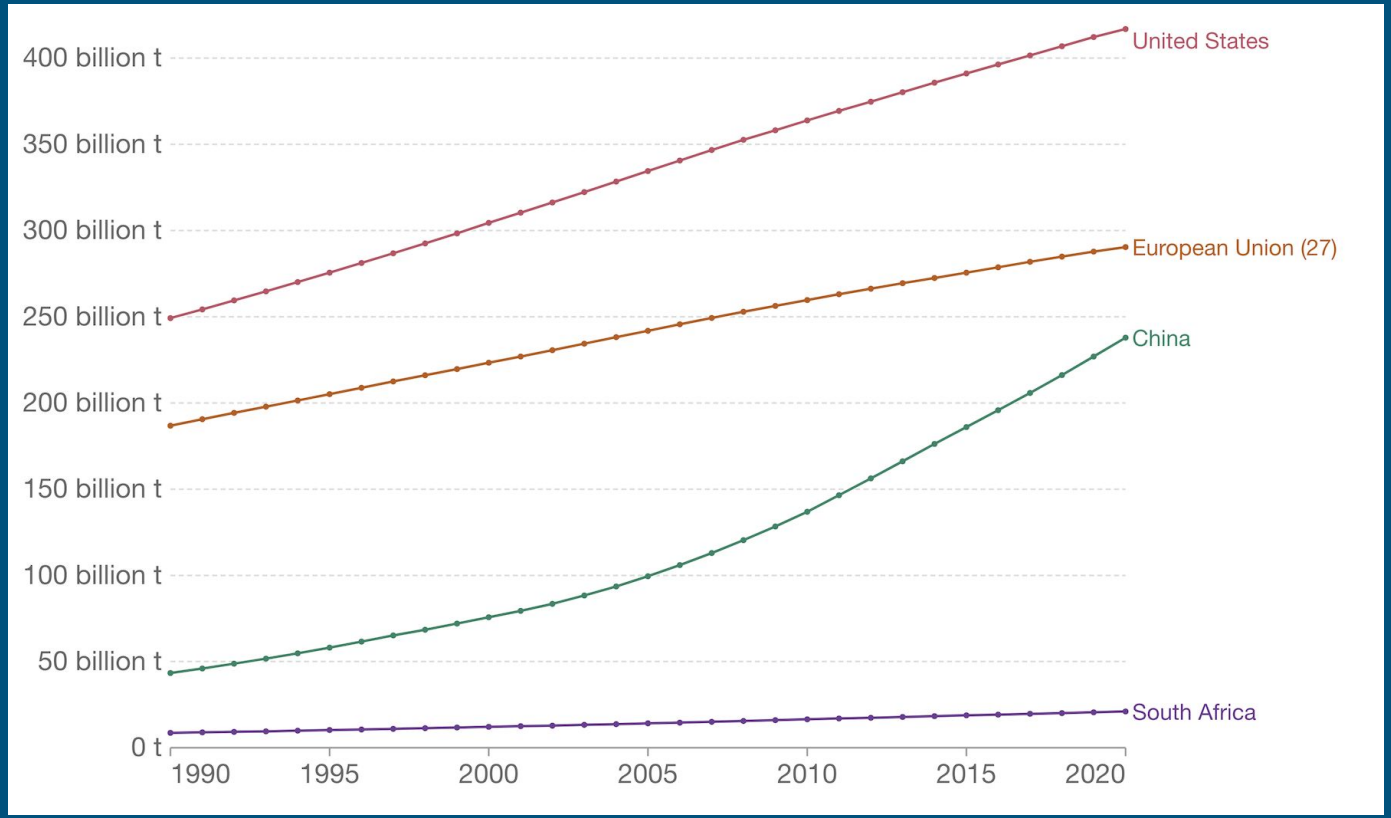


Annual CO_2 emissions - Relative change from 1990 (%)



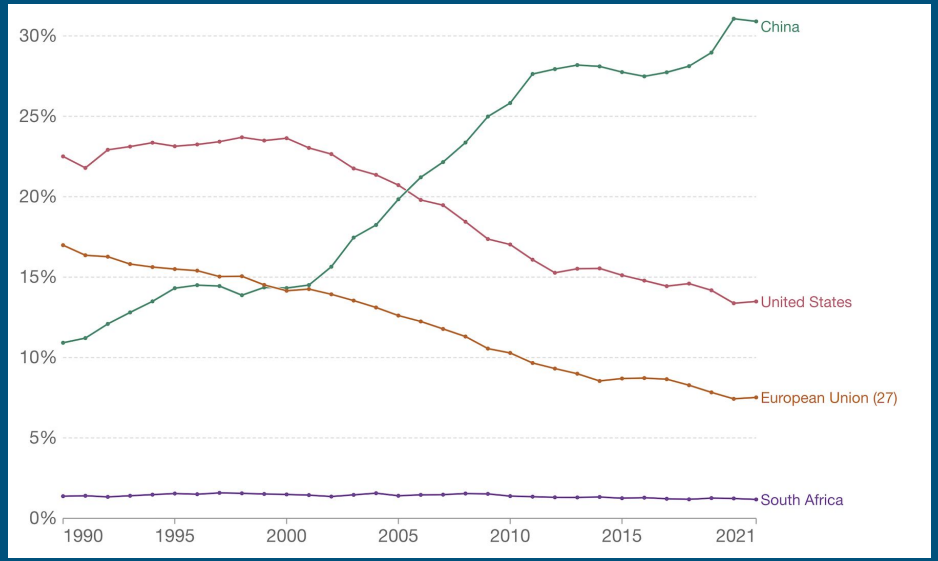
EDA

Cumulative CO_2 emissions

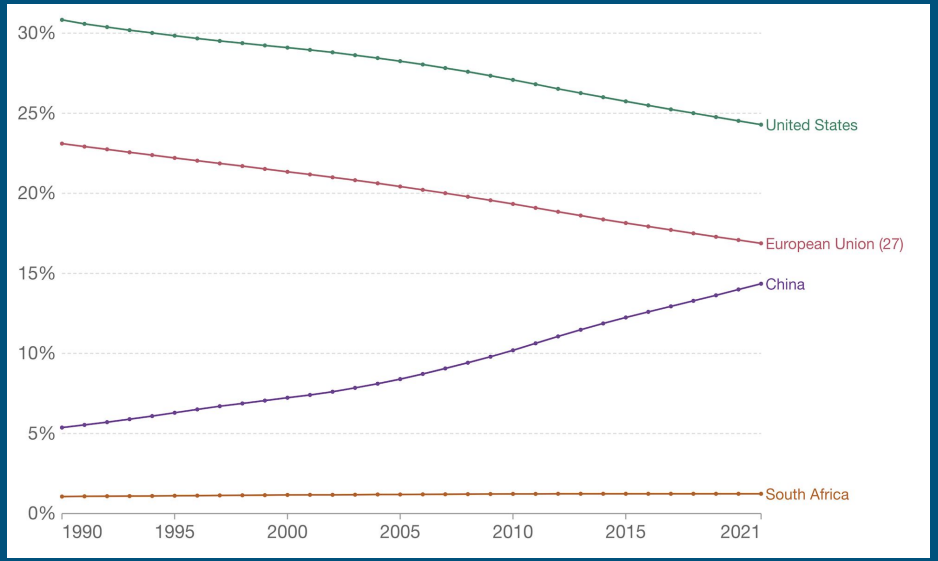


EDA

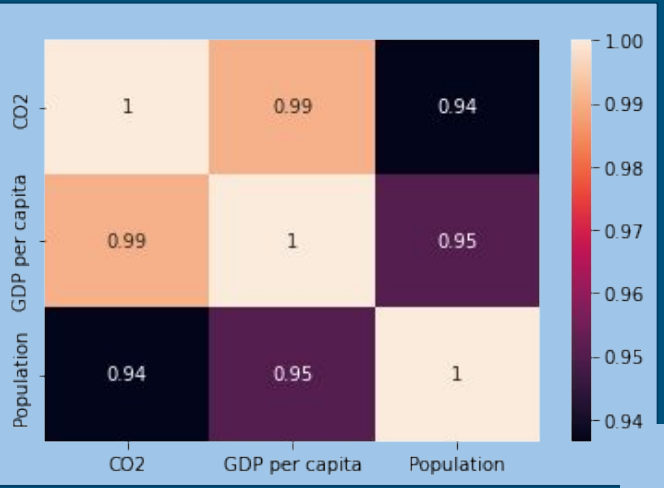
Annual Share of Global CO_2 emissions (%)



Cumulative Share of Global CO_2 emissions (%)

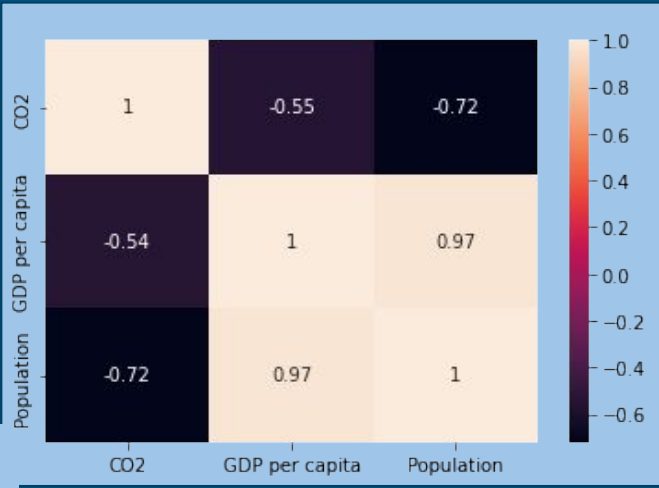


EDA - Correlation Matrix

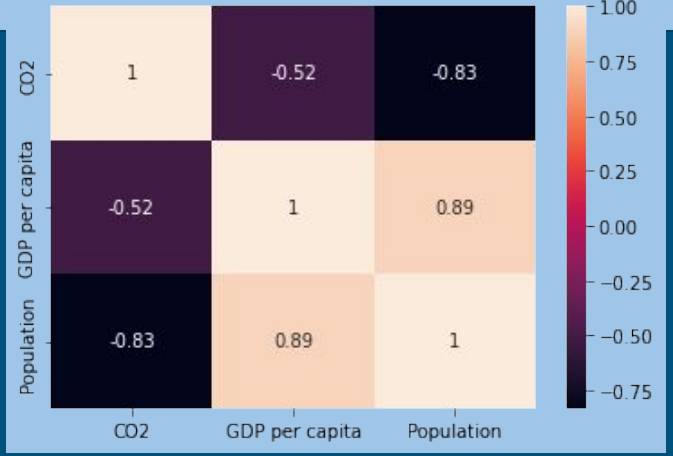


China

EU



USA



MODELS

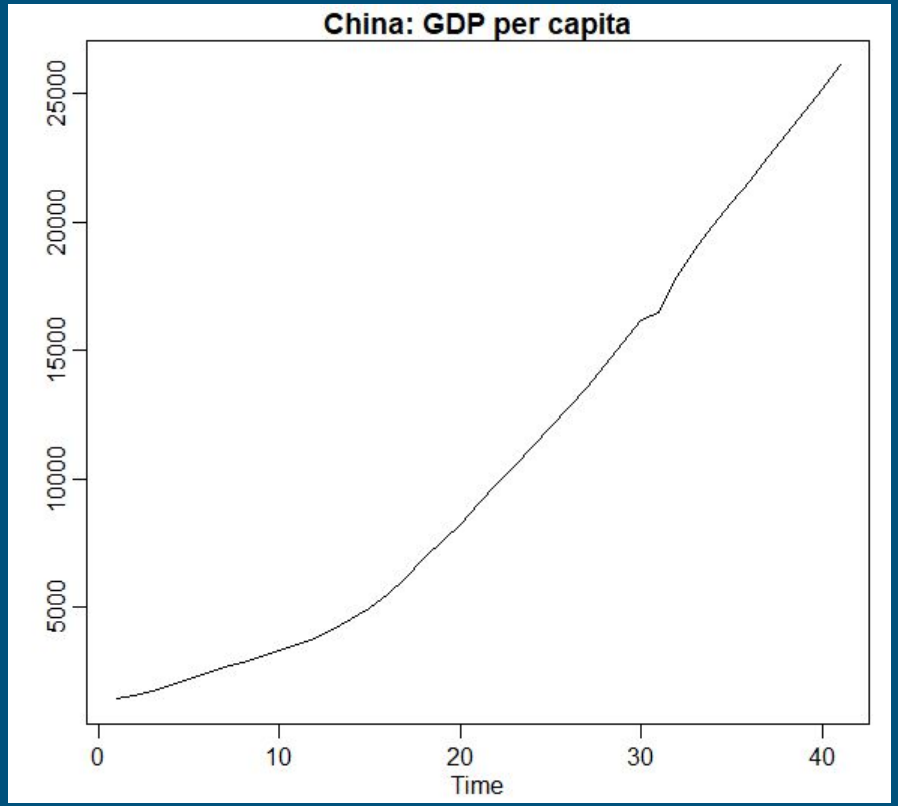
LINEAR MODELS

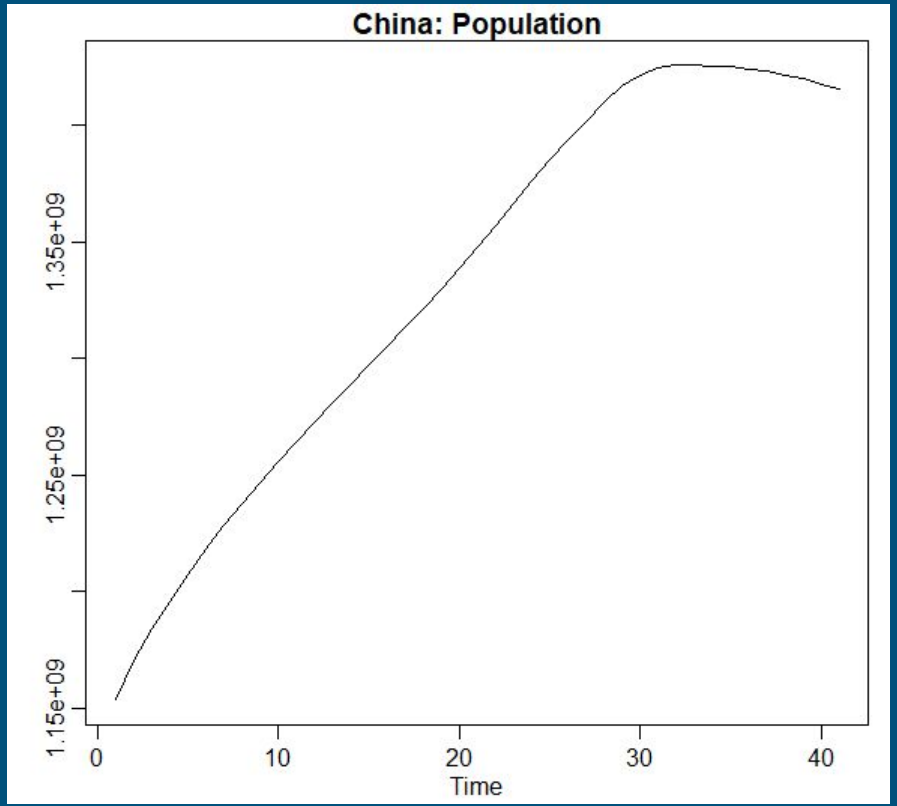
- Univariate Regression -

- Chronological train-test split
- Variables:
  - Trend (Time)
  - GDP
  - Population
- Aims:
  - Analyze interaction between variables
  - Forecast the CO_2 emissions up to 2030
- Performance metrics:
  - AIC
  - Mean Absolute Error on test set
  - R-squared test

