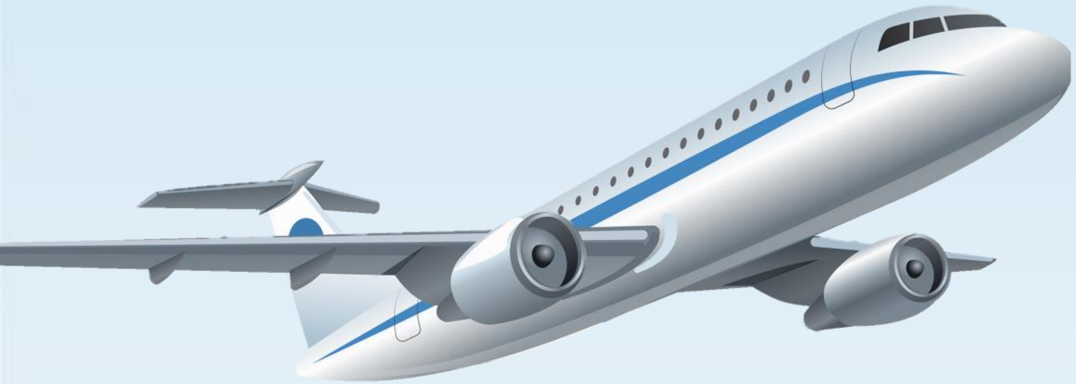

UNIVERSITÀ DEGLI STUDI DI PADOVA
DIPARTIMENTO MATEMATICA

Air traffic through the years

A time-series analysis on three European countries

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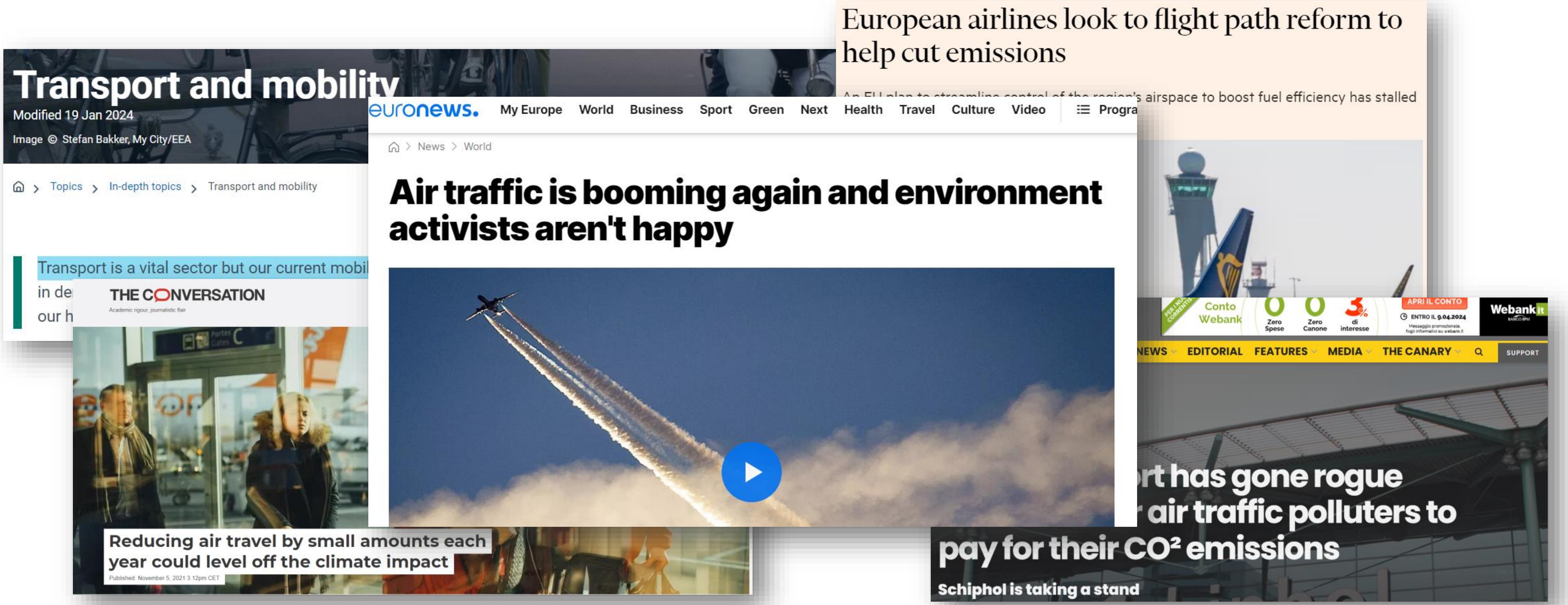
What we will see

- Introduction
- **Evolution of air traffic** throughout the years
- What might **influence** air traffic?
- Statistical modeling
- Discussion

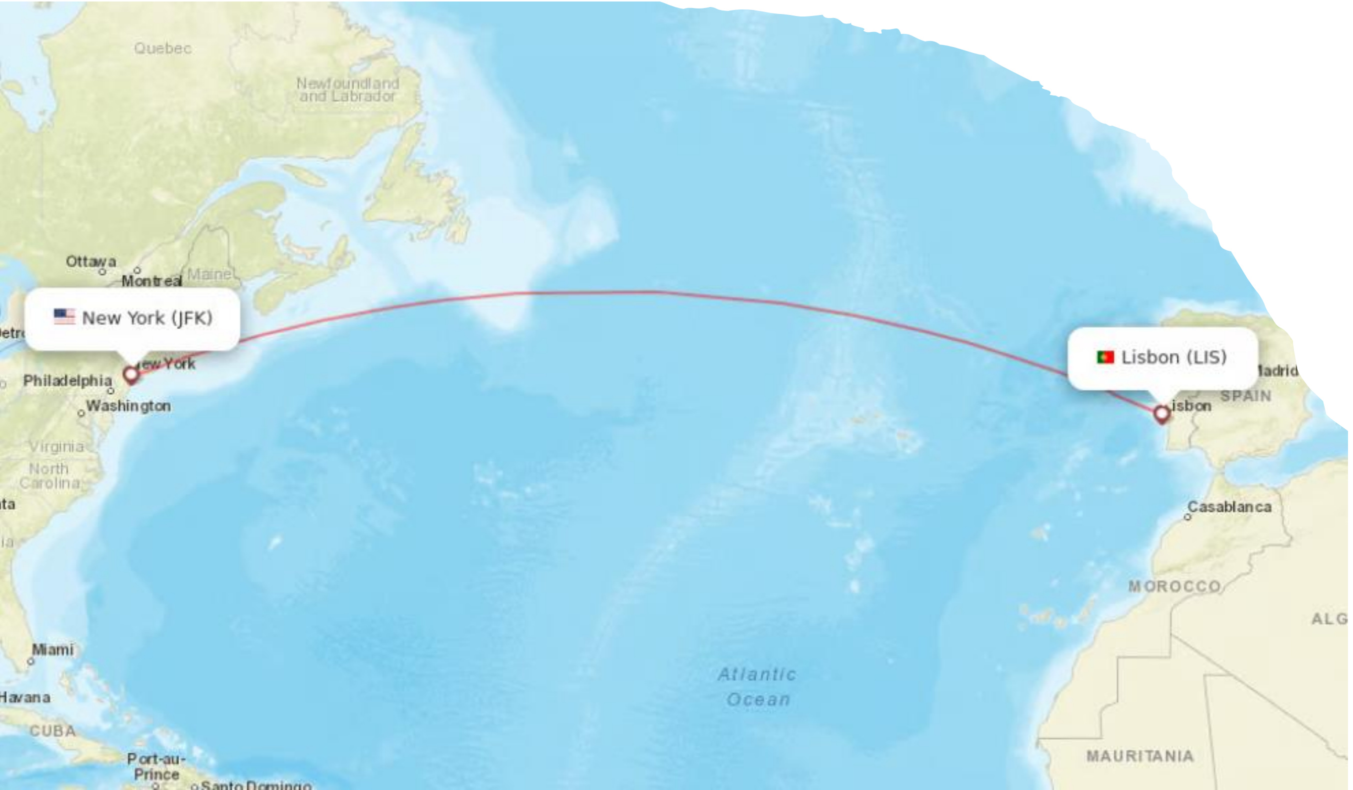
Introduction

As **climate change effects** become more evident, public interest in air traffic has raised.



Introduction

The **aviation sector** creates **13.9% of the emissions** from transport, making it the second biggest source of transport GHG emissions after road transport.



If global aviation were a country, it would rank in the **top 10** emitters.

Someone **flying from Lisbon to New York and back** generates roughly the same level of emissions as the average person in the EU does by **heating their home for a whole year**.

Source: European Commission

Introduction

"To achieve climate neutrality, the European Green Deal sets out the need to reduce transport emissions by 90% by 2050 (compared to 1990-levels). ***The aviation sector will have to contribute to the reduction."***

Source: European Commission

Thus, it is helpful to understand the evolution of air traffic through time.

To restrict the scope of our work, we focus on the **domestic** air traffic of three European countries:

Spain

Italy

Germany

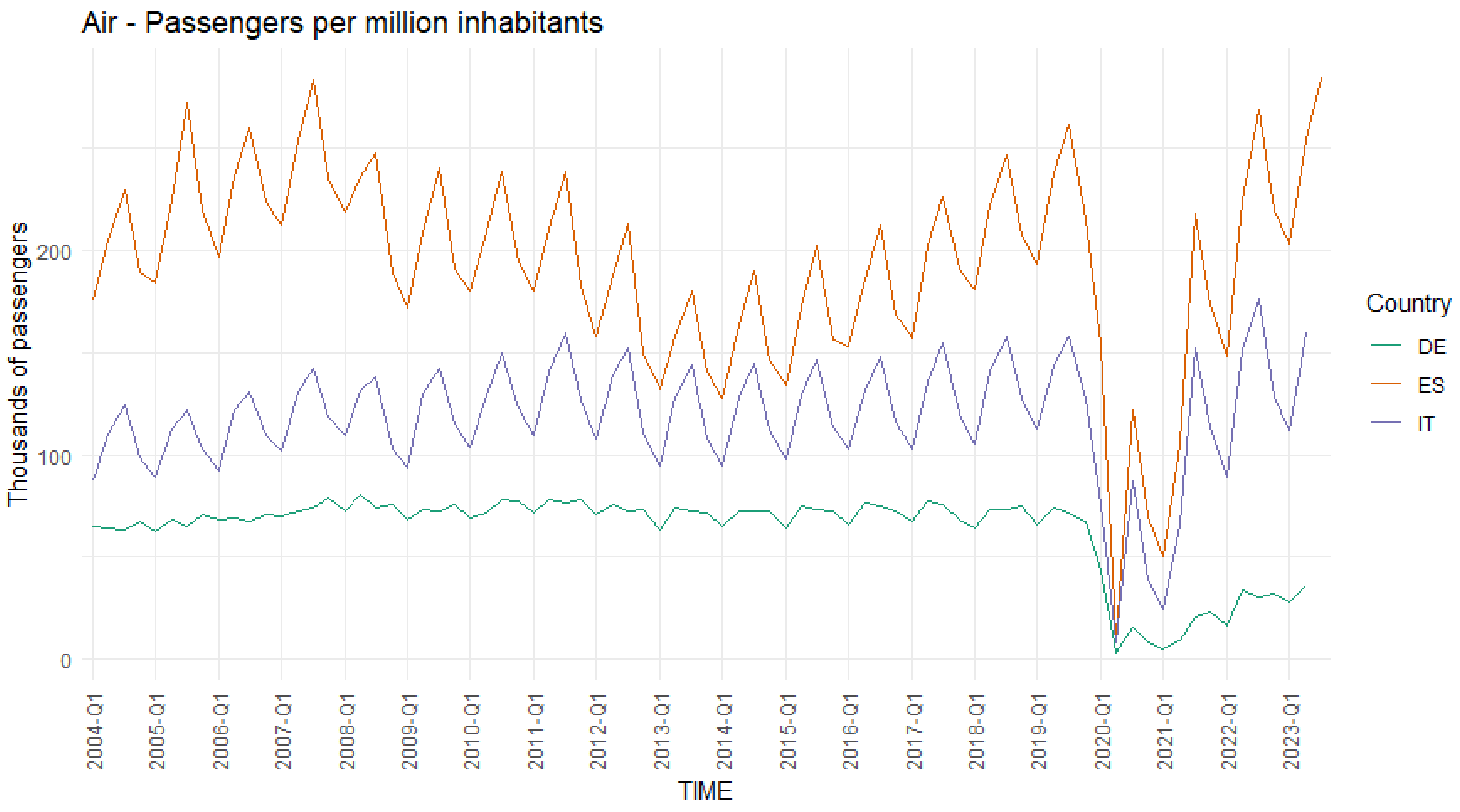
Evolution of air traffic throughout the years

Our data:

- Transportation measurements taken from Eurostat, the Statistical Office of the European Union.
- We used **quarterly data** (to match with our explanatory variables).
- We focus on **internal transportation** only (within the country).
- Complete information from **2002-Q1** to **2023-Q2** for the three countries.
- We focus on passengers carried per million inhabitants* of the country.