LINEAR MODELS

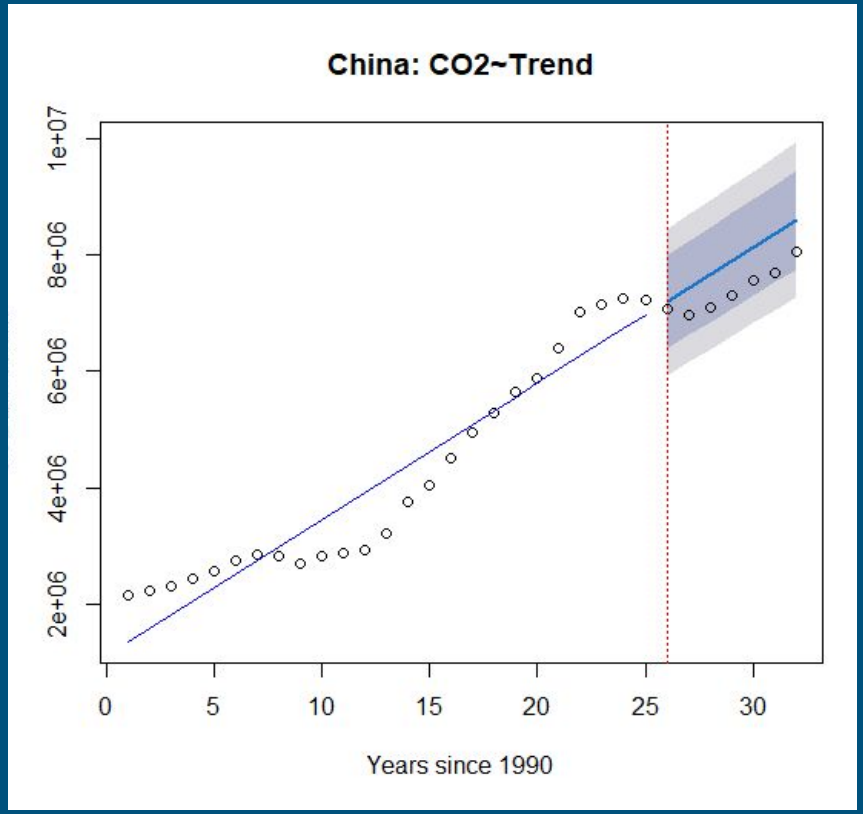
Covariates

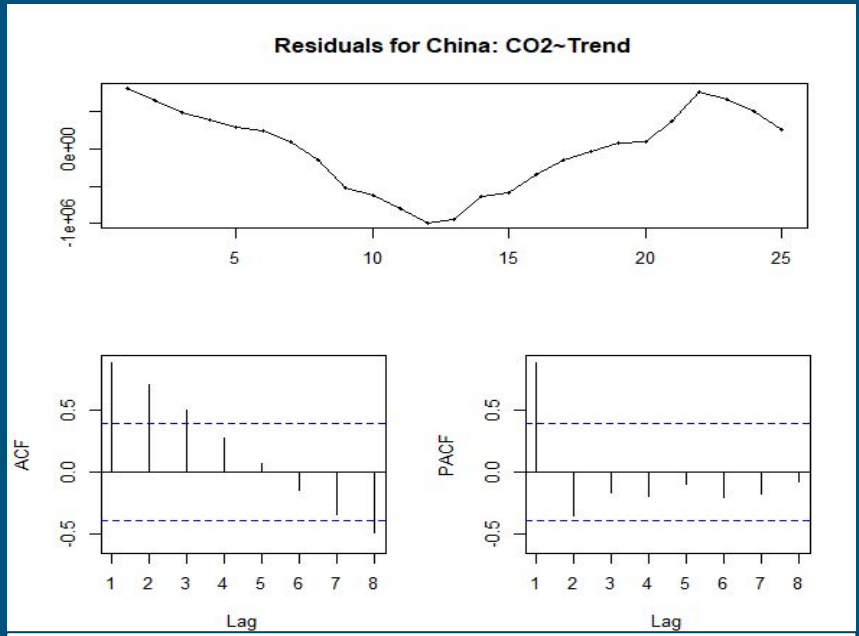




LINEAR MODELS

CO_2 ~ Trend






```
Coefficients:
             Estimate Std. Error t value Pr(>|t|)
(Intercept)  1108046     231130   4.794 7.78e-05 ***
trend         233946      15548  15.047 2.14e-13 ***
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Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
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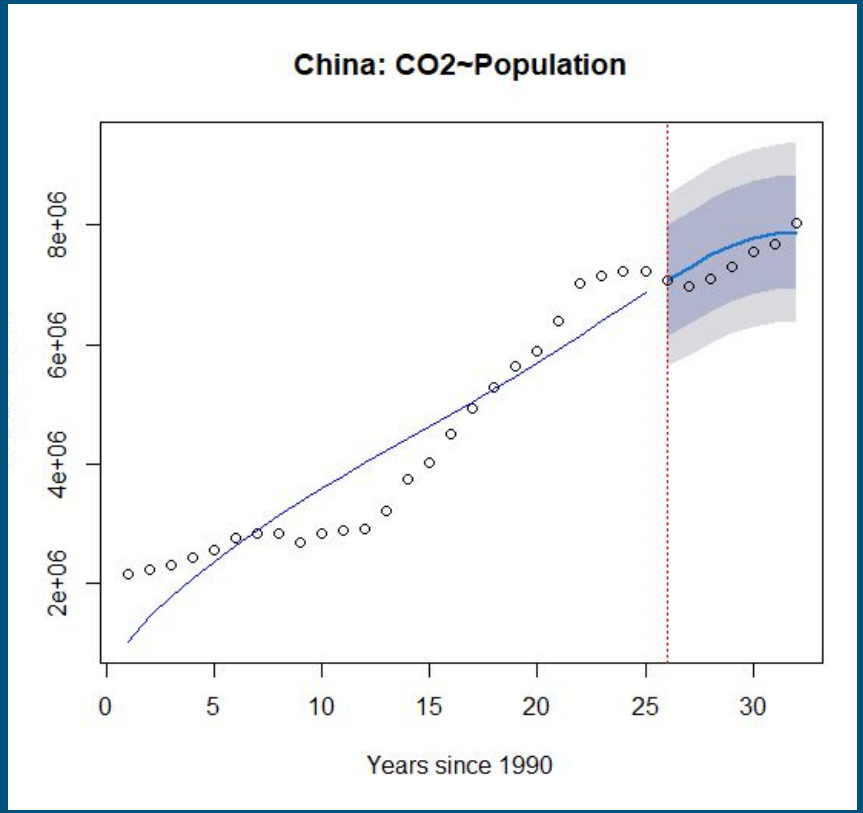
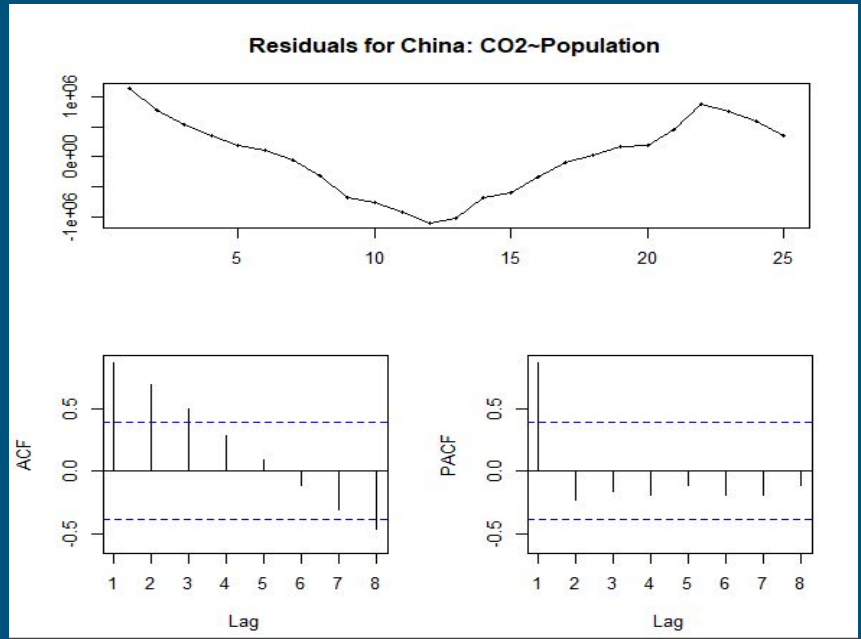
LINEAR MODELS

CO_2 ~ Population



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Coefficients:
             Estimate Std. Error t value Pr(>|t|)
(Intercept) -2.810e+07  2.521e+06  -11.15 9.48e-11 ***
p            2.524e-02  1.970e-03   12.81 5.94e-12 ***
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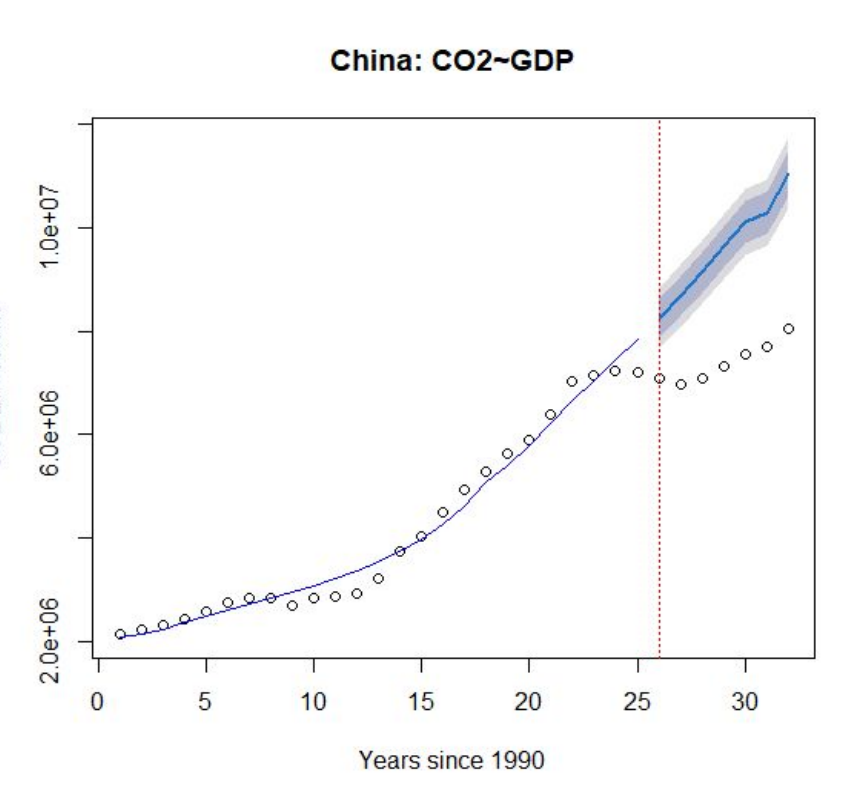
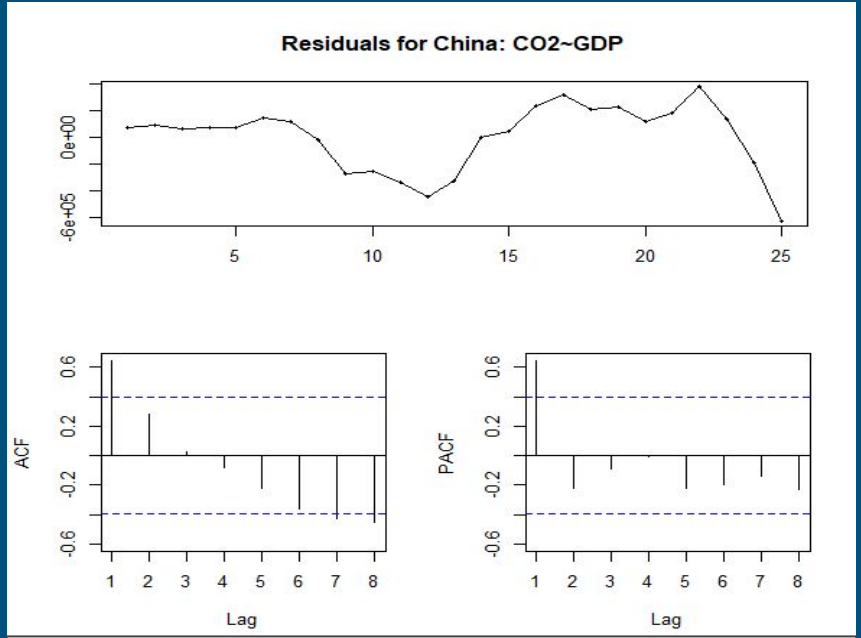
LINEAR MODELS

CO_2 ~ GDP