* We used the annual demographic data from Eurostat. When doing this project, we did not have information from 2023, so we forecasted it by applying an exponential smoothing method with a damped trend.

Evolution of air traffic throughout the years



What might influence air traffic?

From the publicly available data, we considered several factors that could possibly explain the air traffic for these countries throughout the years:

COVID-19
(restrictions)

Economic activity
(Gross Domestic Product)

Ticket prices

Interaction/competition
(with rail transport)

Tourism

Time dependencies
(trend, seasonality, etc.)

COVID restrictions

- Data from the Oxford COVID-19 Government Response Tracker (OxCGRT).
- We used the record of restrictions on internal movement between cities/regions.
- Ordinal variable with three levels*:

0	No measures
1	**Recommend** not to travel between regions/cities
2	Internal movement **restrictions** in place

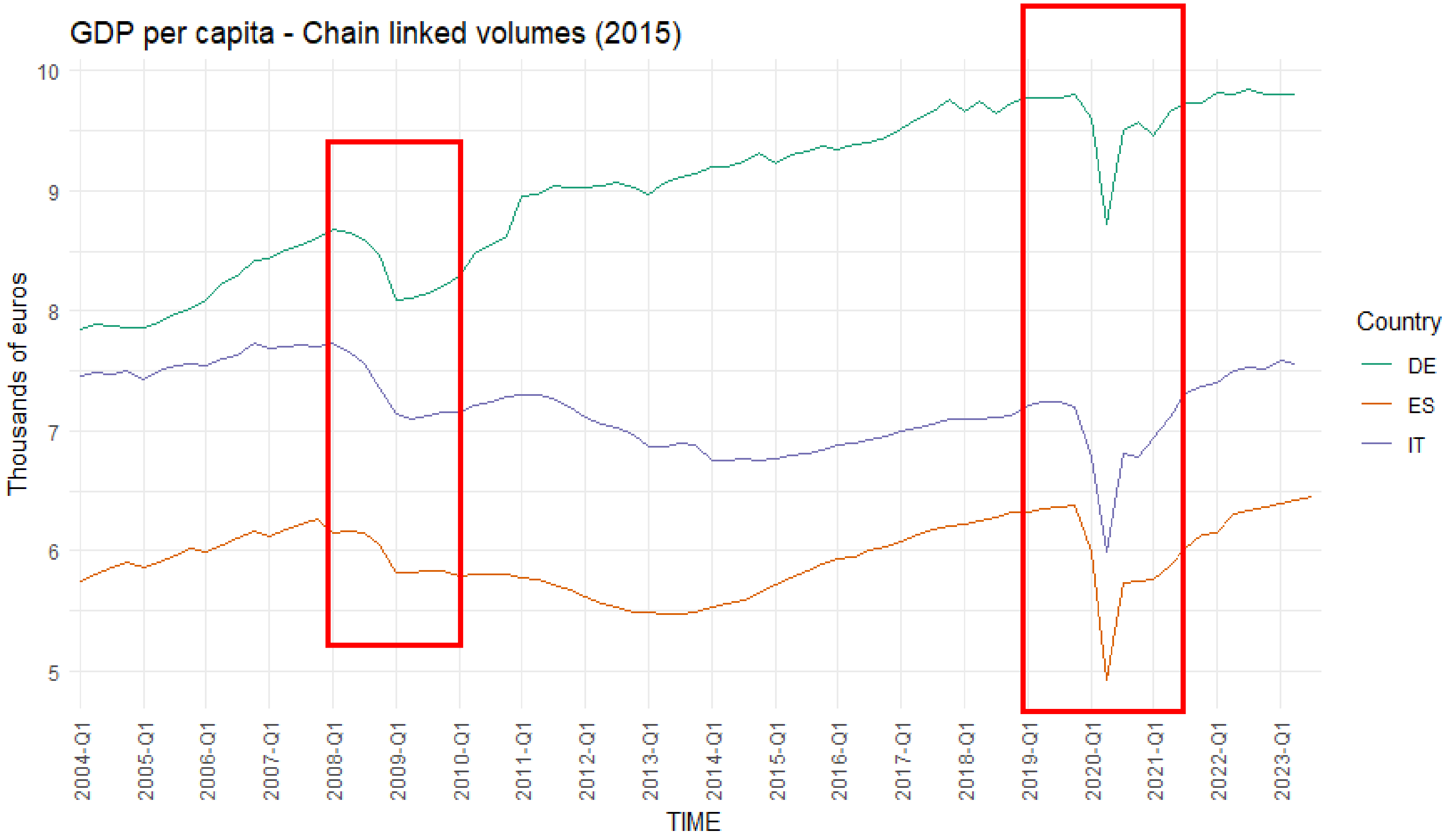
* It was monthly data that we grouped for the quarter and rounded to the closest value to keep it as an ordinal variable.

Economic activity

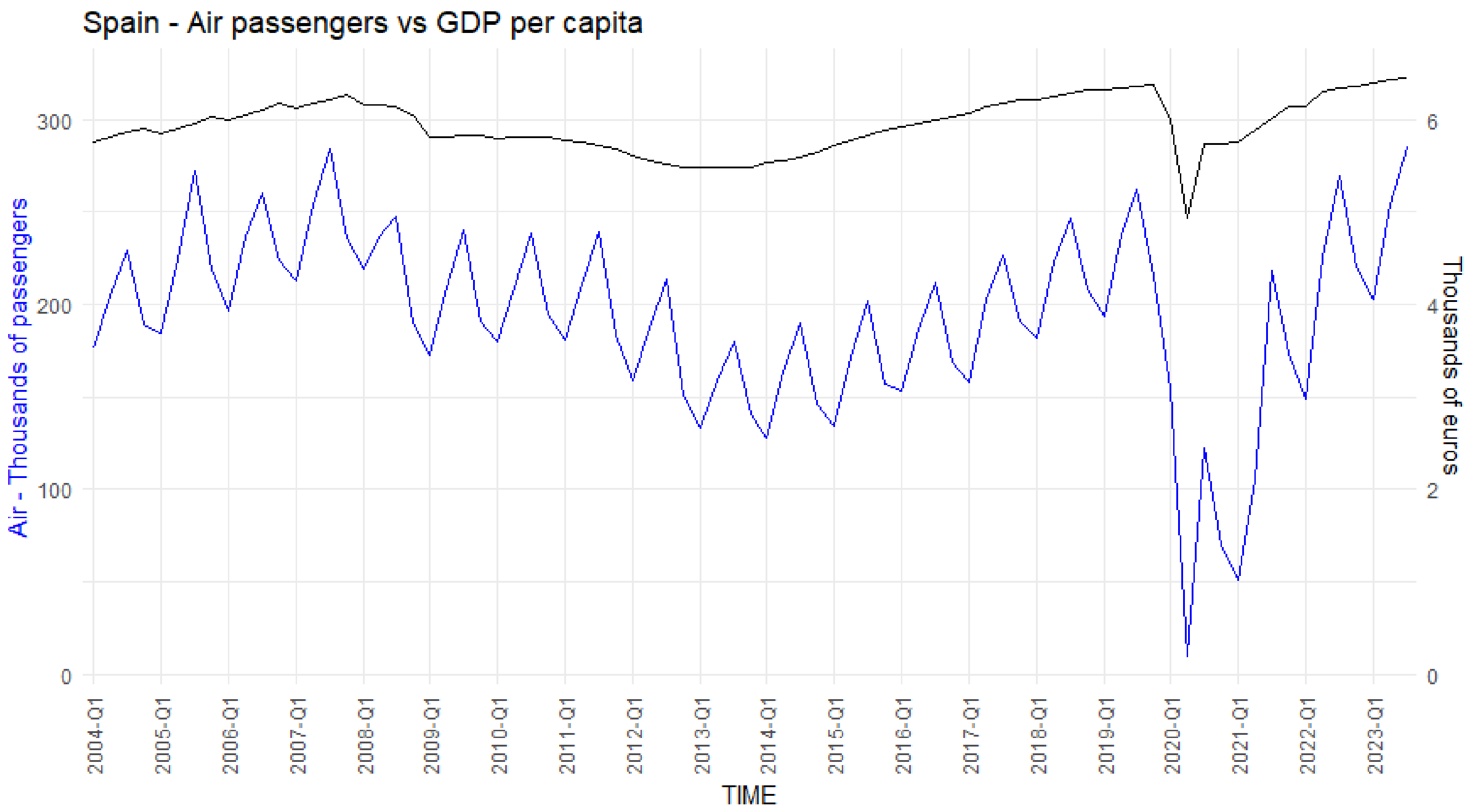
- COVID-19 is not only relevant because of the governments’ policies on movement between regions.
- People were consuming less and earning less money during this time. The world was stalled for a while.
- We think people are less likely to fly under this conditions.
- In fact, extending this reasoning, economic activity (not only in presence of COVID) could be a factor to explain the willingness to travel.
- Gross Domestic Product (per capita) can capture these fluctuations in economic activity.

Economic activity

- GDP data from Eurostat at market prices.
- Was already adjusted for inflation with 2015 as reference.
- Already included calendar and seasonal adjustments (more on this later).
- We used the GDP per capita to control for the population.

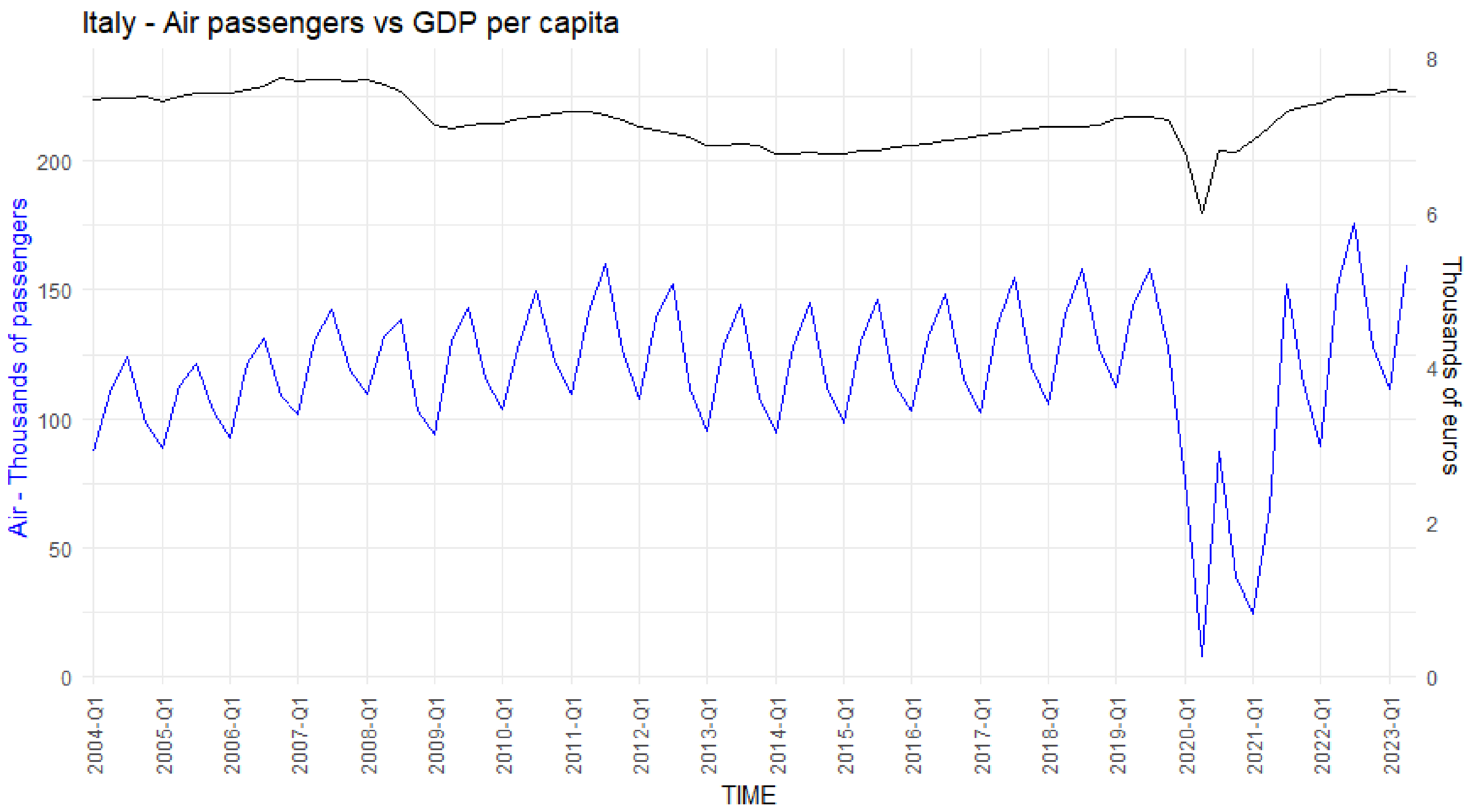


GDP per capita - Spain



* For all the plots that compare two series, we tweaked the scale of the axes to facilitate the visualization of the series' shape.

GDP per capita - Italy



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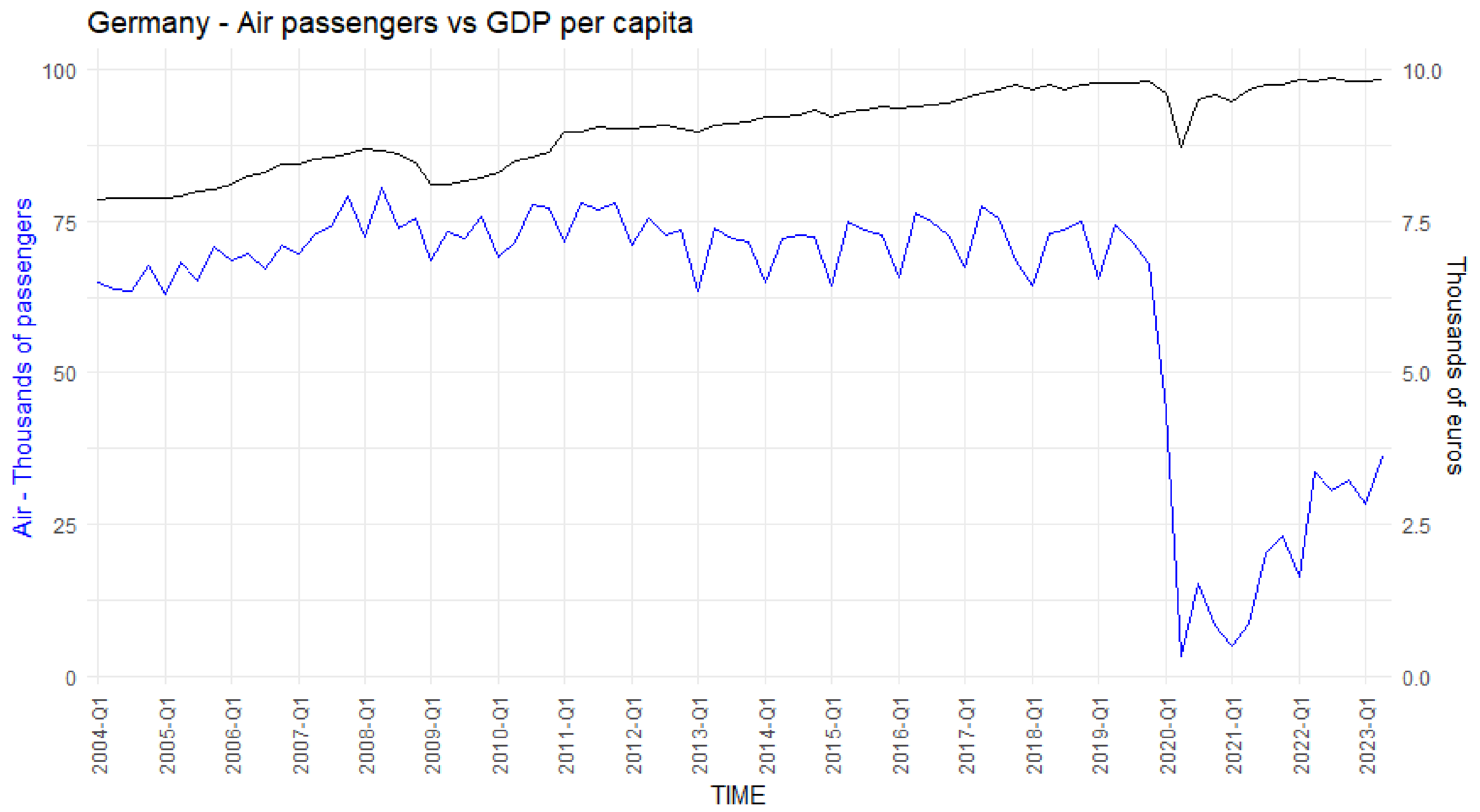
GDP per capita - Germany



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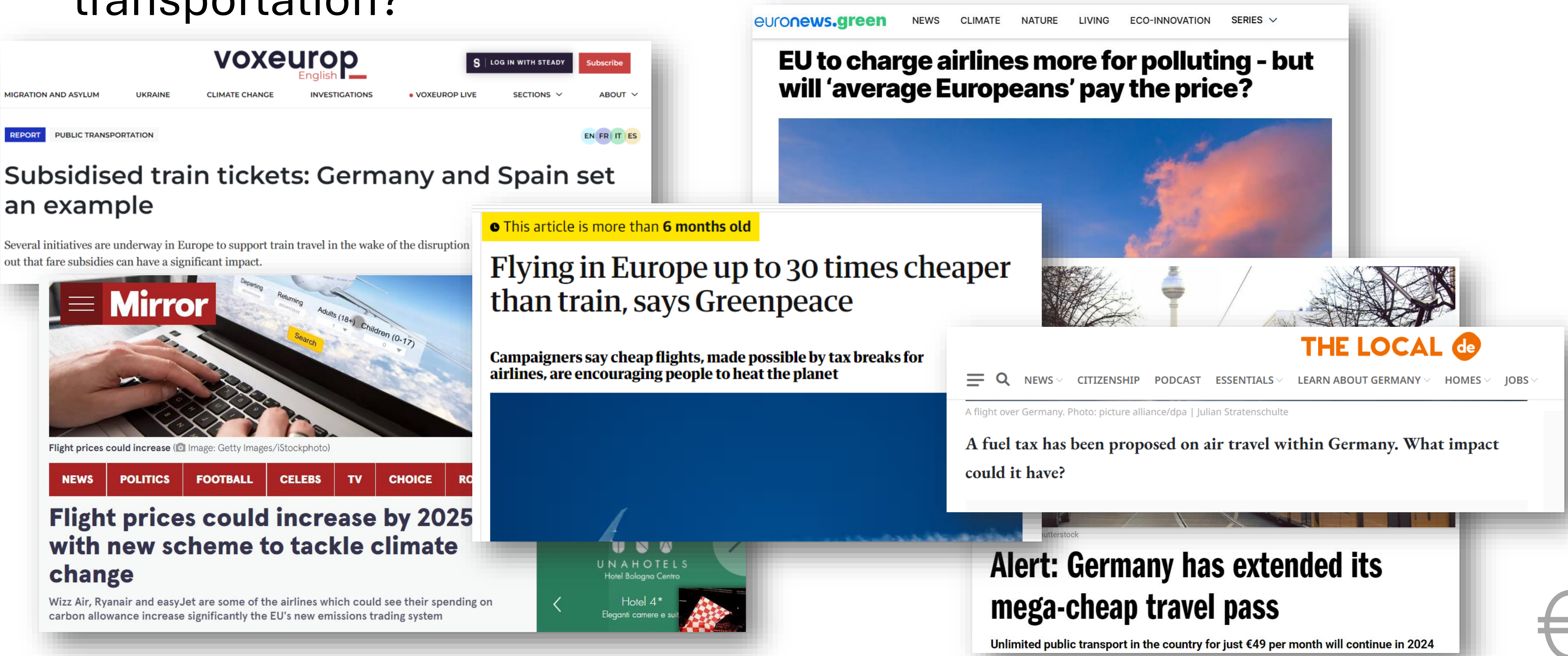
Prices

- How do people react with respect to the price of their mode of transportation?