```
Coefficients:
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(Intercept) 1.298e+06  9.722e+04   13.35 2.57e-12 ***
g           5.448e+02  1.582e+01   34.44  < 2e-16 ***
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Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
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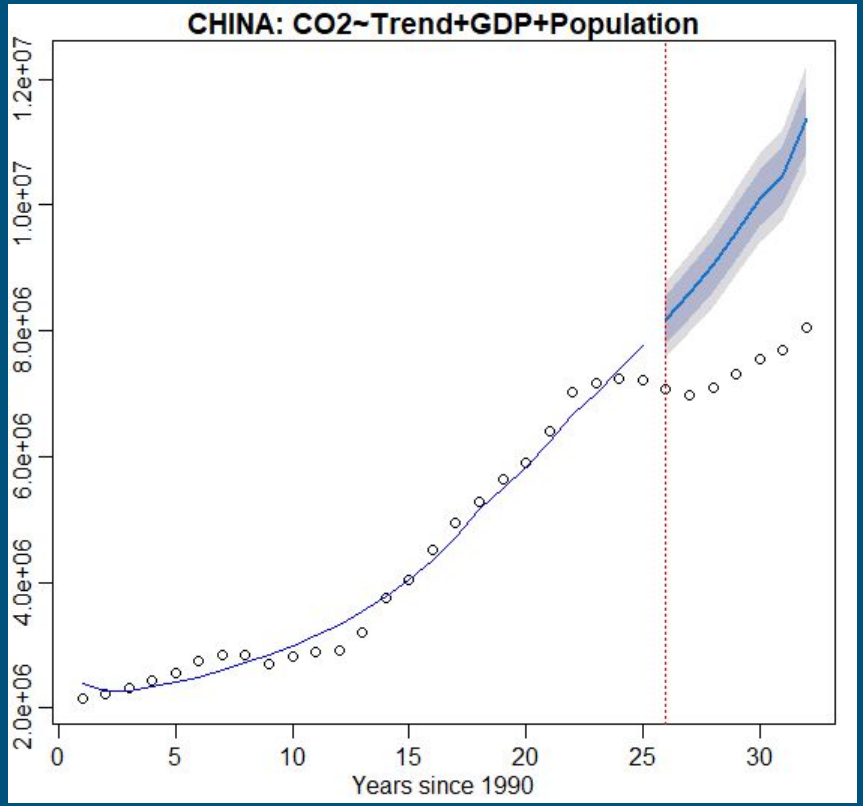
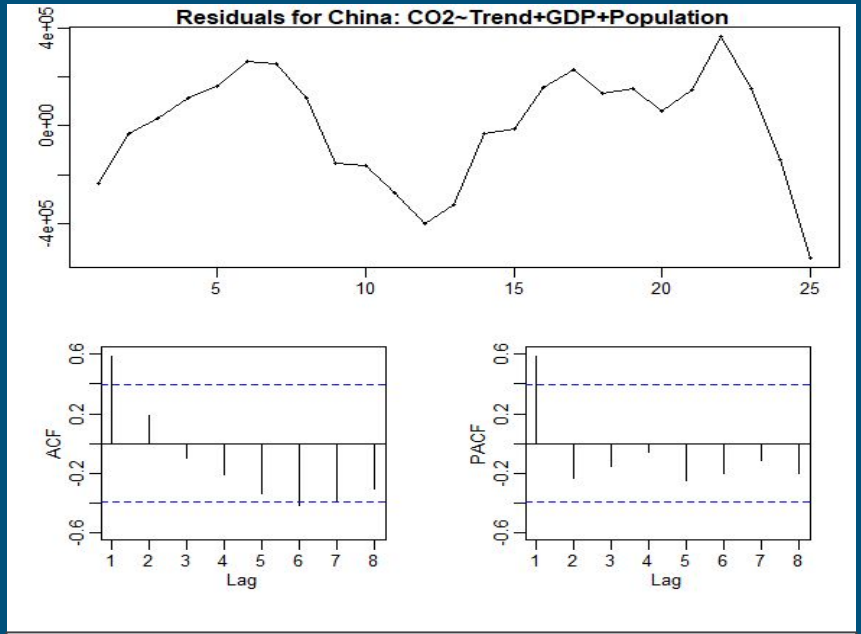
LINEAR MODELS

CO_2 ~ Trend + Population + GDP






```
Coefficients:
             Estimate Std. Error t value Pr(>|t|)
(Intercept)  3.287e+07  1.569e+07   2.095   0.0485 *
trend        2.786e+05  1.434e+05   1.943   0.0655 .
g            4.718e+02  7.049e+01   6.693 1.27e-06 ***
p           -2.724e-02  1.354e-02  -2.012   0.0573 .
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

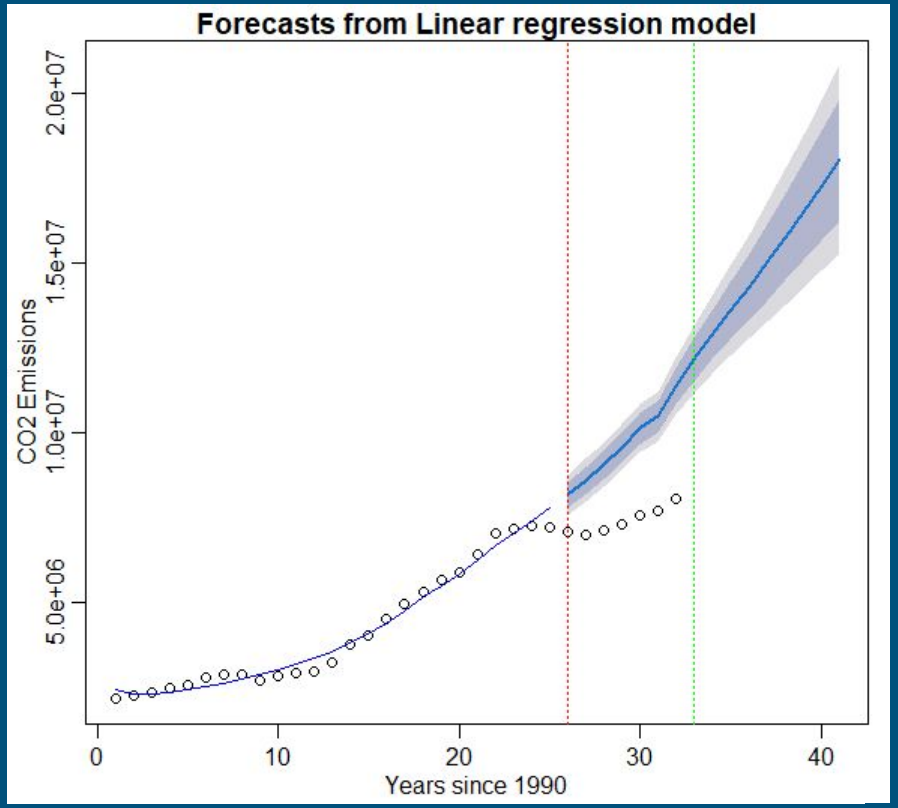
LINEAR MODELS

Performance

Covariates	AIC	Test MAE, 10^3	Adjusted R^2
Trend	736	501	0.9
GDP	697	2202	0.98
Population	743	235	0.87
Trend, GDP	699	2232	0.98
Population, GDP	699	2280	0.98
Trend, Population, GDP	696	2227	0.98

LINEAR MODELS

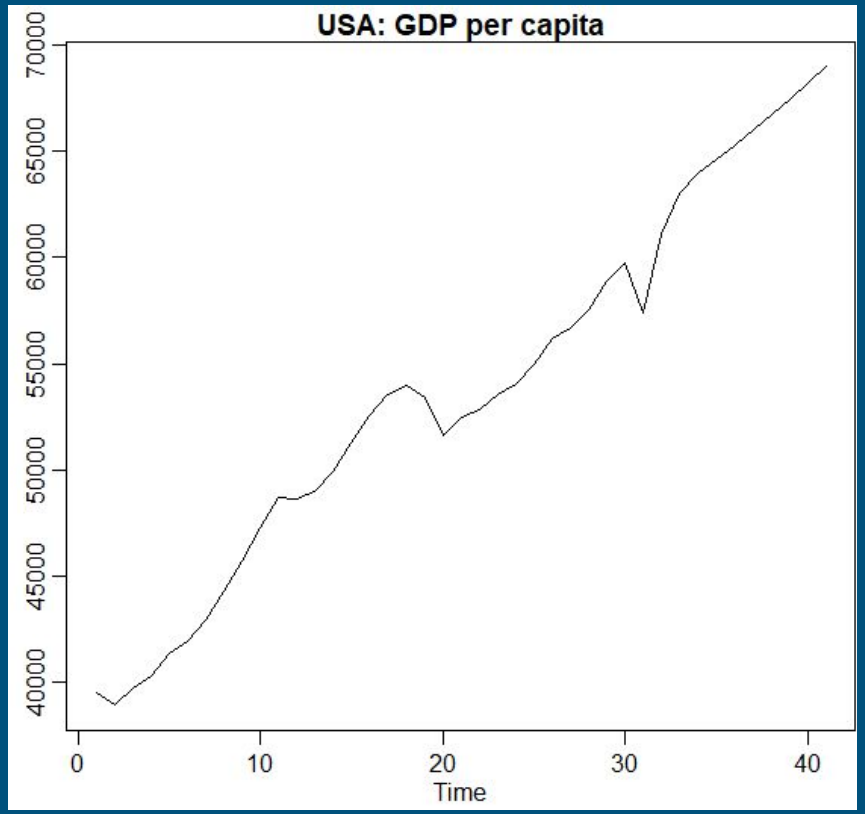
Forecasting

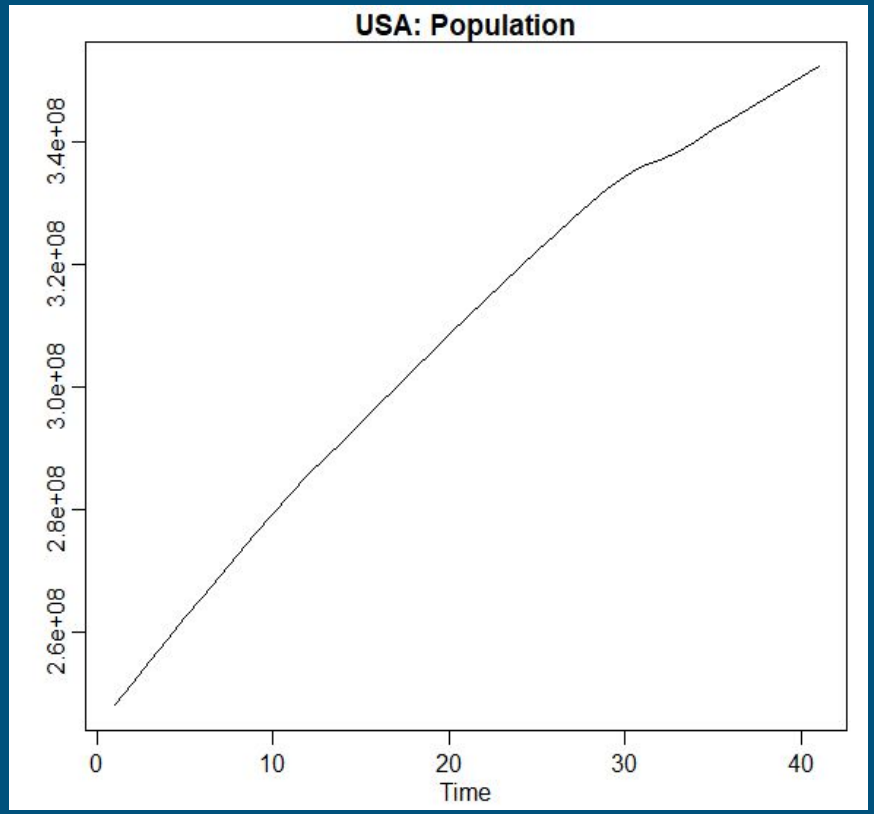


China Forecast for 2030:
25.5 billion tCO_2e

LINEAR MODELS

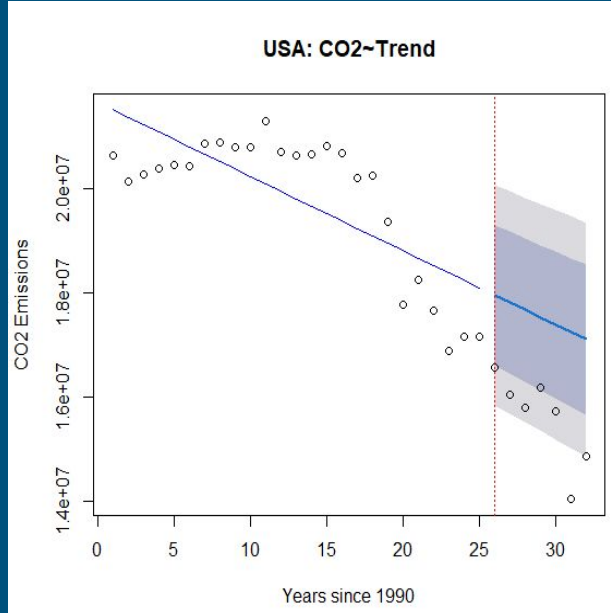
Covariates





LINEAR MODELS

CO_2 ~ Trend




```
Coefficients:
             Estimate Std. Error t value Pr(>|t|)
(Intercept) 21662513     390243  55.510  < 2e-16 ***
trend        -142405      26251  -5.425 1.64e-05 ***
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Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
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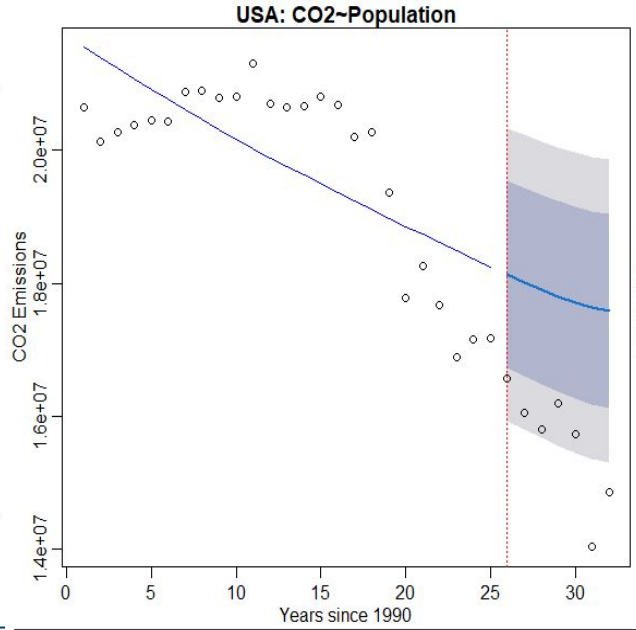


```
Coefficients:
              Estimate Std. Error t value Pr(>|t|)
(Intercept)  3.263e+07  2.576e+06  12.667 7.45e-12 ***
p           -4.466e-02  8.948e-03  -4.991 4.77e-05 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
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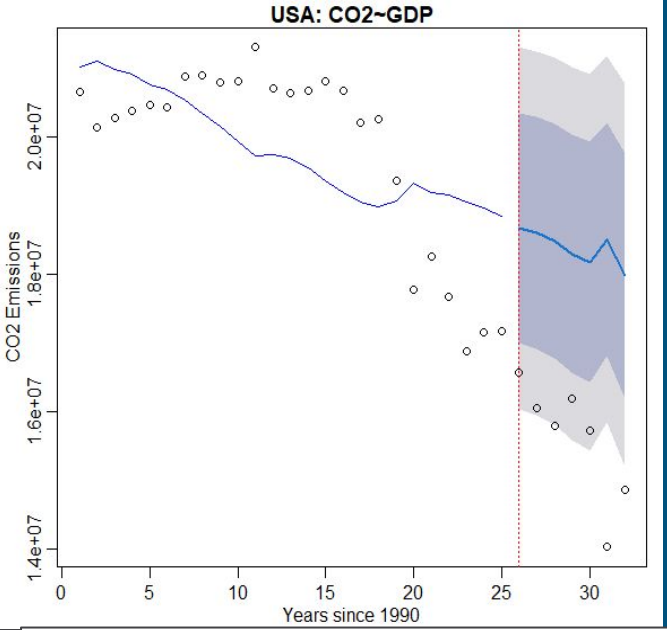


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Coefficients:
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(Intercept)  2.656e+07  2.161e+06   12.29 1.38e-11 ***
g           -1.403e+02  4.469e+01   -3.14  0.00459 **
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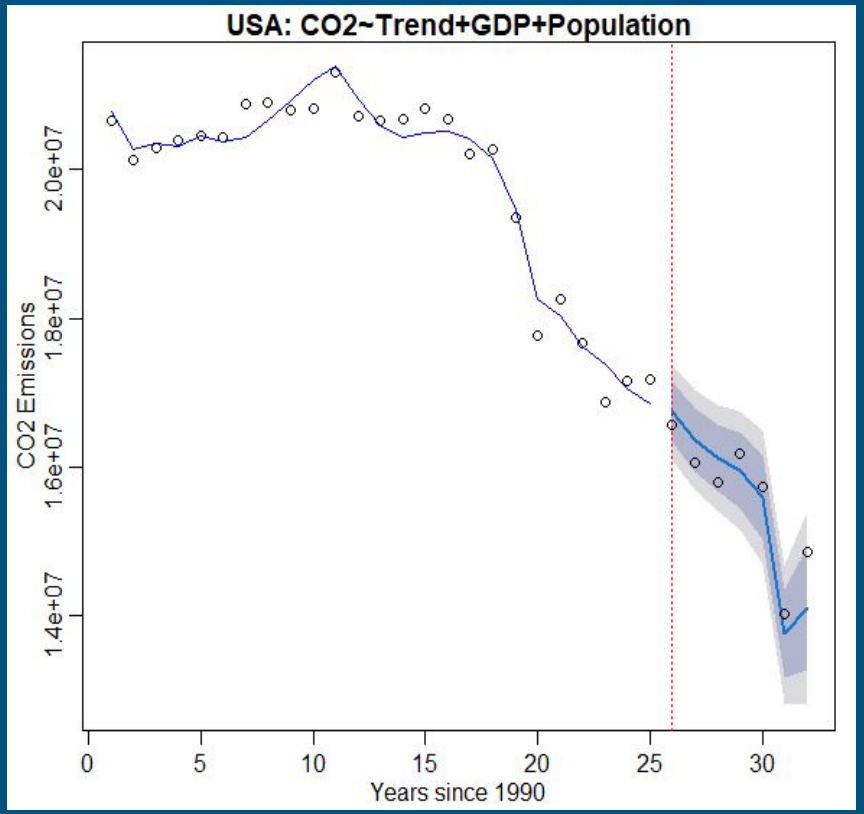
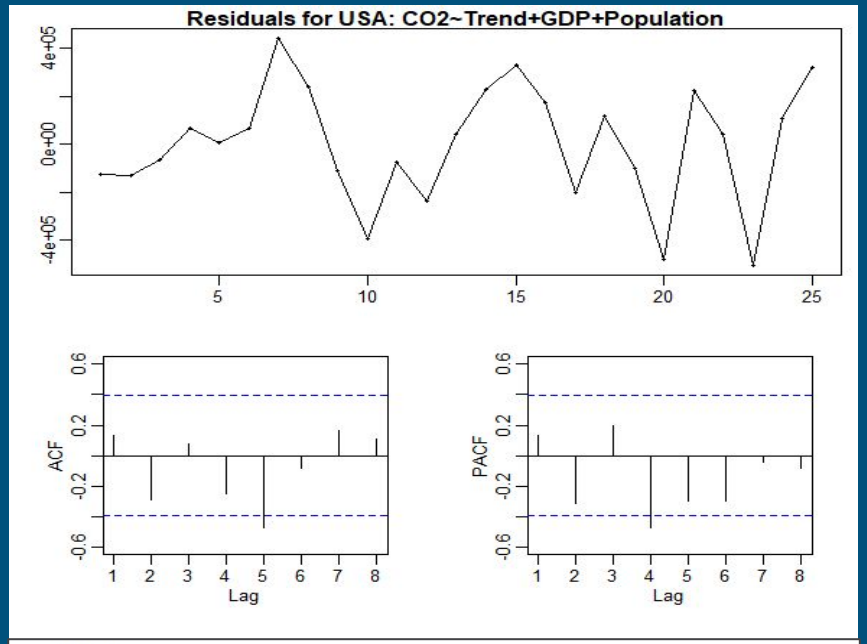
LINEAR MODELS

CO_2 ~ Trend + Population + GDP



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Coefficients:
              Estimate Std. Error t value Pr(>|t|)
(Intercept) -7.739e+07  1.557e+07  -4.971 6.42e-05 ***
trend       -1.460e+06  1.863e+05  -7.836 1.15e-07 ***
p            3.400e-01  6.807e-02   4.995 6.07e-05 ***
g            3.866e+02  4.858e+01   7.960 8.93e-08 ***
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Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
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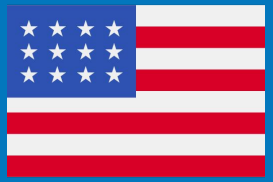
LINEAR MODELS

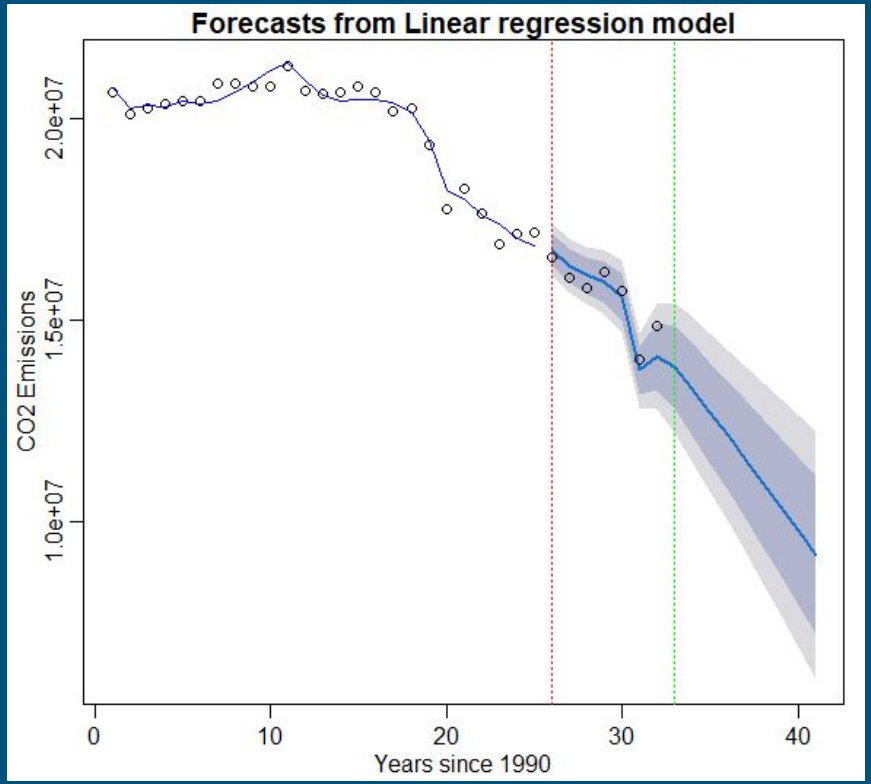
CO_2 ~ Trend + Population + GDP