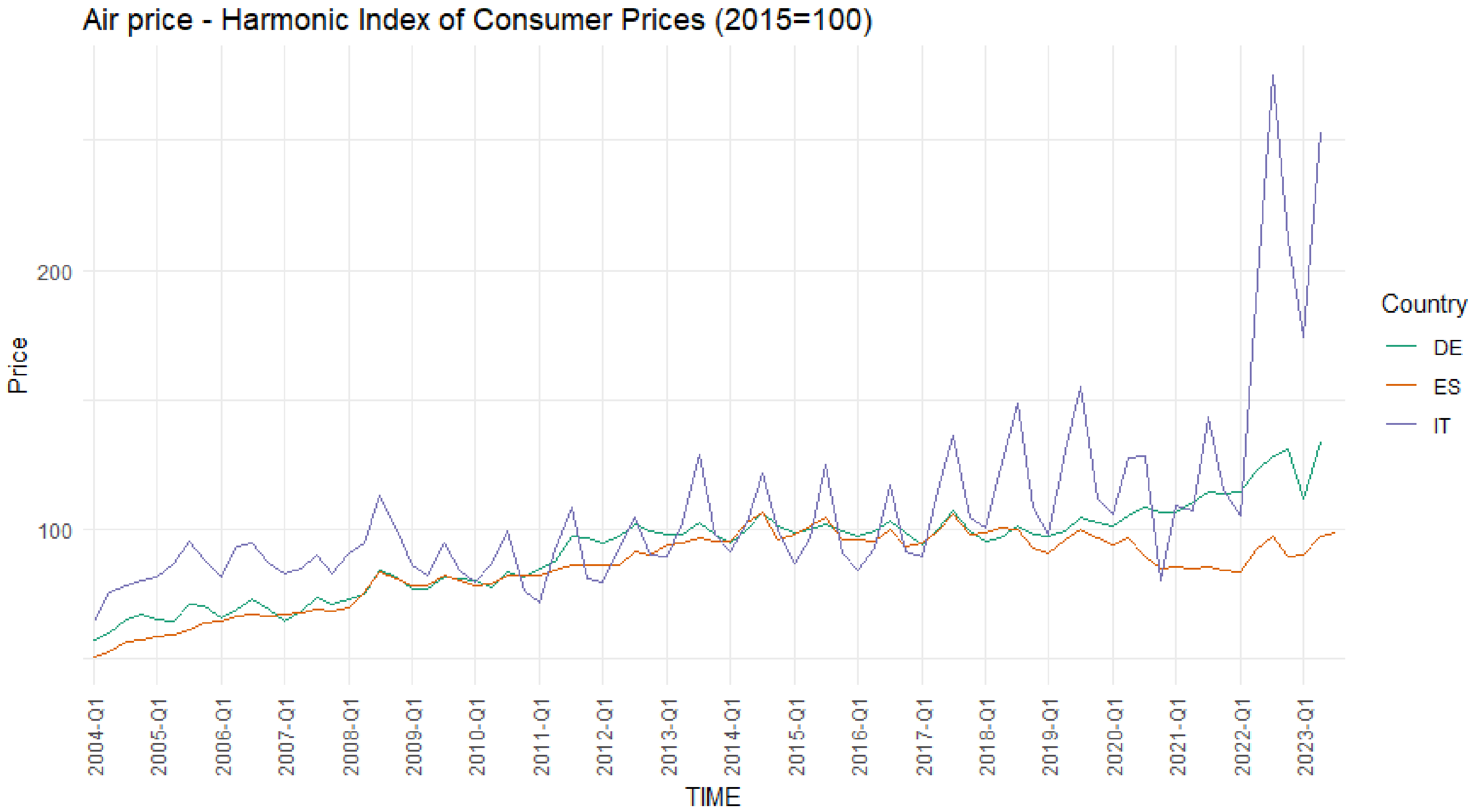


Prices

- Harmonised index of consumer prices (HICP) from Eurostat.
- HICP measures **consumer price inflation**, harmonized to compare between countries.
- We took the prices for:
  - Passenger transport by air*
  - Passenger transport by railway
- Monthly data, grouped as the average per quarter.
- Unit of measure: Index, 2015=100

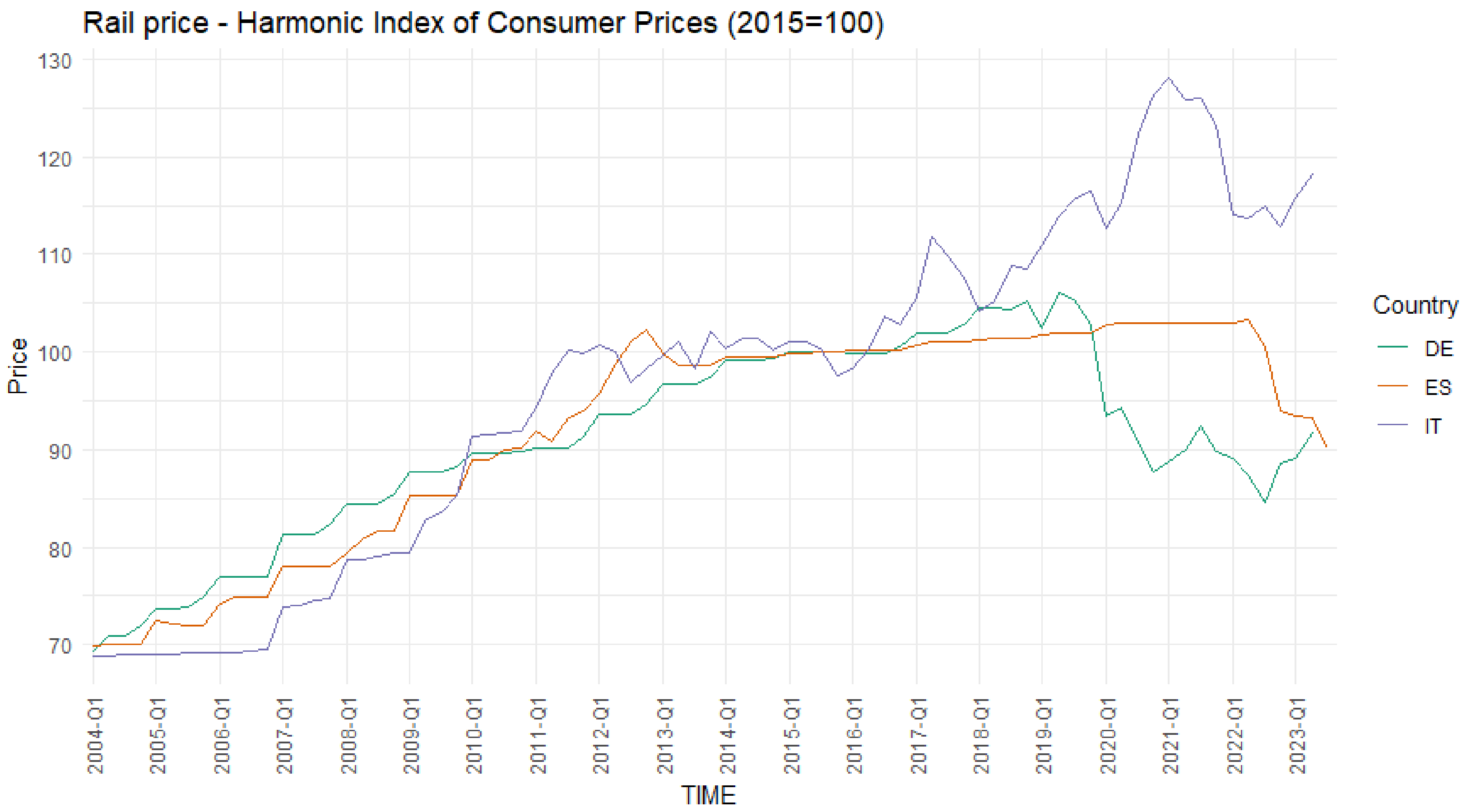
* There is also a measurement of domestic flights prices. Unfortunately, it is too recent and there are many missing values.

Air prices



Air price - Harmonic Index of Consumer Prices (2015=100)
Price
200
100
2004-Q1
2005-Q1
2006-Q1
2007-Q1
2008-Q1
2009-Q1
2010-Q1
2011-Q1
2012-Q1
2013-Q1
2014-Q1
2015-Q1
2016-Q1
2017-Q1
2018-Q1
2019-Q1
2020-Q1
2021-Q1
2022-Q1
2023-Q1
TIME
Country
DE
ES
IT