Covariates	AIC	Test MAE, 10^3	Adjusted R^2
Trend	762	1928	0.54
GDP	774	2782	0.27
Population	765	2217	0.5
Trend, GDP	717	1238	0.927
Population, GDP	732	2050	0.87
Trend, Population, GDP	700	315	0.965

LINEAR MODELS

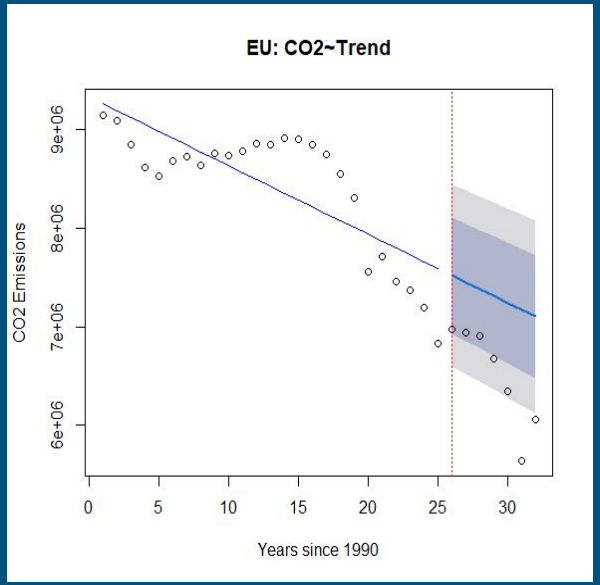
Forecasting

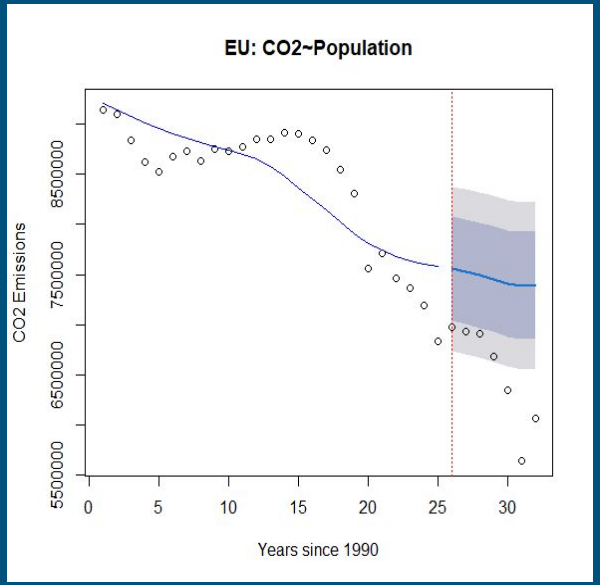


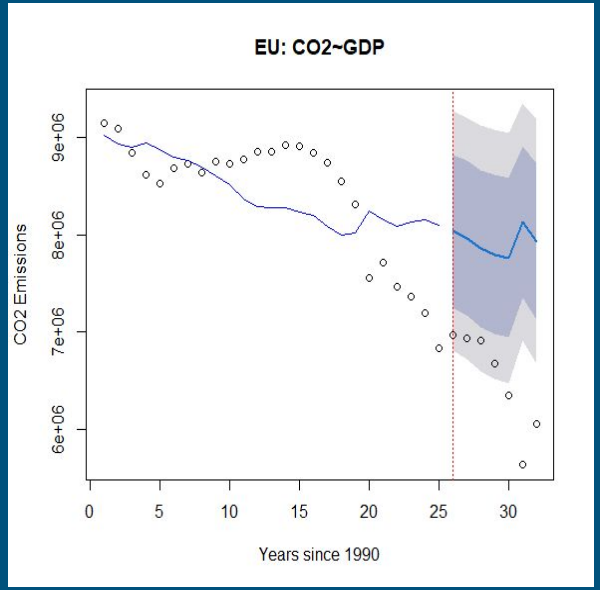
USA Forecast for 2030:
3.2305 billion tCO_2e

LINEAR MODELS

Univariate models







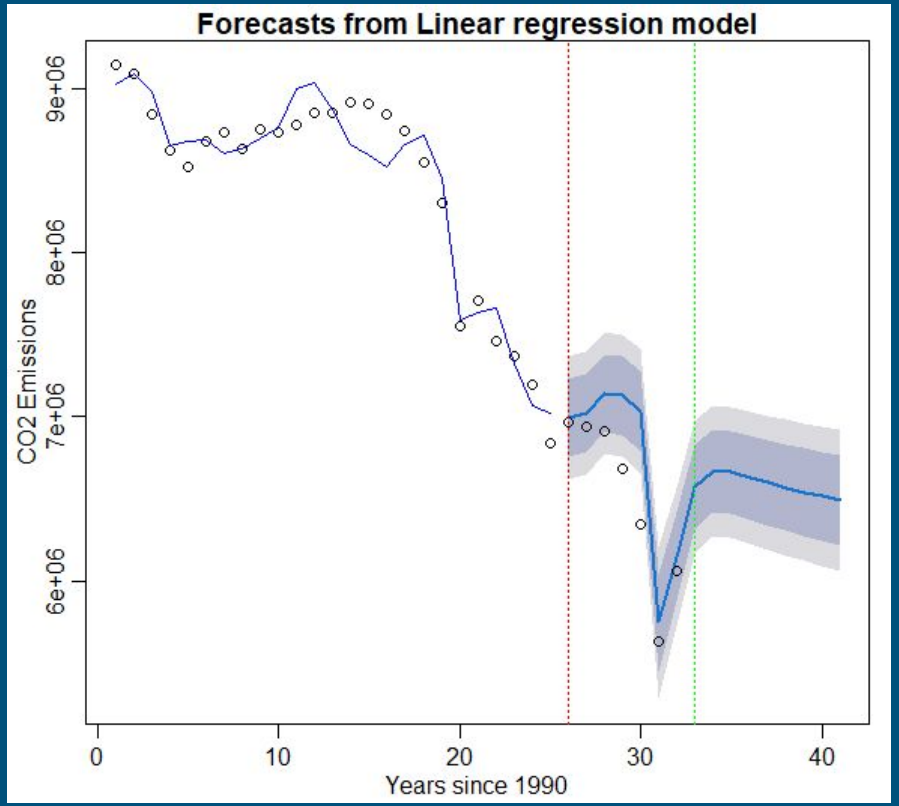
LINEAR MODELS

Performance Summary

Covariates	AIC	Test MAE, 10^3	Adjusted R^2
Trend	721	806	0.601
GDP	737	1420	0.24
Population	715	955	0.68
Trend, GDP	675	240	0.9386
Population, GDP	687	884	0.9
Trend, Population, GDP	676	348	0.9378

LINEAR MODELS

Forecasting



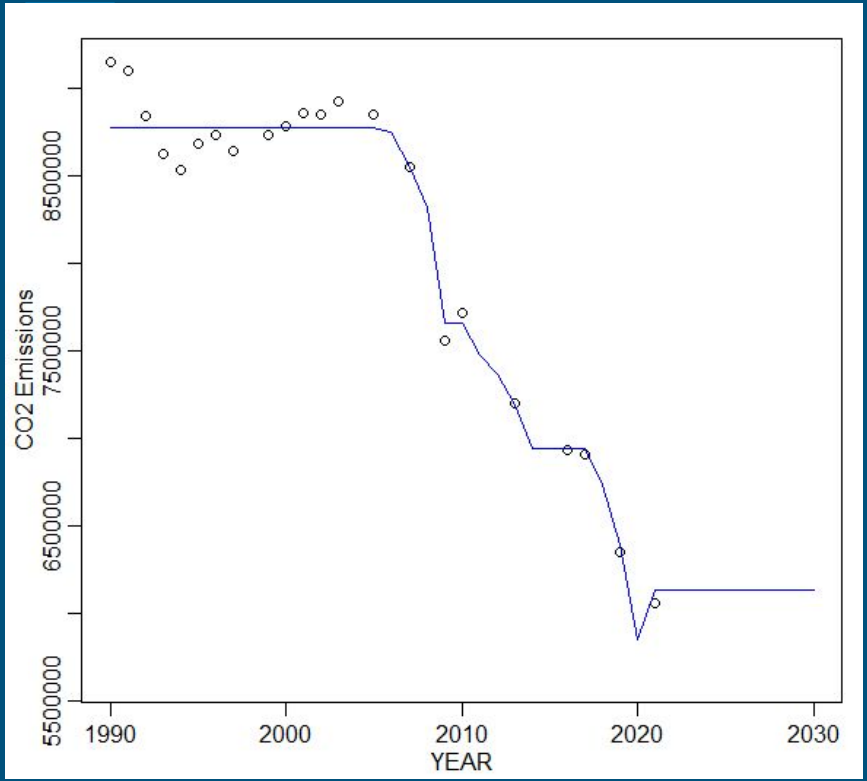
EU Forecast for 2030:
1.642 billion tCO_2e

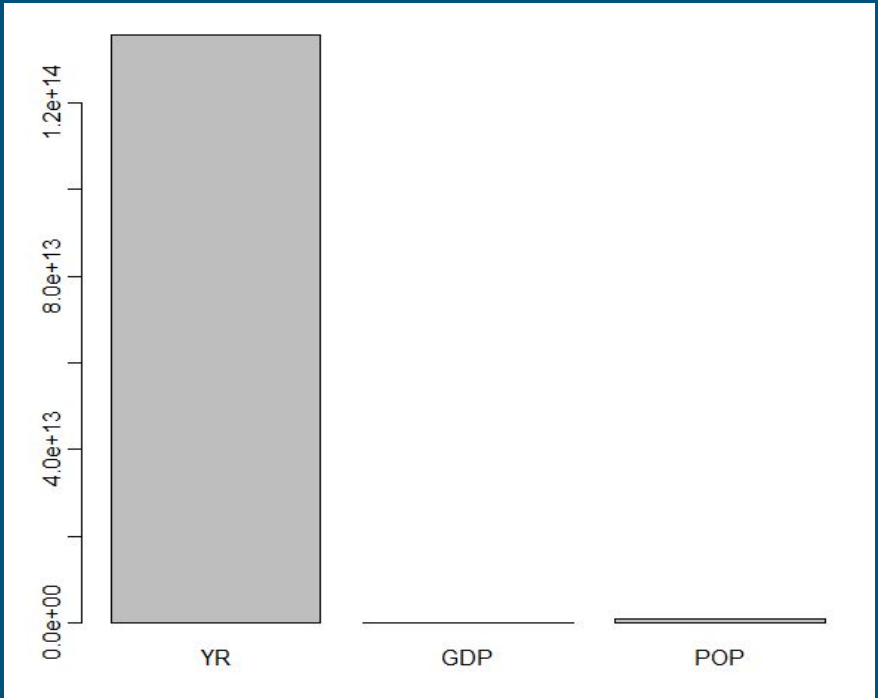
Gradient Boosting

- Aims:
  - Try to capture feature importance
  - Another forecasting method
- Training:
  - Cross-validation
  - 100 trees

Gradient Boosting

Year, GDP, and Population

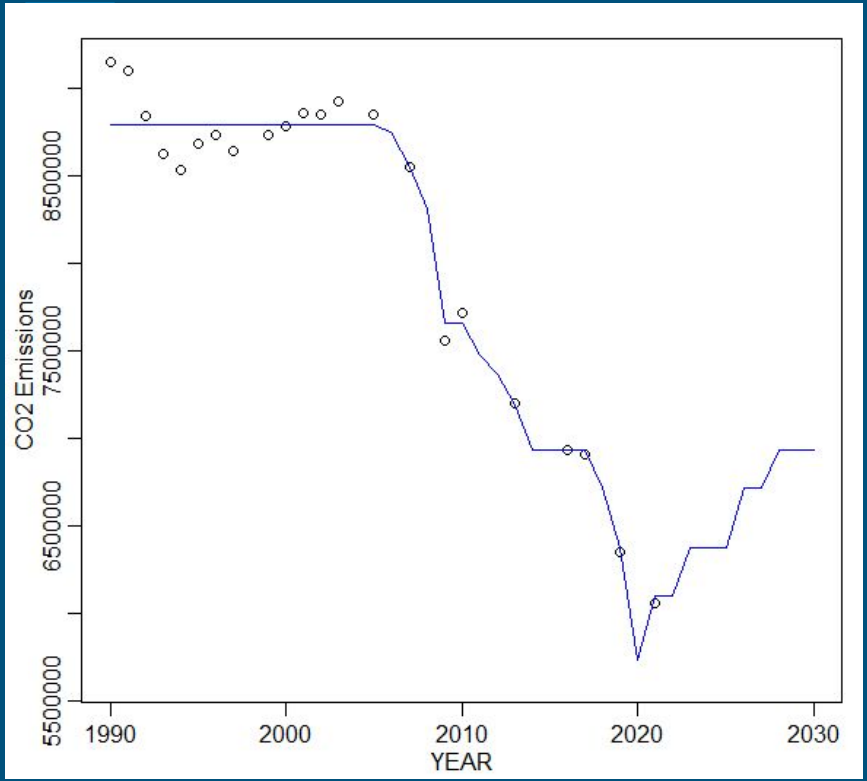


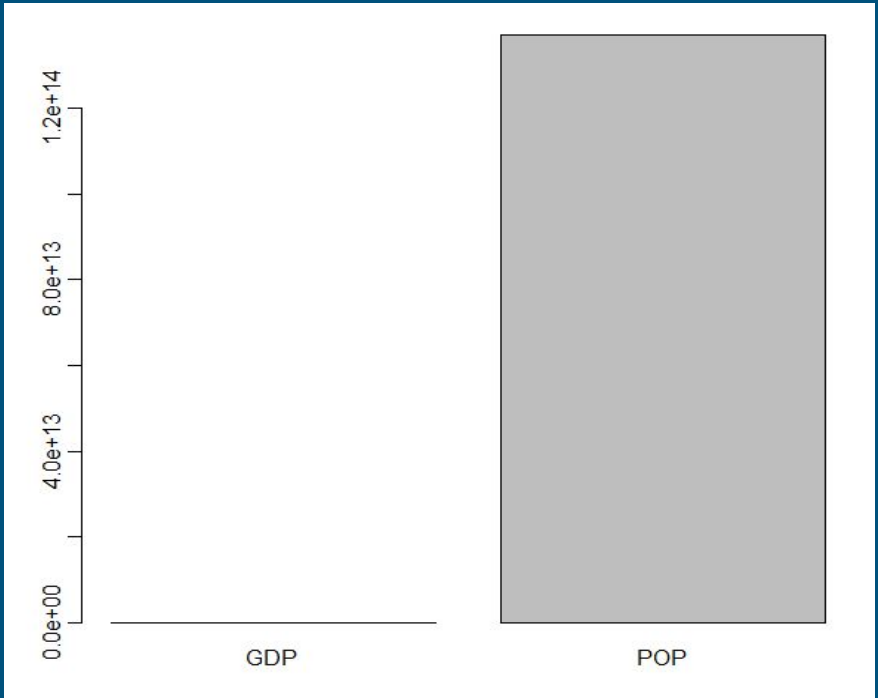


Test RMSE: 233,546

Gradient Boosting

GDP and Population

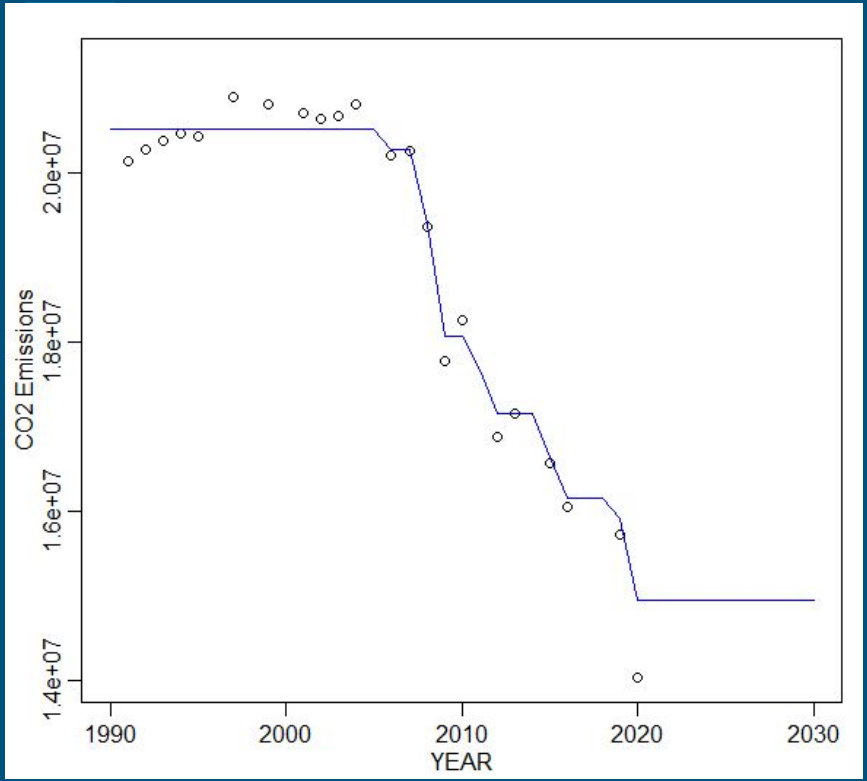


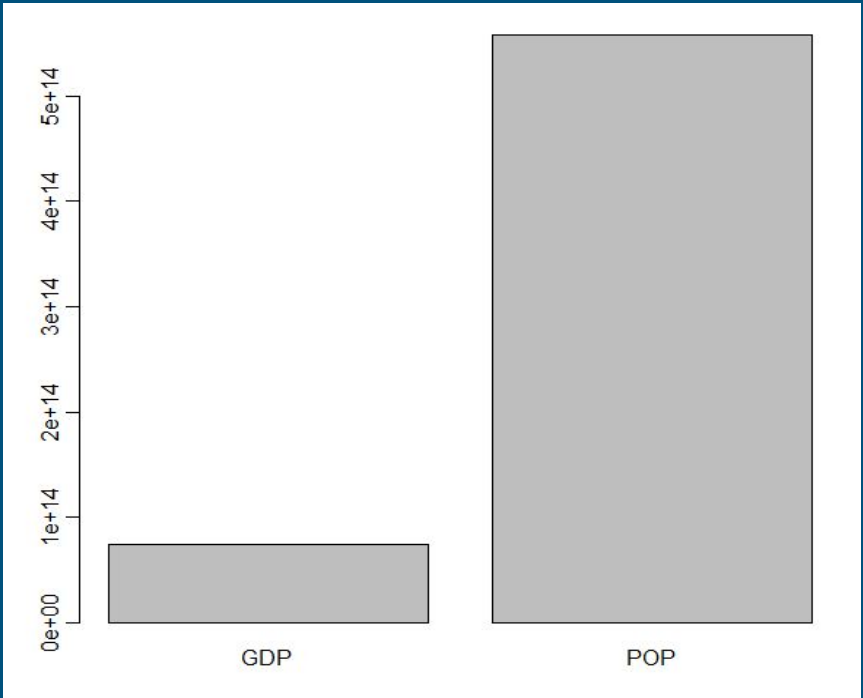


Test RMSE: 235,869

Gradient Boosting

GDP and Population

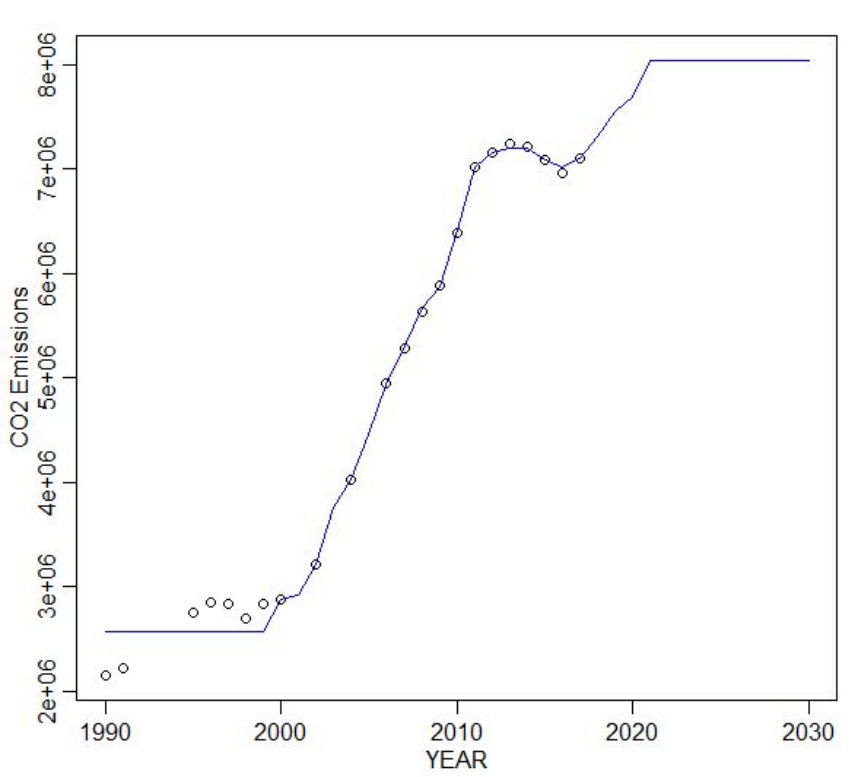


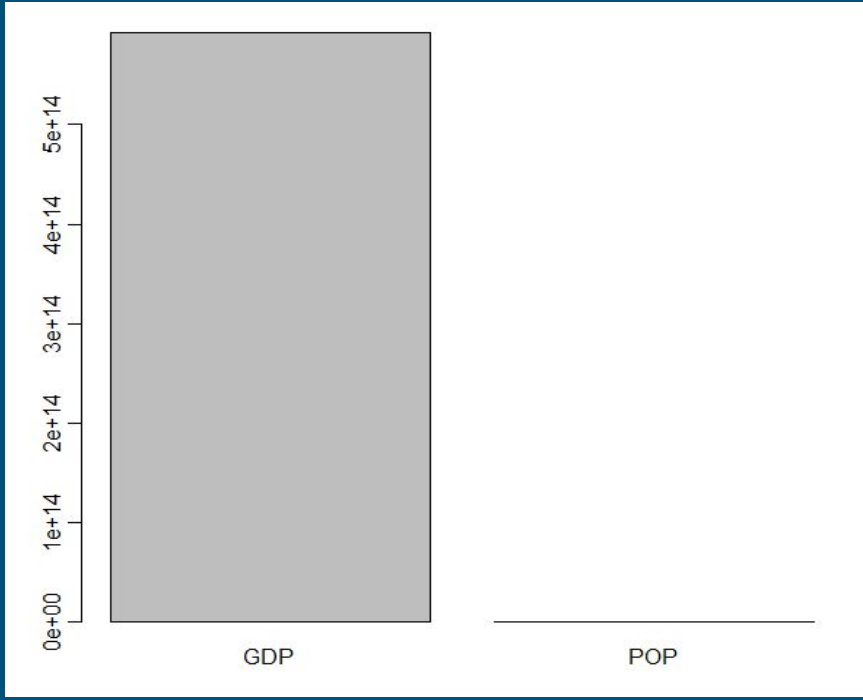


Test RMSE: 590,995

Gradient Boosting

GDP and Population



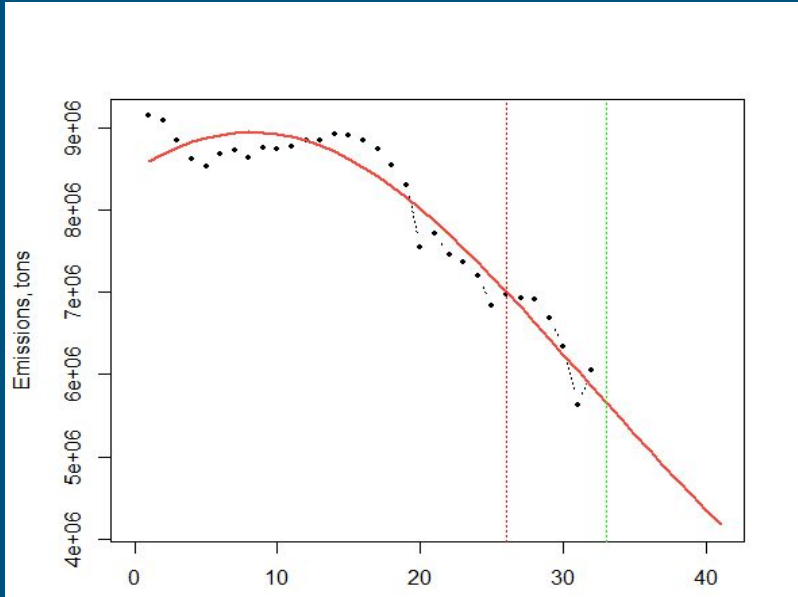


Test RMSE: 294,573.6

BASS MODELS

- Not what the model was designed for
- However, the shape of the data is somewhat similar
- Shocks may help account for world events (GBM)

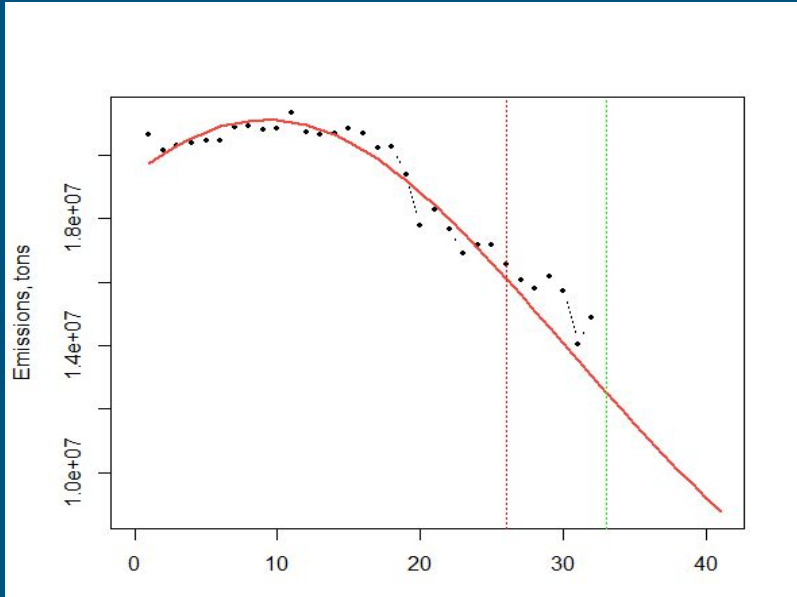
BASS MODELS - EU & USA




```
Coefficients:
       Estimate     Std.Error        Lower        Upper  p-value
m 3.835124e+08 1.674180e+07 3.506991e+08 4.163257e+08 7.67e-17 ***
p 2.227107e-02 7.925482e-04 2.071770e-02 2.382444e-02 9.88e-19 ***
q 3.436376e-02 3.108135e-03 2.827193e-02 4.045559e-02 1.89e-10 ***
---
 Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

 Residual standard error  578039  on  22  degrees of freedom
 Multiple R-squared:   0.9999777  Residual squared sum:  8.2221e+12
```

EU MAE: **200*10^3**

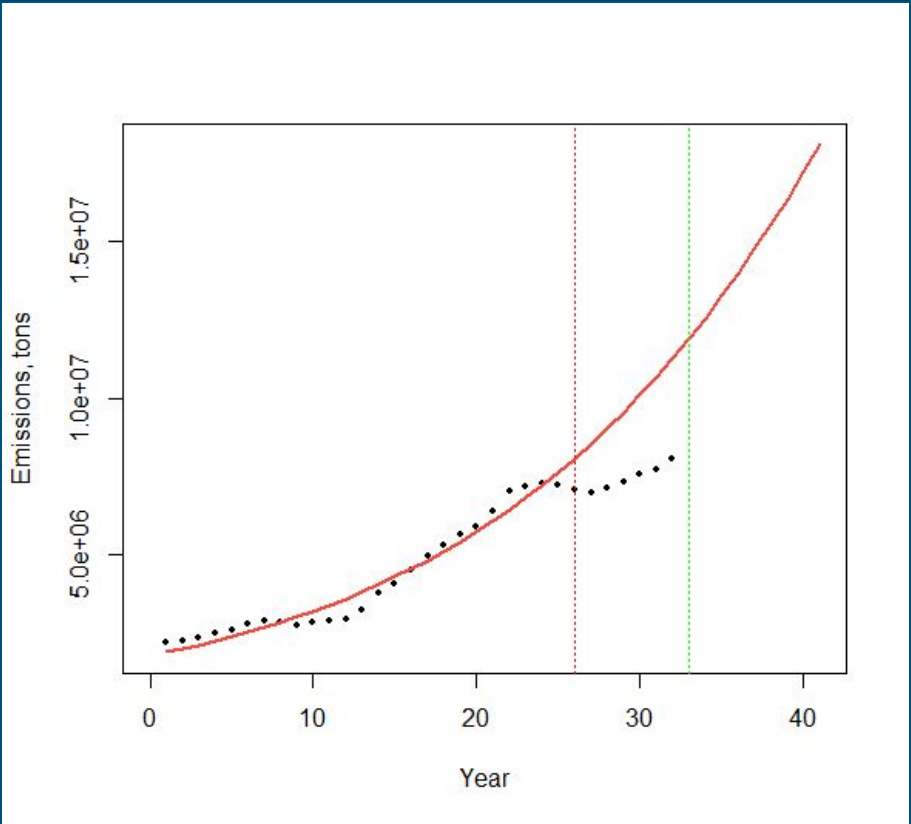



```
Coefficients:
       Estimate     Std.Error        Lower        Upper  p-value
m 8.449800e+08 1.491577e+07 8.157456e+08 8.742144e+08 2.46e-25 ***
p 2.316301e-02 3.156887e-04 2.254427e-02 2.378175e-02 8.55e-28 ***
q 4.020286e-02 1.481672e-03 3.729884e-02 4.310689e-02 2.09e-18 ***
---
 Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

 Residual standard error  689645.2  on  22  degrees of freedom
 Multiple R-squared:   0.9999942  Residual squared sum:  1.167592e+13
```

USA MAE: **1036*10^3**

BASS MODELS - China




```
Coefficients:
       Estimate    Std.Error         Lower        Upper  p-value
m 3.567792e+09 1.853938e+10 -3.276873e+10 3.990432e+10 8.49e-01
p 5.036000e-04 2.597467e-03 -4.587342e-03 5.594542e-03 8.48e-01
q 6.080632e-02 9.627116e-03  4.193752e-02 7.967512e-02 2.35e-06 ***
---
 Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

 Residual standard error  947808  on  22  degrees of freedom
 Multiple R-squared:   0.999596  Residual squared sum:  2.331437e+13
```

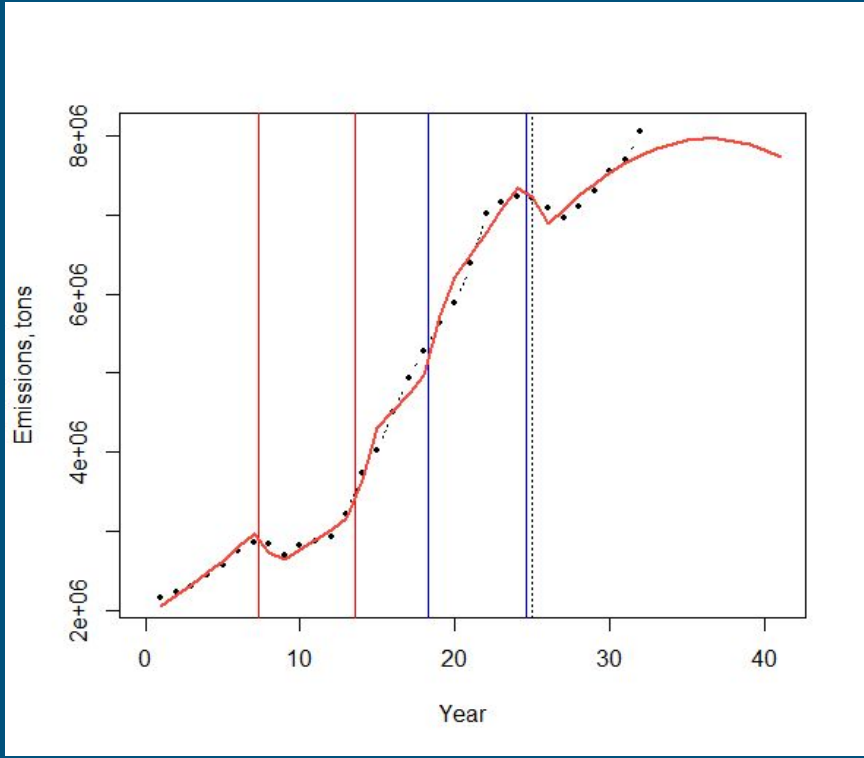
China MAE: **$2216*10^3$**

Generalized Bass Model - China

- Two rectangular shocks

```
Coefficients:
           Estimate    Std.Error         Lower         Upper  p-value
m     4.004242e+08 1.728644e+07  3.665434e+08  4.343050e+08 1.92e-17 ***
p     4.965802e-03 1.908334e-04  4.591776e-03  5.339829e-03 1.46e-18 ***
q     6.923316e-02 1.814789e-03  6.567624e-02  7.279008e-02 2.67e-22 ***
a1    7.344942e+00 2.480435e-01  6.858786e+00  7.831098e+00 8.10e-20 ***
b1    1.356427e+01 2.169156e-01  1.313913e+01  1.398942e+01 3.45e-27 ***
c1   -1.952898e-01 1.143896e-02 -2.177097e-01 -1.728698e-01 1.48e-14 ***
a2    1.826884e+01 2.494531e-01  1.777992e+01  1.875776e+01 9.27e-29 ***
b2    2.459646e+01 1.811628e-01  2.424138e+01  2.495153e+01 6.54e-35 ***
c2    1.356631e-01 1.026630e-02  1.155415e-01  1.557847e-01 3.15e-12 ***
---
 Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

 Residual standard error  126874.4  on  23  degrees of freedom
 Multiple R-squared:   0.9999927  Residual squared sum:  500950060472
```

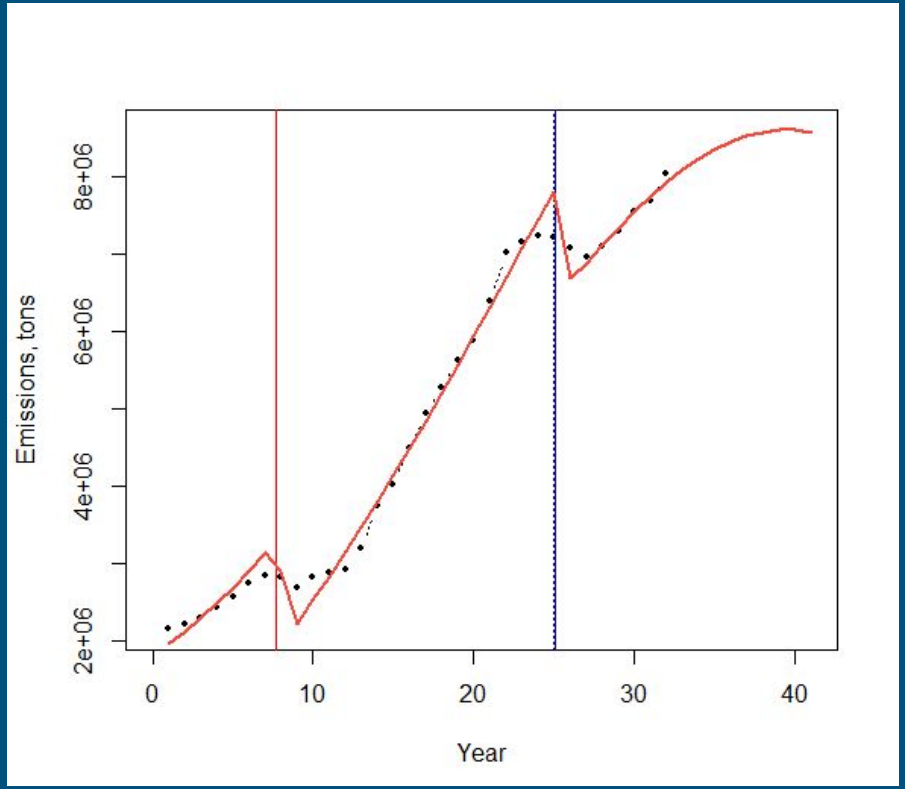


Generalized Bass Model - China

- Two exponential shocks

```
Coefficients:
           Estimate    Std.Error         Lower         Upper  p-value
m     4.384906e+08 1.511880e+08  1.421675e+08  7.348136e+08 8.07e-03  **
p     4.303213e-03 1.345732e-03  1.665626e-03  6.940800e-03 4.00e-03  **
q     8.555907e-02 1.285613e-02  6.036152e-02  1.107566e-01 8.65e-07 ***
a1    7.674835e+00 2.878392e-01  7.110681e+00  8.238990e+00 8.46e-19 ***
b1   -1.551215e-01 5.355572e-02 -2.600888e-01 -5.015424e-02 8.14e-03  **
c1   -4.274406e-01 3.132330e-02 -4.888331e-01 -3.660480e-01 1.63e-12 ***
a2    2.503769e+01 2.998430e-01  2.445001e+01  2.562537e+01 4.58e-30 ***
b2   -7.177831e-03 5.592460e-02 -1.167880e-01  1.024324e-01 8.99e-01
c2   -1.812792e-01 2.783477e-02 -2.358343e-01 -1.267240e-01 1.21e-06 ***
---
 Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