Rail prices


Rail price - Harmonic Index of Consumer Prices (2015=100)
130
120
110
100
90
80
70
Price
2004-Q1
2005-Q1
2006-Q1
2007-Q1
2008-Q1
2009-Q1
2010-Q1
2011-Q1
2012-Q1
2013-Q1
2014-Q1
2015-Q1
2016-Q1
2017-Q1
2018-Q1
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2020-Q1
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TIME
Country
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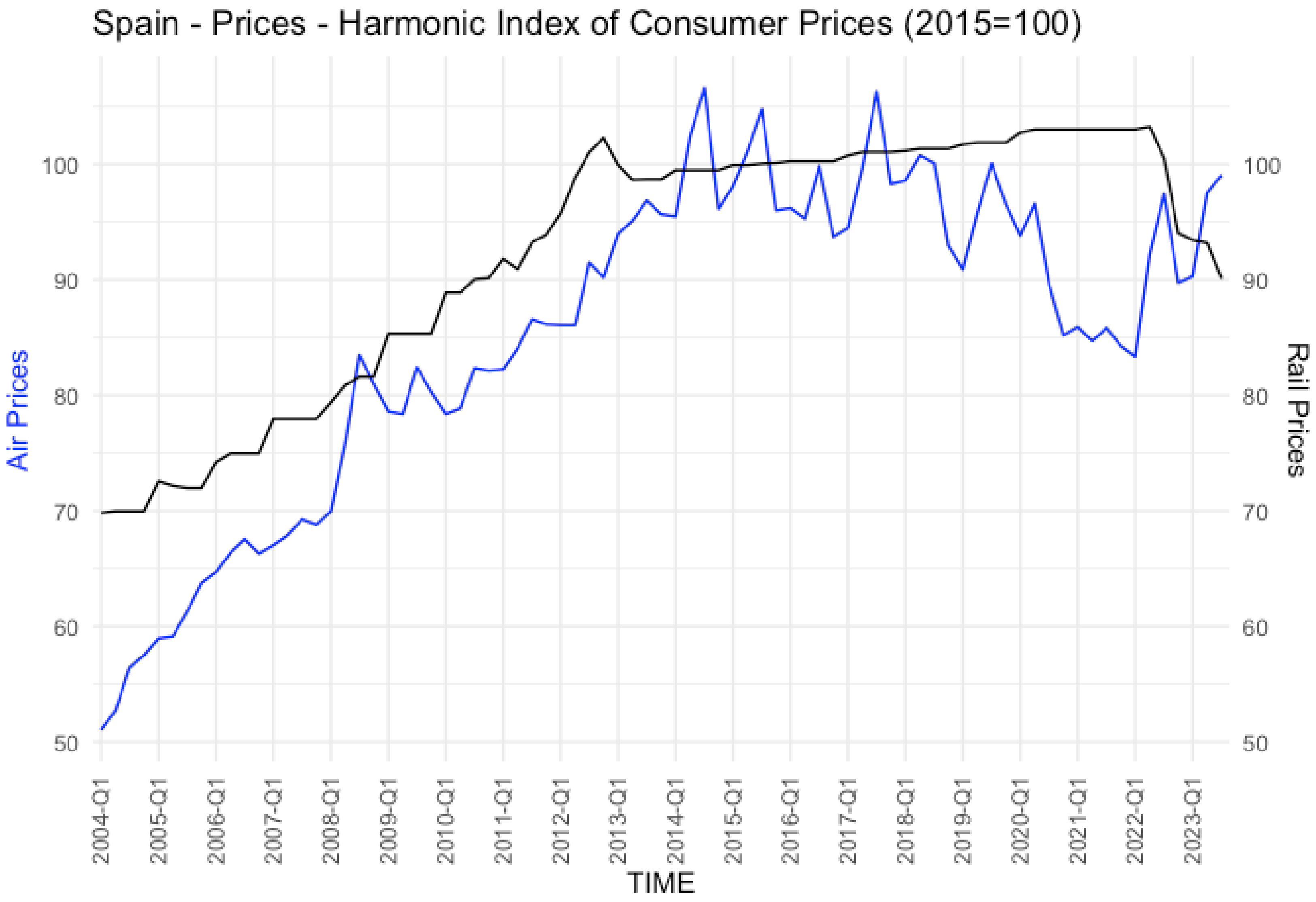
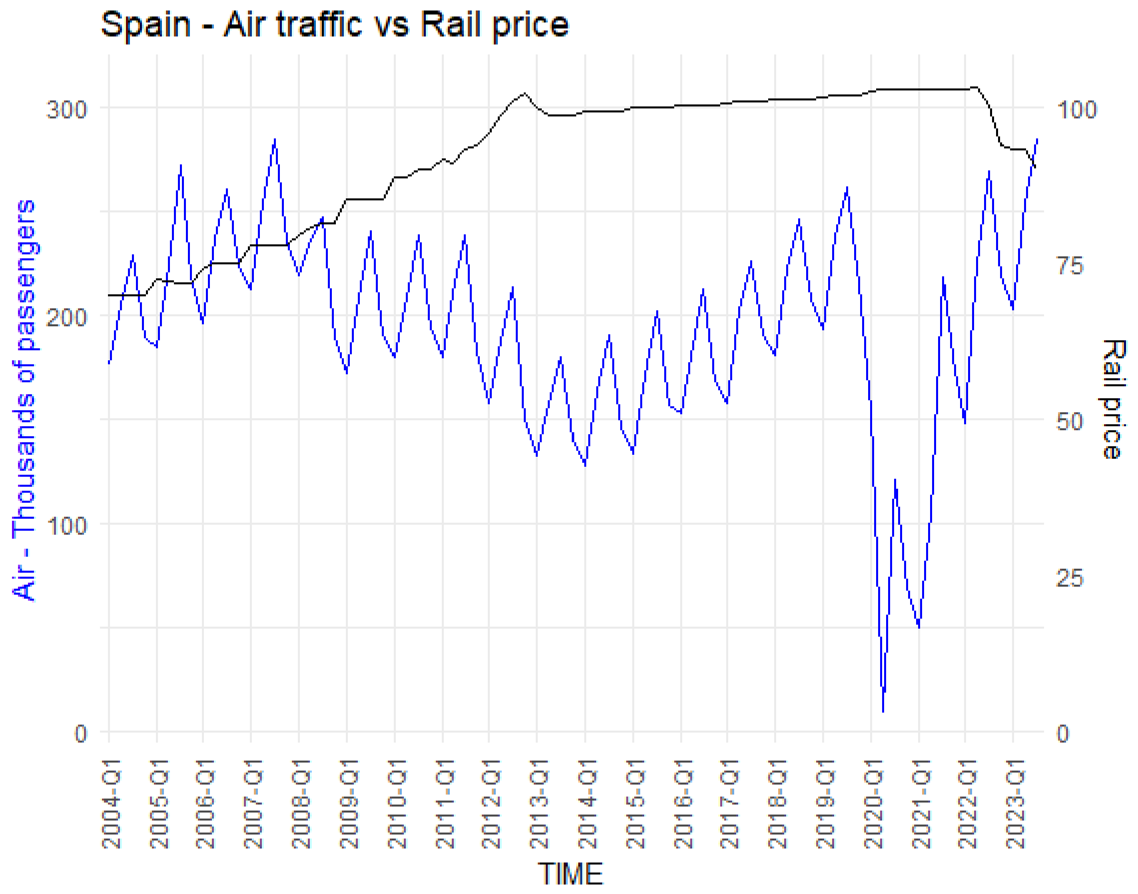
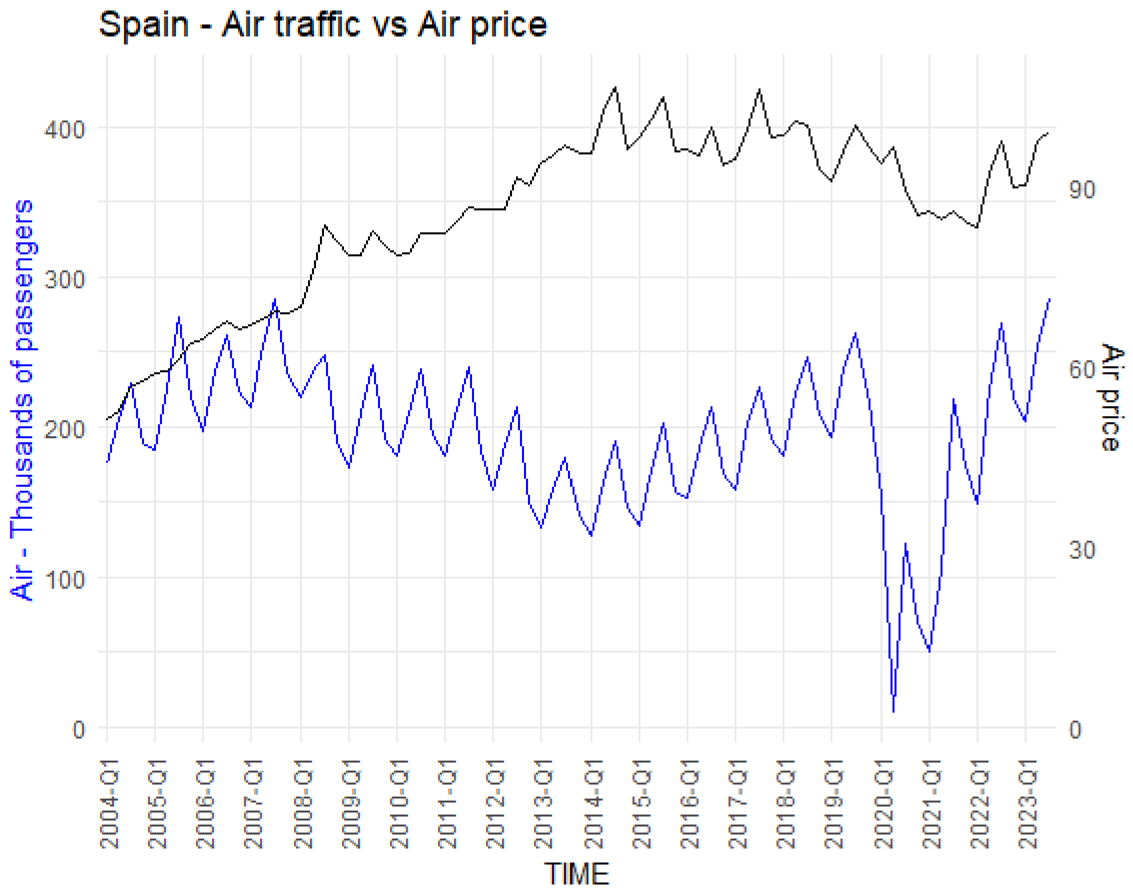
Transportation prices – Spain



Air traffic vs Ticket prices – Spain

- Not a clear pattern with respect to prices.



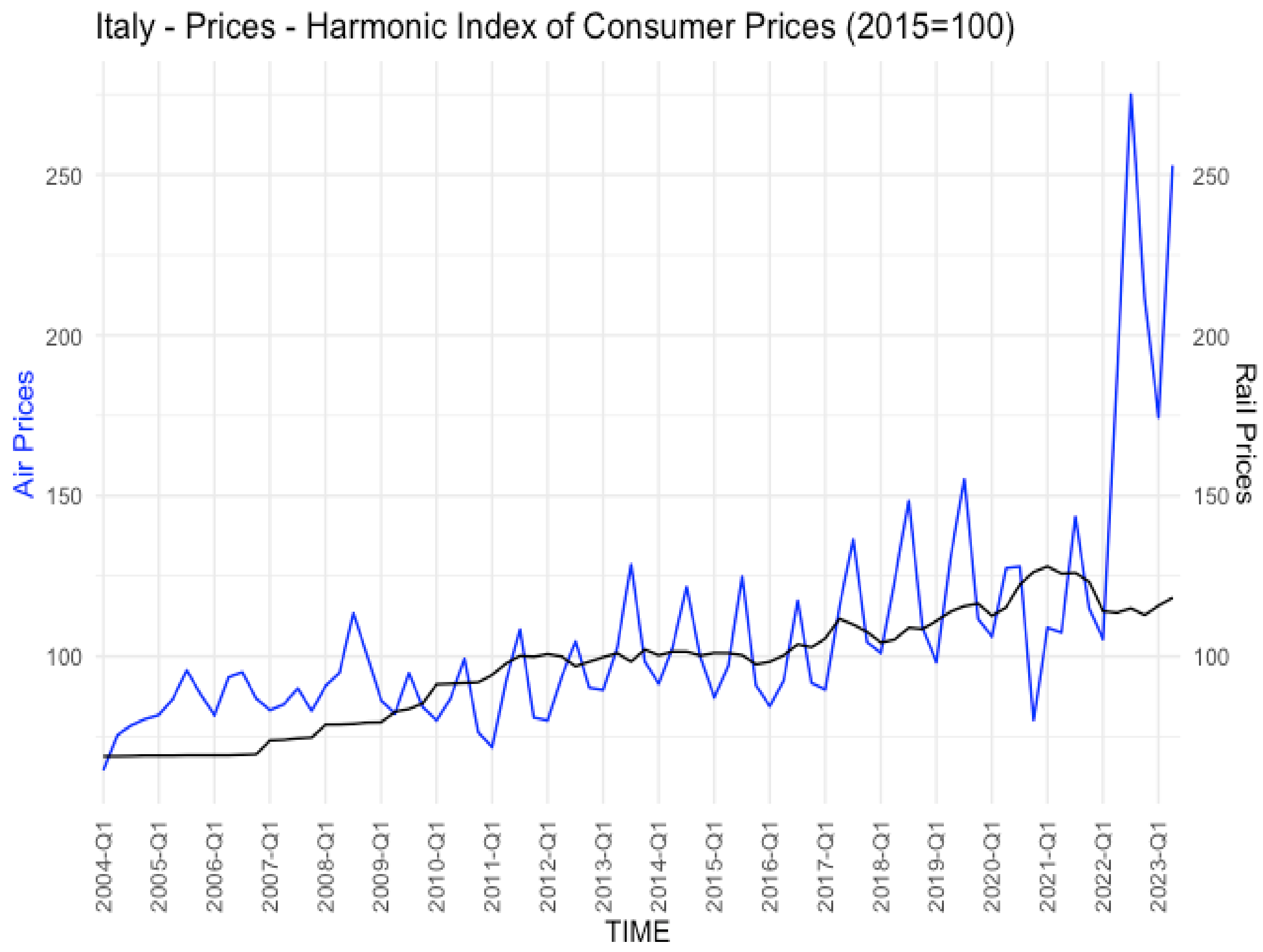


Transportation prices – Italy

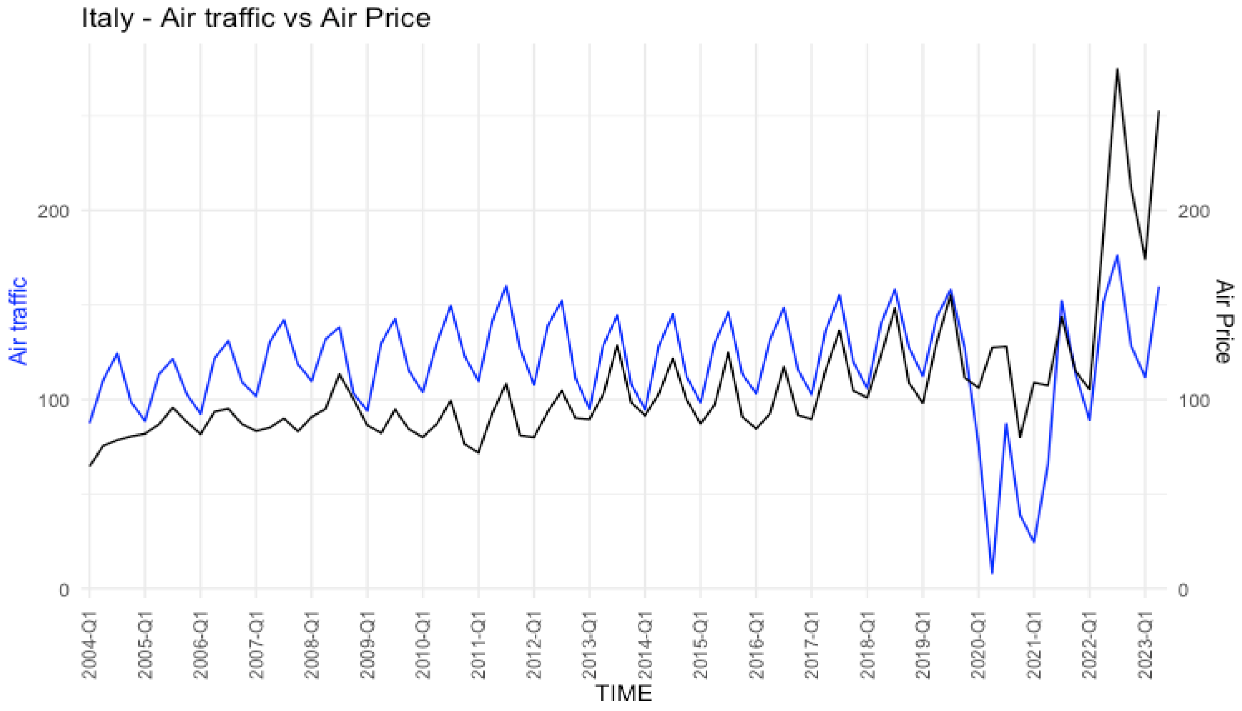
Flight prices from Sardinia and Sicily to Rome were as much as **830 per cent** above average. (Corriere.it)