 Residual standard error  221960.8  on  23  degrees of freedom
 Multiple R-squared:   0.9999776  Residual squared sum:  1.542154e+12
```

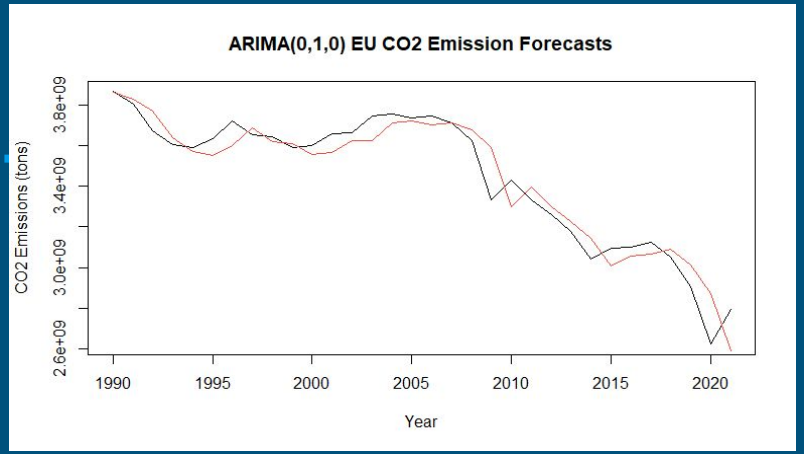


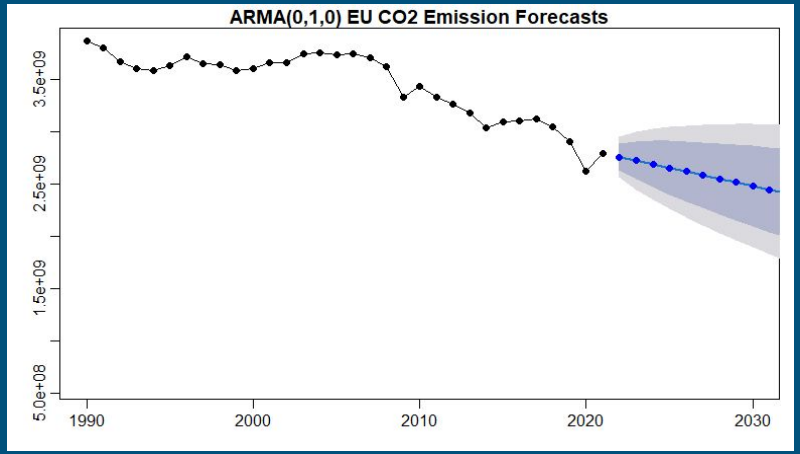
ARIMA

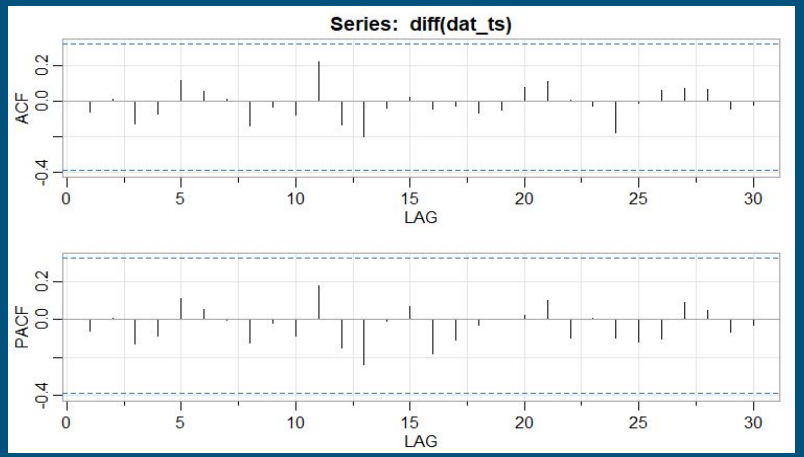
Methodology

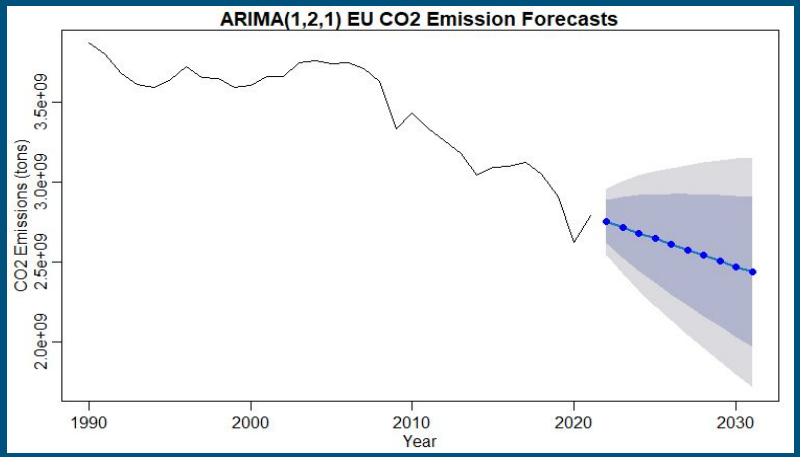
- **3** models:
  - **ARIMAX**
  - **Auto ARIMA**
  - **SARIMA**
- ARIMA steps:
  - Time difference data
  - Plot (P)ACF
  - Determine best p,d, q parameters
  - Fit model and analyse standardised residuals, ACF, Normal Q-Q Plot and Ljung-Box statistic(test of independence at all lags)
  - Forecast using best model
- Auto ARIMA steps:
  - Let R determine best p,d,q parameters
  - Forecast
- Performance metrics
  - AIC

EU : ARIMA, ARMAX

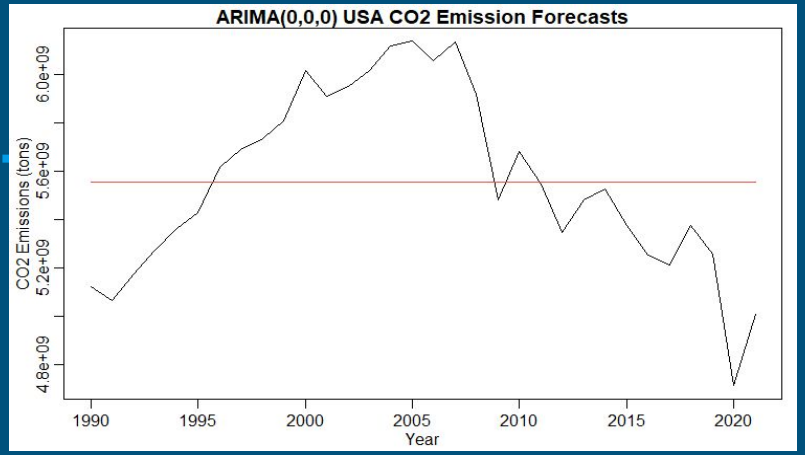


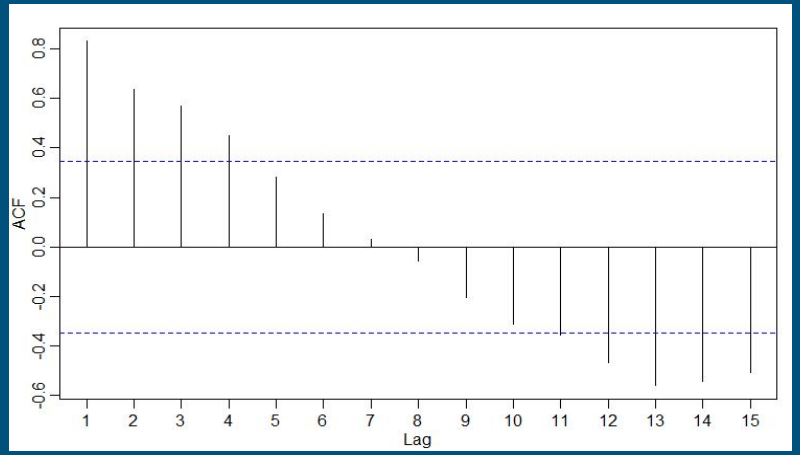


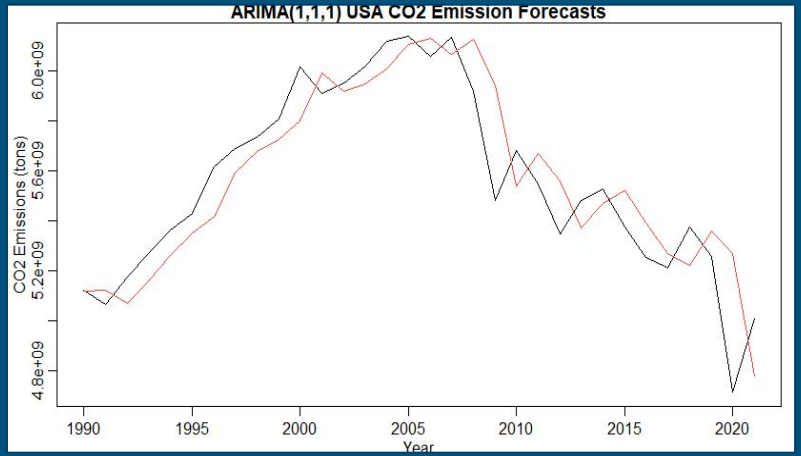


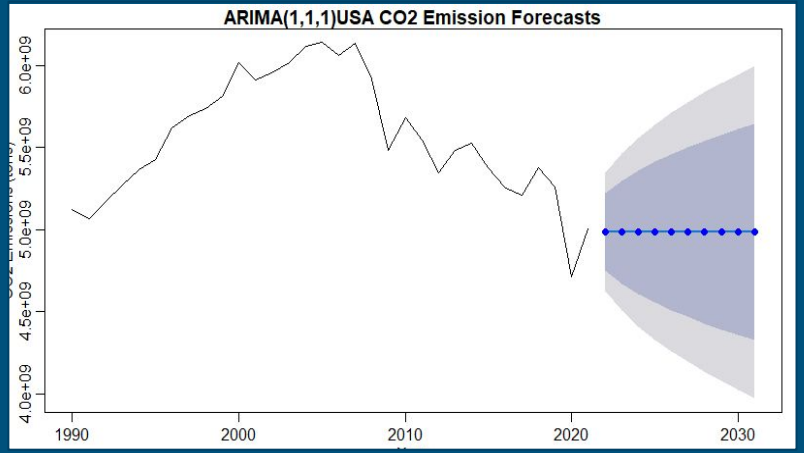


USA : ARIMA, ARIMAX

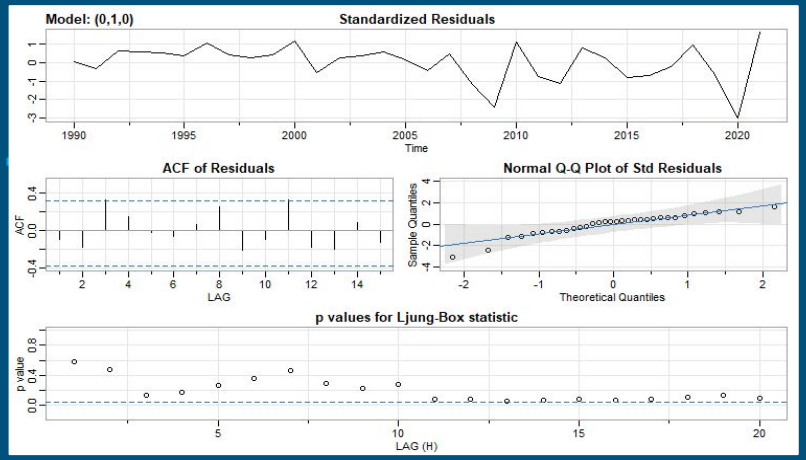


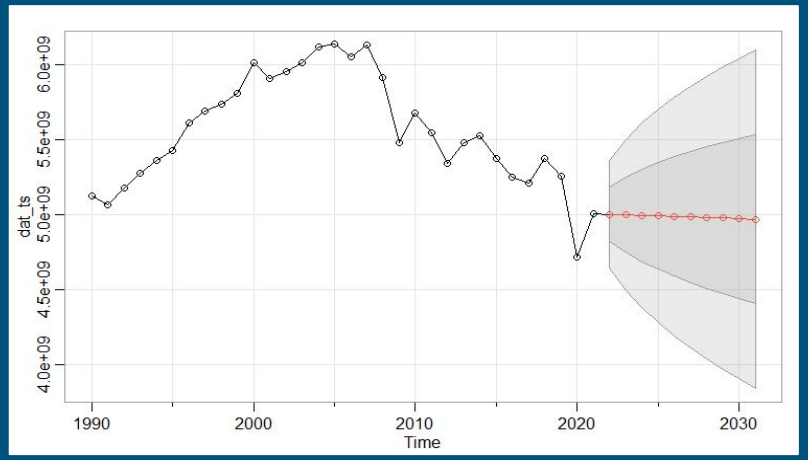


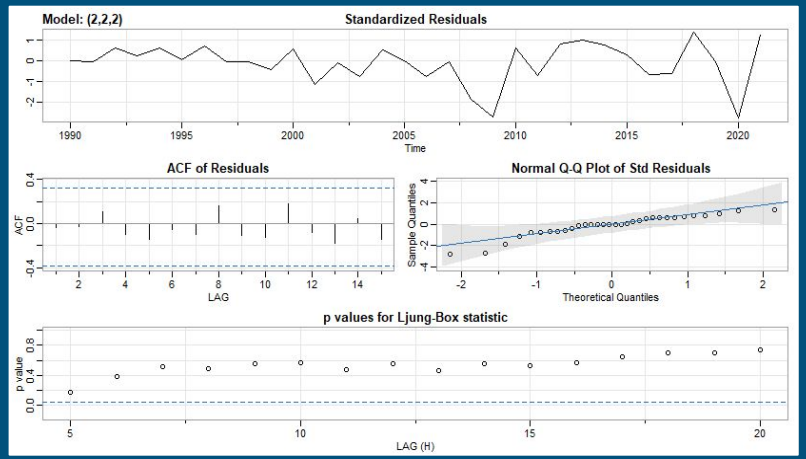


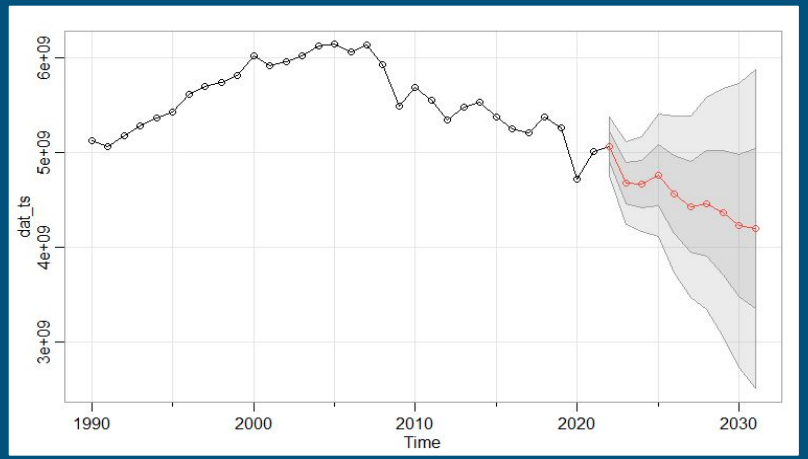


USA : SARIMA


Model: (0,1,0)
Standardized Residuals
Time
ACF of Residuals
ACF
LAG
Normal Q-Q Plot of Std Residuals
Sample Quantiles
Theoretical Quantiles
p values for Ljung-Box statistic
p value
LAG (H)


dat_ts
Time

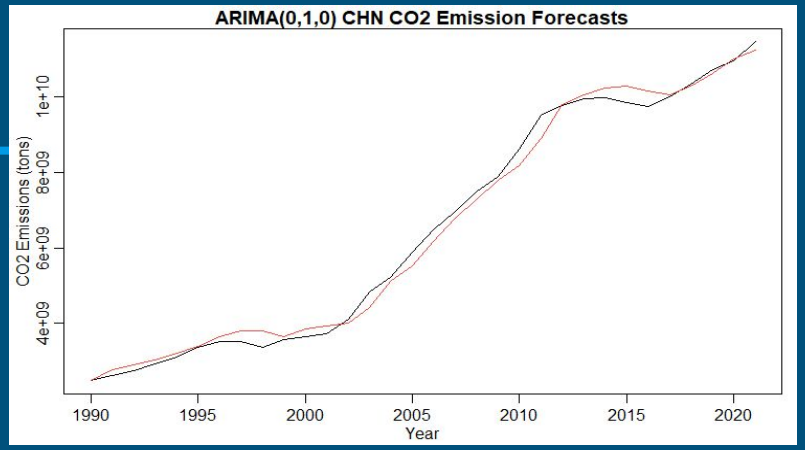

Model: (2,2,2)
Standardized Residuals
Time
ACF of Residuals
ACF
LAG
Normal Q-Q Plot of Std Residuals
Sample Quantiles
Theoretical Quantiles
p values for Ljung-Box statistic
p value
LAG (H)

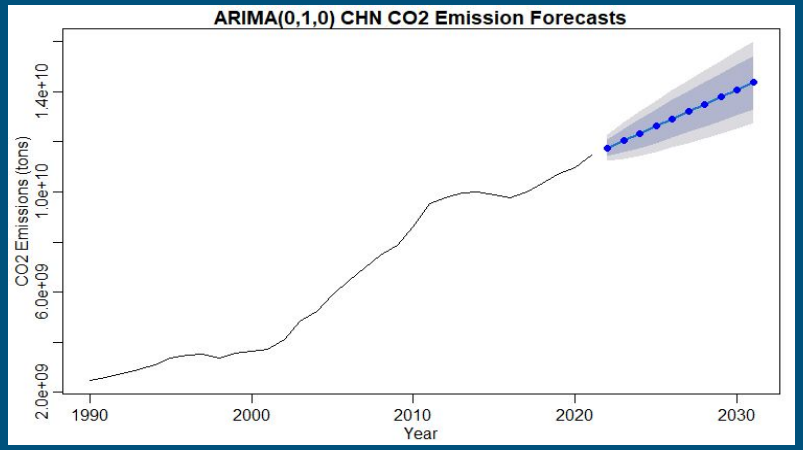

dat_ts
Time

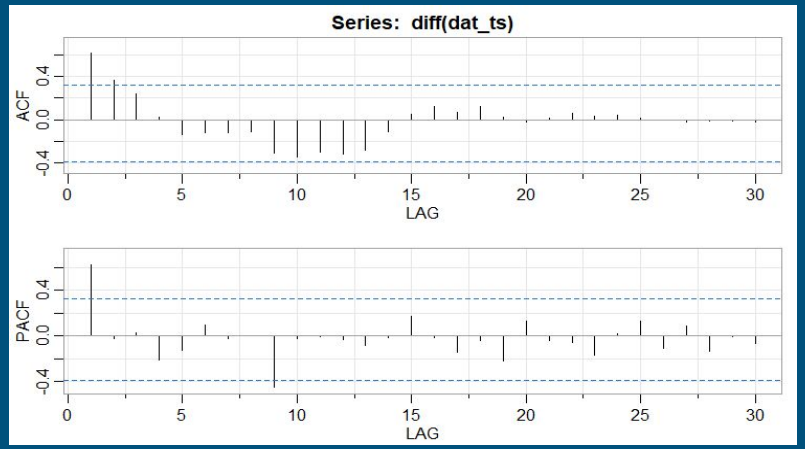
Comments

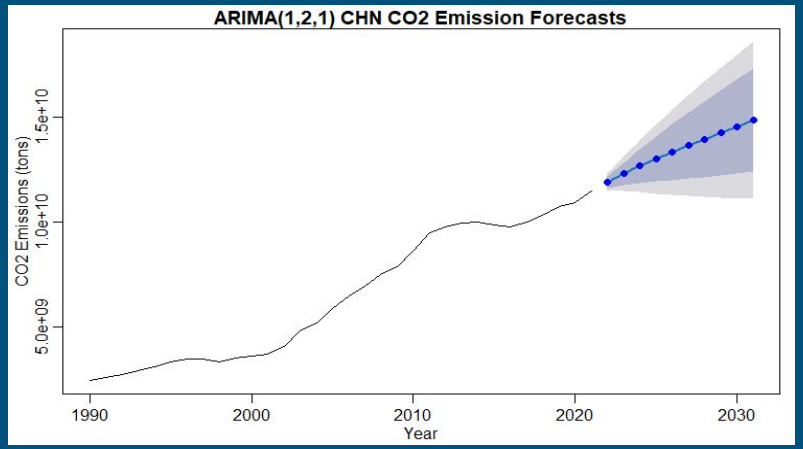
- Auto-Arima fails to capture the trend and is unable to produce a proper forecast
- ACF suggests seasonality
- Using different parameters for a ARAMAX model produces forecast with constant mean
- SARIMA models have most of the residuals on the Q-Q plot are normally distributed; and their p-values are sufficiently above the blue line on the Ljung Box Statistic plot and so are sufficient to use as forecasting models

China: ARIMA, ARIMAX

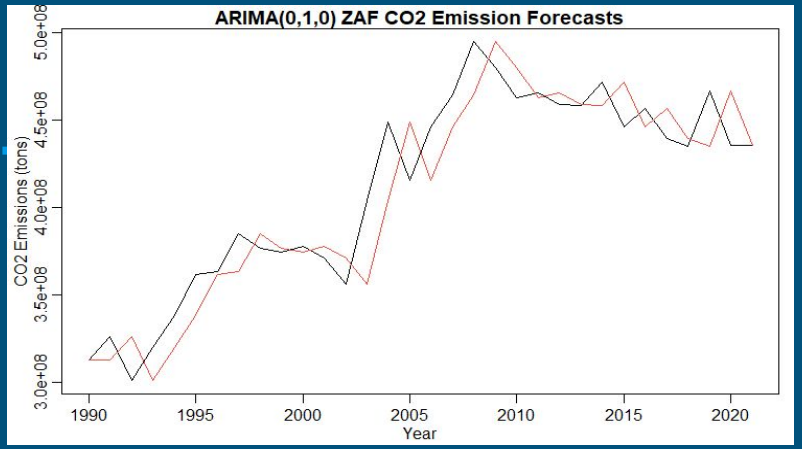


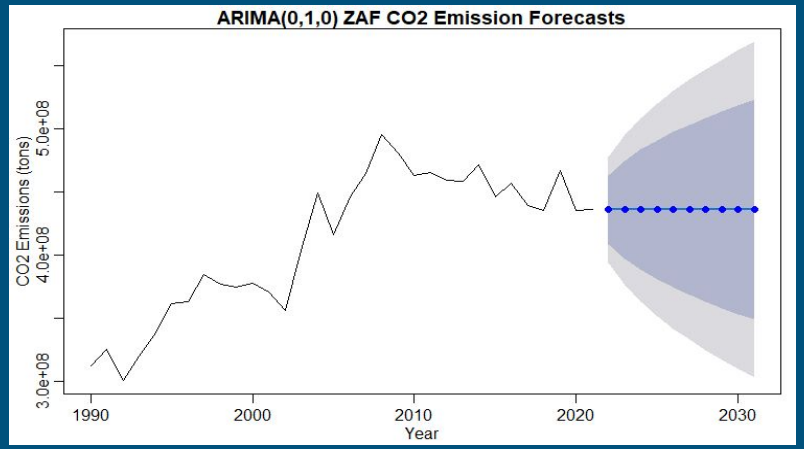


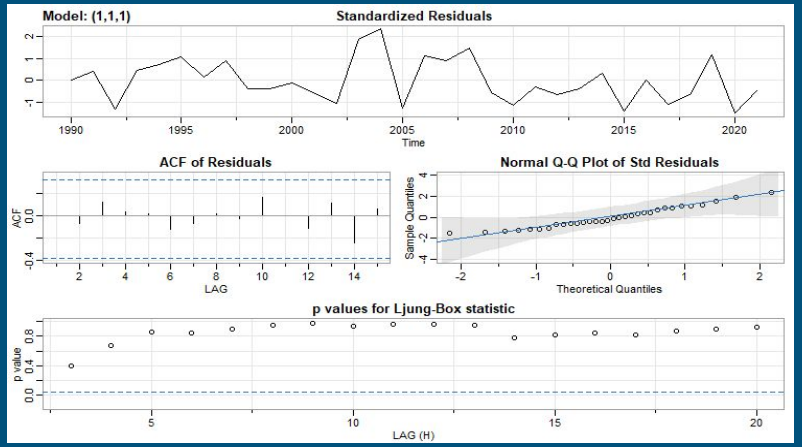


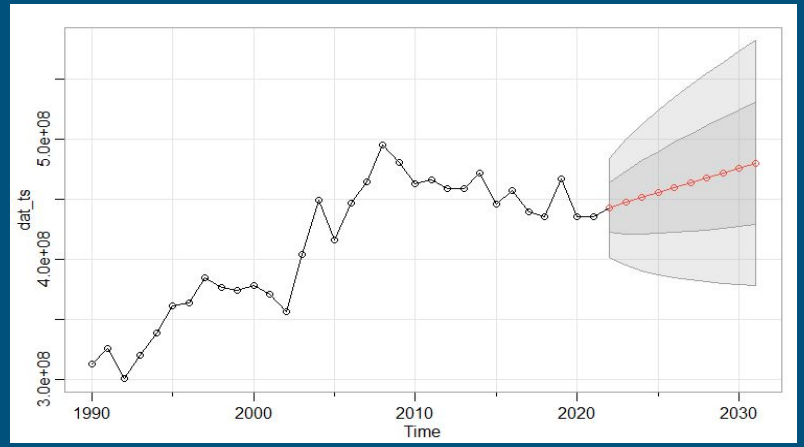


South Africa: ARIMA, SARIMA









ARIMA Summary

Country/ Region	PA Goal	2030 CO_2 Target (tCO_2e)	ARIMA Forecast (tCO_2e)	(S)ARIMAX Forecast (tCO_2e)	ARIMA AIC	(S)ARIMAX AIC	Trend
EU	55% below 1990 levels	1,739,471,265	2,481,652,474	2,473,325,975	(0,1,0): 1233.22	(1,2,1): 1199.95	Decreasing
United States	50-52% below 2005 levels	2,946,049,728	N/A	(1,1,1,) : 4,985 758,181 (S)(0,1,0) : 4 973,902,452 (S)(2,2,2) : 4 228,602,259	(0,0,0): 1357.23	(1,1,1,): 1271.53 (0,1,0): 40.96504 (S)(2,2,2): 40.99671	Fluctuating but mainly decreasing
China	60% below 2005 levels	2,350,622,120	14,081,647 316	14,565,923,693	(0,1,0): 1292.83	(1,2,1): 1240.92	Increasing
South Africa	350 - 420 MtCO2e	350,000,000-420,000,000	353,578,740	476,055,950	(0,1,0): 1136.52	(S)(1,1,1): 36.77454	Increasing

ARIMA Summary

Country/ Region	PA Goal	ARIMA % Difference	(S)ARIMAX % Difference
EU	55% below 1990 levels	+29.9	+29.7
United States	50-52% below 2005 levels	N/A	(1,1,1,) : +40.9 (S)(0,1,0): +40.8 (S)(2,2,2): +30.3