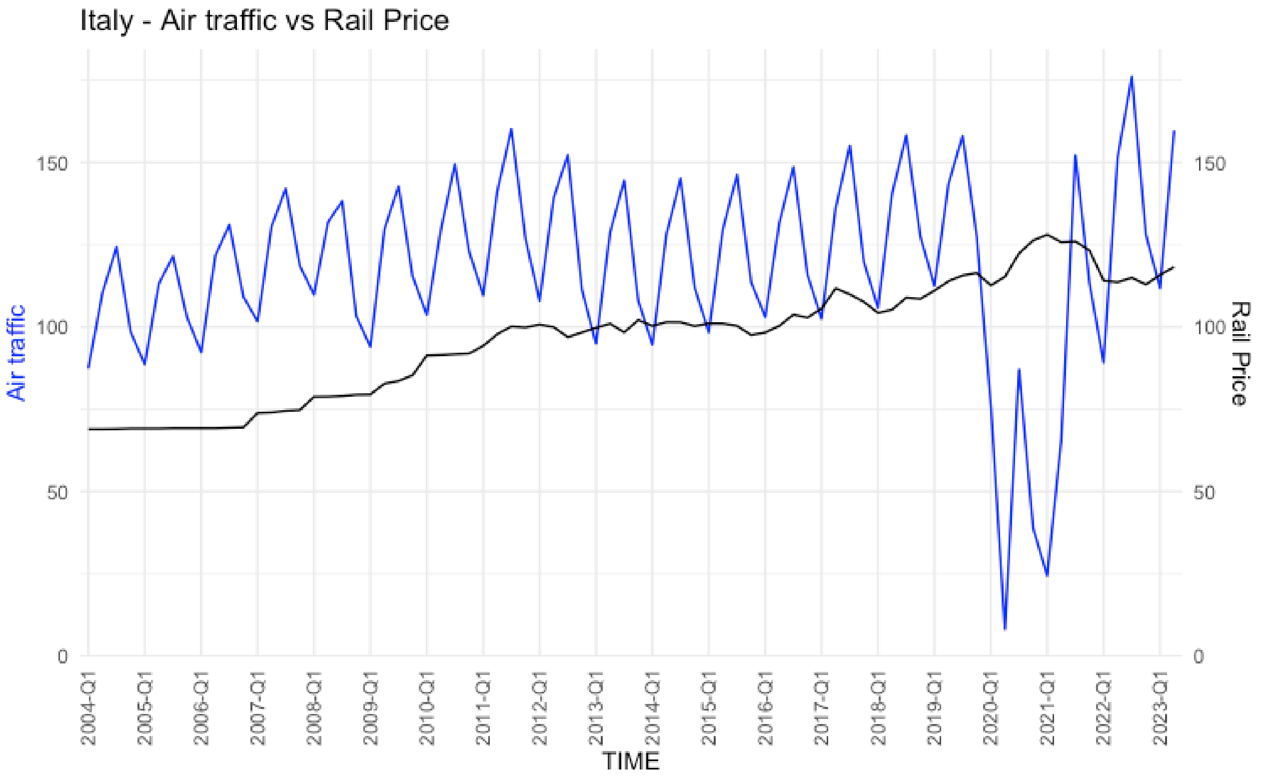
- **Pent-up demand** after COVID crisis
- Inflated **fuel prices**
- **Airlines algorithms** (customer data, dates of booking and travel, competitor's fares, etc.)
- **Scarcity of connections** between mainland and islands

In 2013, Italian government attempts to put a cap on internal flight prices, but quickly retreats.

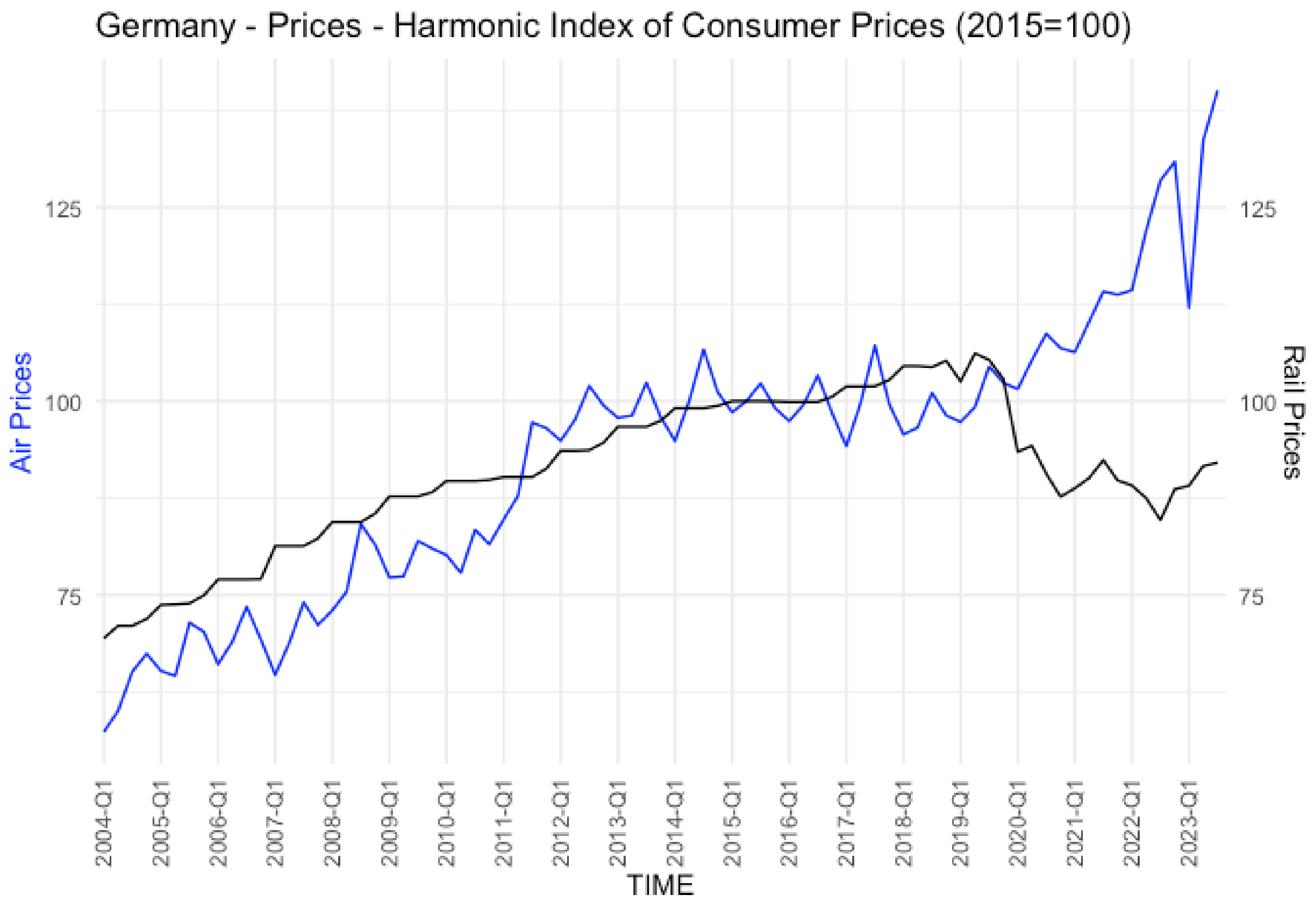


Air traffic vs Ticket prices - Italy

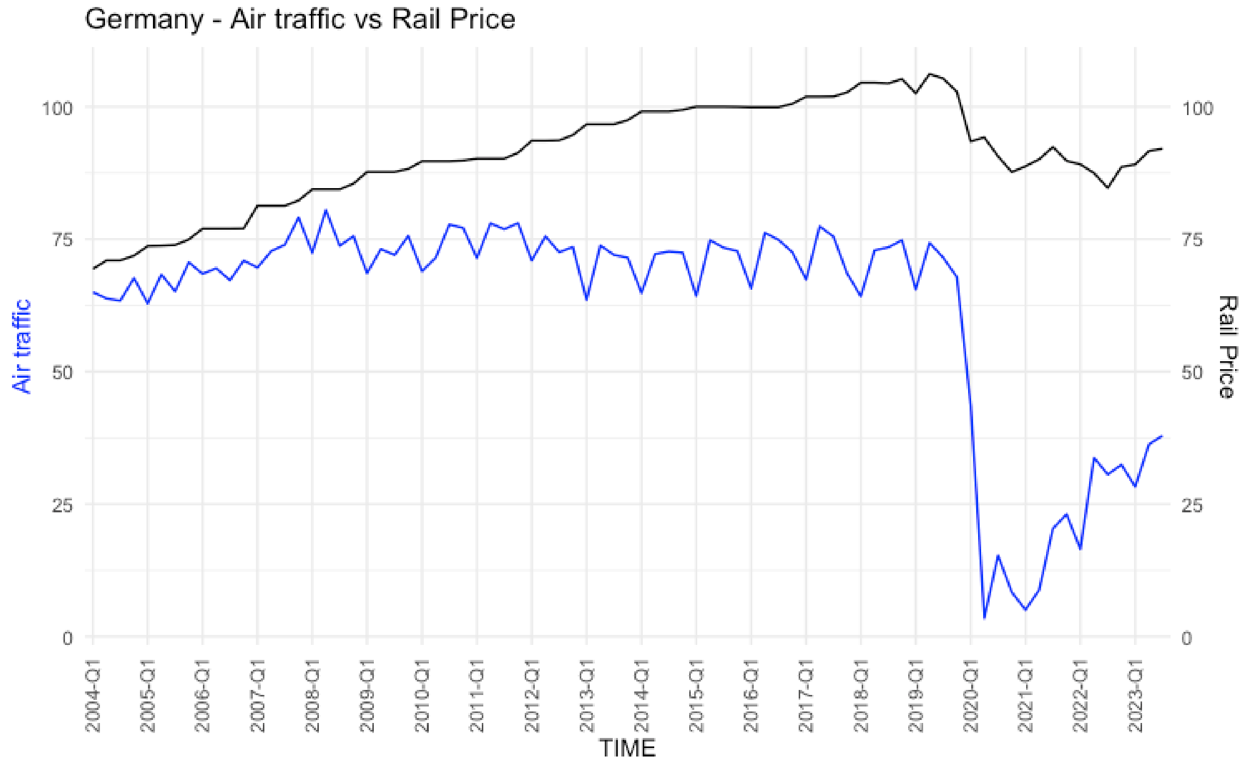


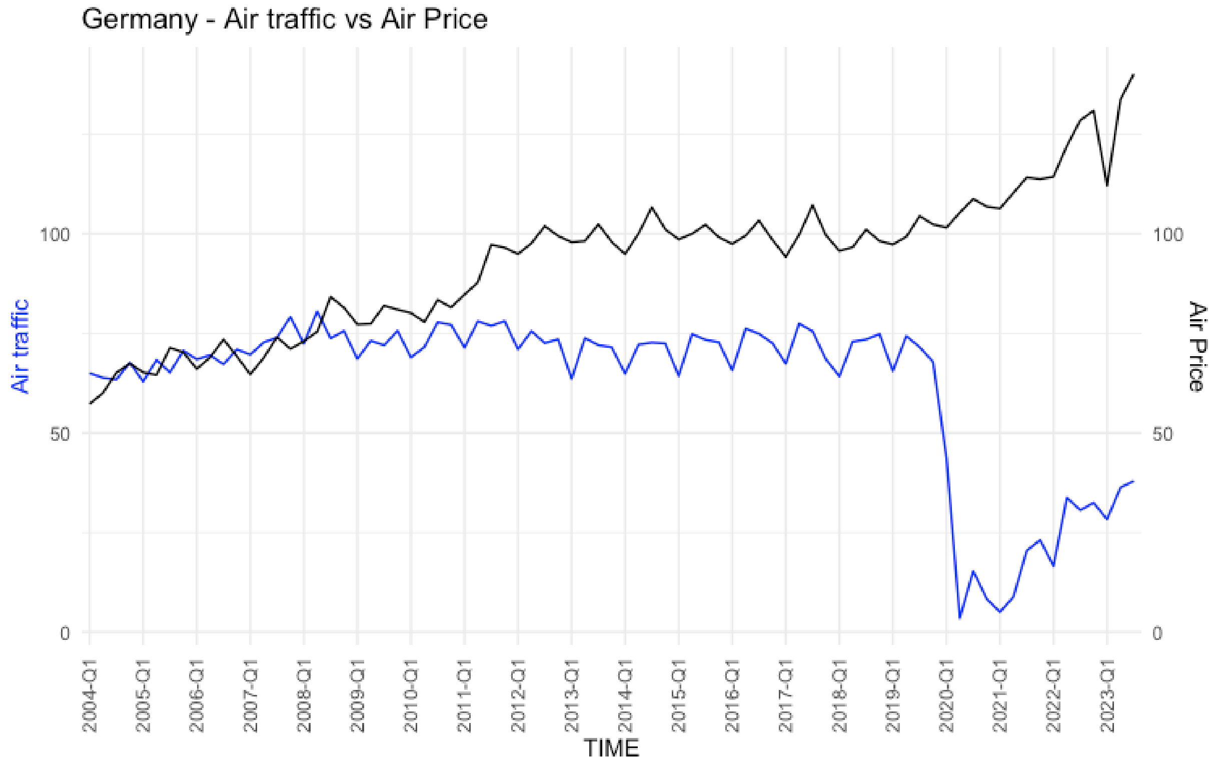


Transportation prices - Germany



Air traffic vs Ticket prices - Germany





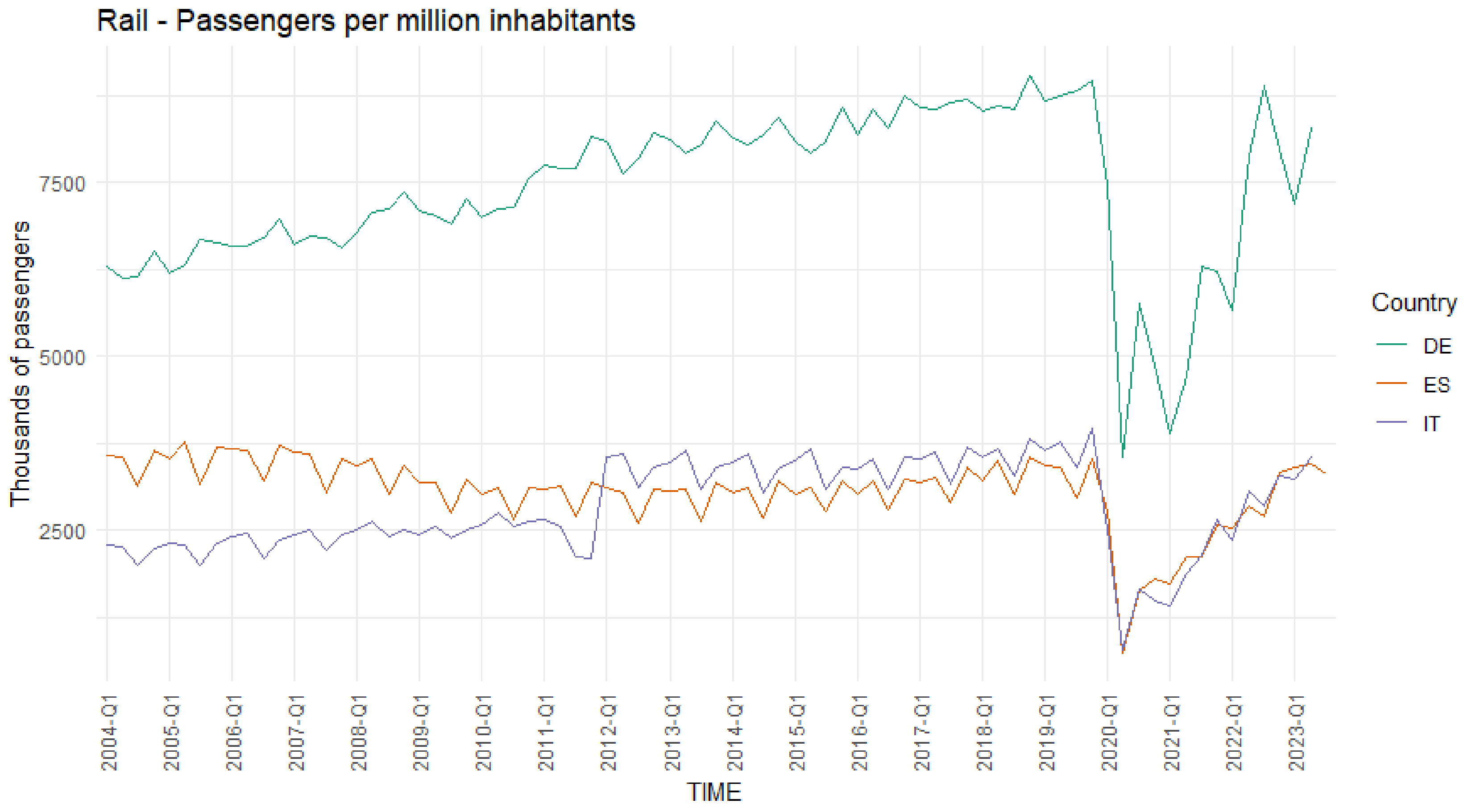
Interaction/competition with rail transport

- Again, we used rail transport measurements from Eurostat.
- Only **quarterly** data available*.
- Complete information from **2004-Q1** to **2023-Q2** for the three countries
- We considered two variables:
    1. Thousands of passengers carried
    2. Millions of passenger-kilometers (pkm)**
- We also **normalized** the variables per million inhabitants of the country.

* This is why we used the quarterly data for the air traffic time-series.
** A passenger-kilometre (pkm) represents the transport of one passenger over one kilometer. It is obtained by multiplying the two measurements.

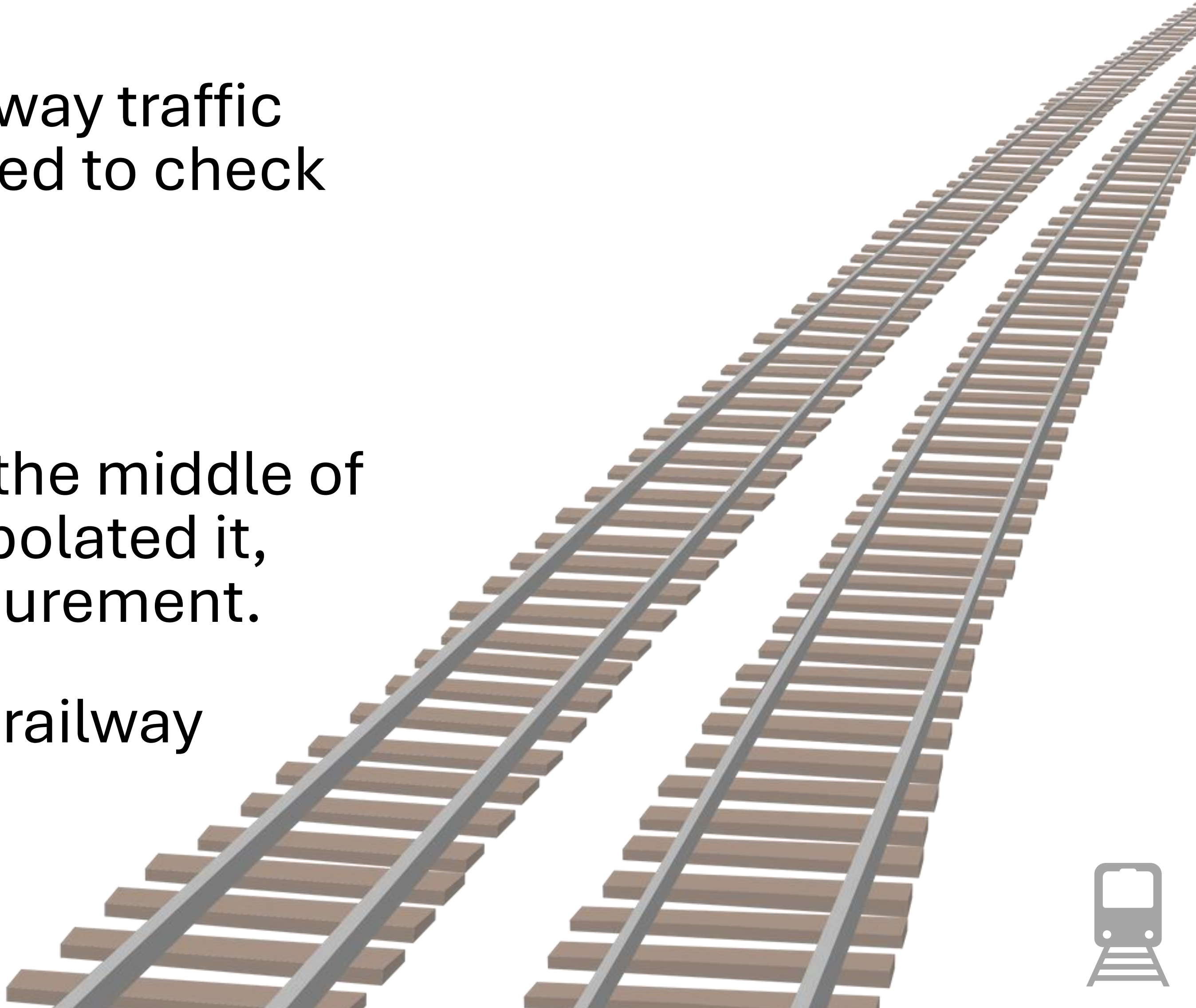
Railway traffic

Contrary to what we saw with the air traffic, Germany has a much higher volume of passengers in comparison to Spain and Italy.