China	60% below 2005 levels	+83.3	+83.9
South Africa	350 - 420 MtCO2e	+1.01	+11.8

Comments:

- All ARIMA models forecast within similar ranges and agree with each other
- For EU and USA (MEDC) CO2 emissions are decreasing but will not meet 2030 goals
- China and SA CO2 (NICs in BRICS) emissions are increasing
- China is the worst performing nation
- SA emission goals appear to be met in one model and slightly missed in the other but important to not GDP~CO2 positive correlation.

KEY FINDINGS

Goal I :

Investigate whether the EU and other top CO_2 emitting countries will meet the Paris Climate Agreement targets to reduce CO_2 emissions.

Country/ Region	2030 CO2 target	Linear Model % Difference	Boosting % Difference	BASS % Difference	ARMA % Difference	(S)ARIMA % Difference	Goal achieved?
EU	55% below 1990 levels	+5.6	-10.8	-39.6	+29.9	+29.7	No
United States	50-52% below 2005 levels	+8.8	+43.3	+4.5	N/A	+40.8	No
China	60% below 2005 levels	+90.8	+79.3	+90.8	+83.3	+83.9	No

Positive values imply emissions are above targets and thus, targets are **not met.*

Goal II : Investigate whether economic growth has decoupled from CO_2 emissions - relationship between GDP and CO_2 emissions

Country	Territory	Economic Rank	GDP, CO2 Correlation
Germany	EU	MEDC	-0.8759835
Italy	EU	MEDC	-0.420634
Poland	EU	MEDC	-0.6424758
France	EU	MEDC	-0.8145815
Spain	EU	MEDC	-0.1603071
Netherlands	EU	MEDC	-0.7214299
China	AS	NIC	0.9369638
United States	NA	MEDC	-0.8813746
South Africa	AF	NIC	0.8518396
		Combined	0.6127075

Comments:

- All MEDCs have a negative correlation between GDP and CO2 emissions
- NICs have a strong positive correlation. Similar pattern in LEDCs as well

Goal III :

Compare trends between MEDCs and NICs

- **CO_2** emissions for **MEDCs** are **decreasing** whilst for **NICs** they are **increasing**
- NICs with rapidly growing GDPs have corresponding CO_2 emissions with the same behaviour

Questions Arising:

- Is it fair to expect NICs to develop their economies without the resources that MEDCs previously used to develop theirs?
- Are the financial resources provided by rich countries in the Paris Accord enough to address this?

The Current State of Things

- **THING 1** : Effects of **Covid 19**
  - Initial **CO_2 emission decrease** in 2020 as **lockdowns** were put in place. Ozone layer reported to be “healing”. However a **rapid increase** may occur as many countries seek to **stabilise** affected **supply chains**
  - **GDP** growth **slowing** down in many countries and there is wild **inflation,** which may affect the **burden sharing** goals set out by the accord and make it **infeasible** for LEDCs and NICs to adhere to proposed emission goals
  -
- **THING 2** : **Ukraine war** impact
  - **Energy crisis** forcing countries like UK and Germany to **revert** back to “unclean” **fossil** fuels for energy. E.g. South African **coal exports** to the EU are up by **+582.7%** for the period between Jan - September 2022.
- **THING 3** : **Politicisation** of Climate change
  - Rise of populism and casting doubt on the science behind climate change particularly in MEDCs meant to be at the helm of the cause (e.g. USA abandoning the accord during the MAGA years) can slow down progress

Thank you

DATA SCIENCE

UNIVERSITY OF PADOVA