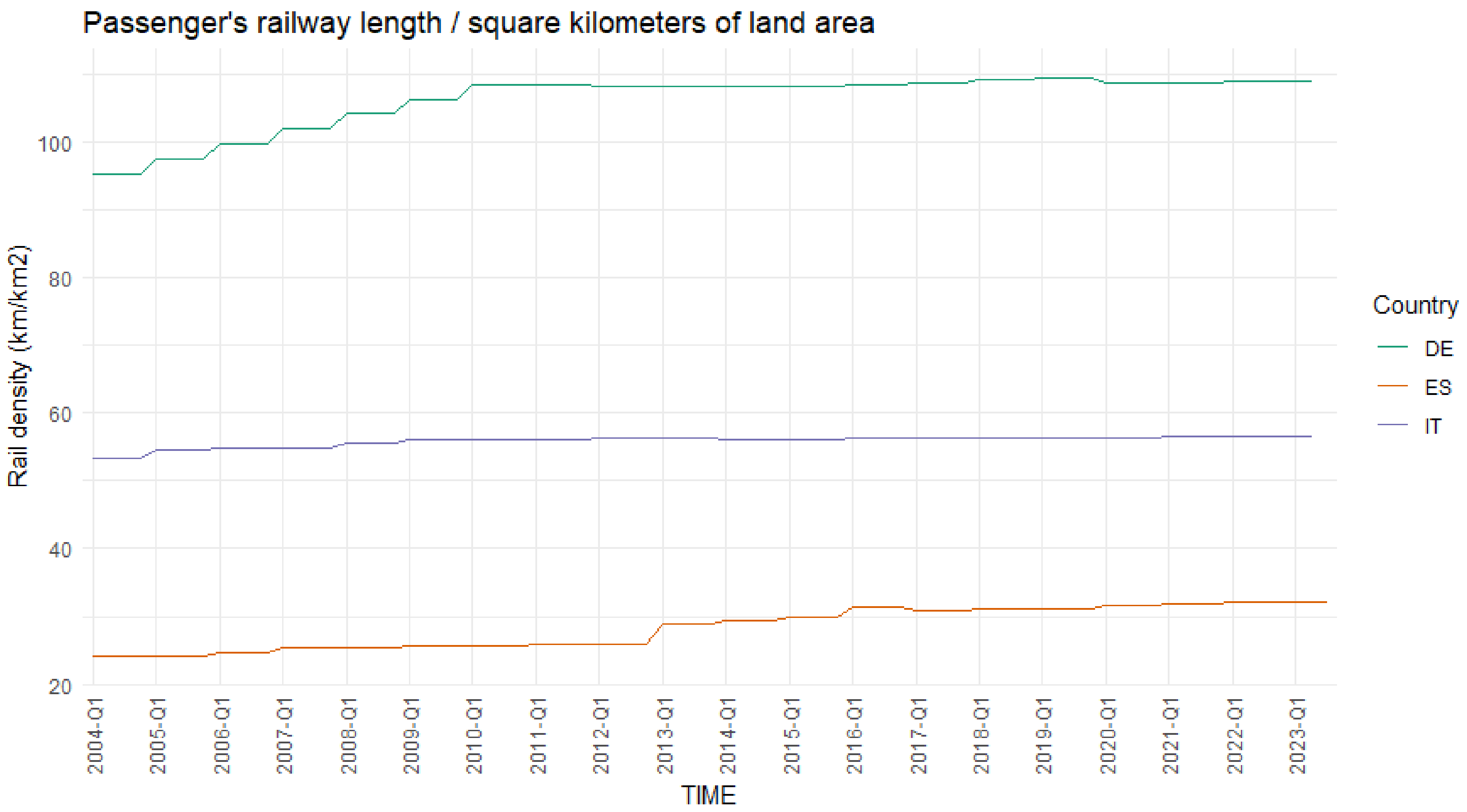


Railway density

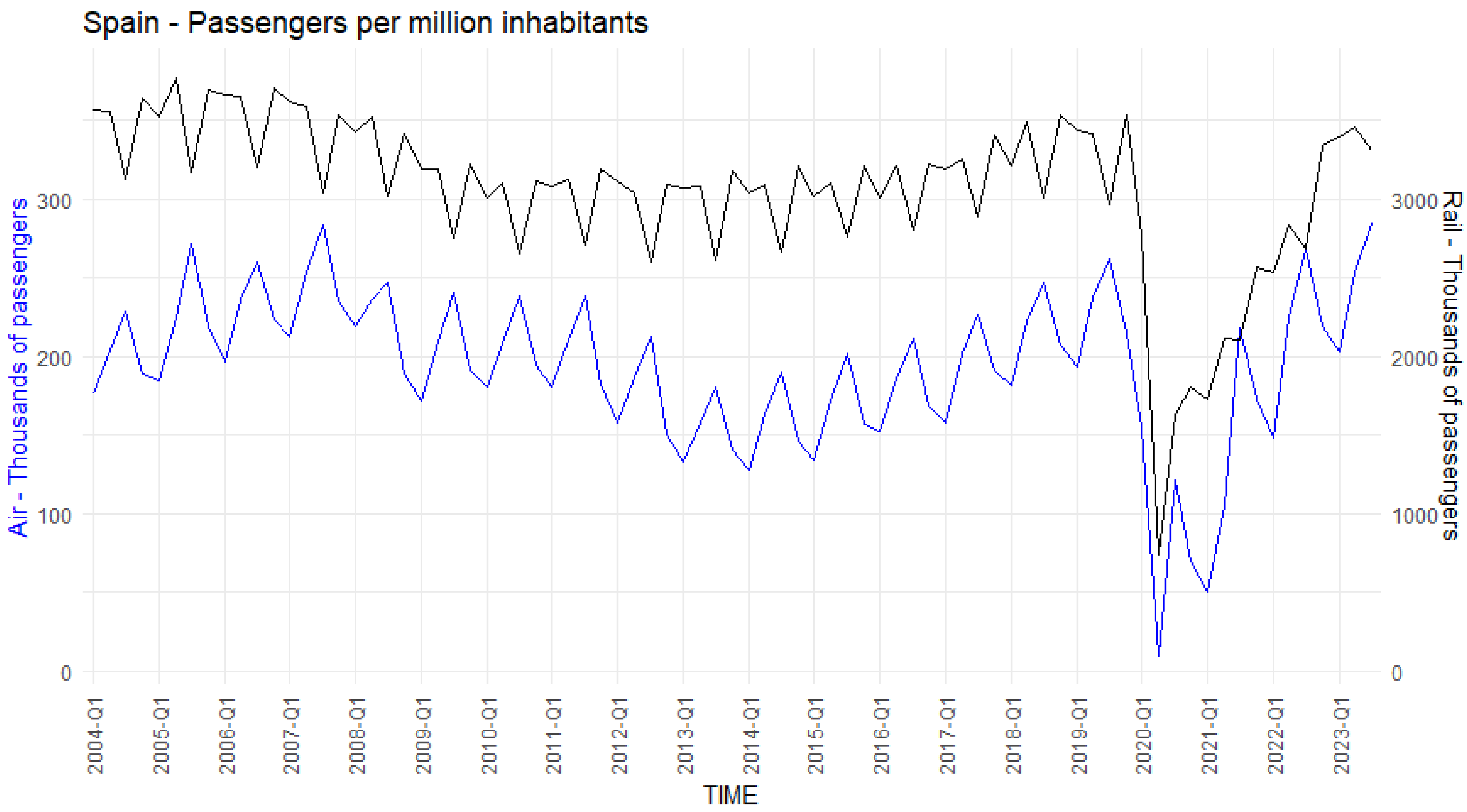
- Given the difference of the railway traffic among the countries, we wanted to check the rail densities.
- Also data from Eurostat.
- It had some missing values in the middle of the series, so we linearly interpolated it, since it is a rather stable measurement.
- It is computed as passenger's railway length / land area



Railway density



Railway traffic - Spain



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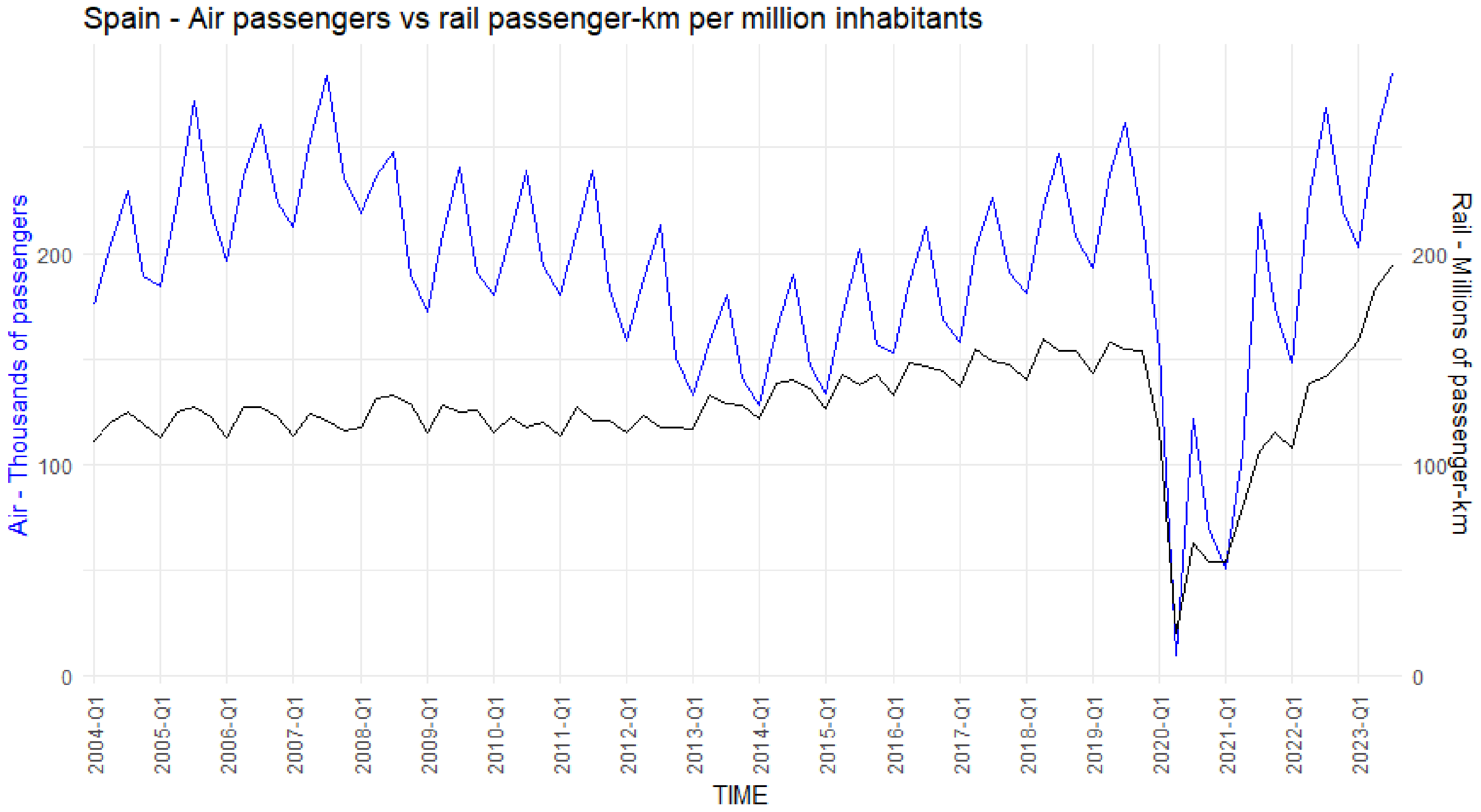
Railway traffic - Spain



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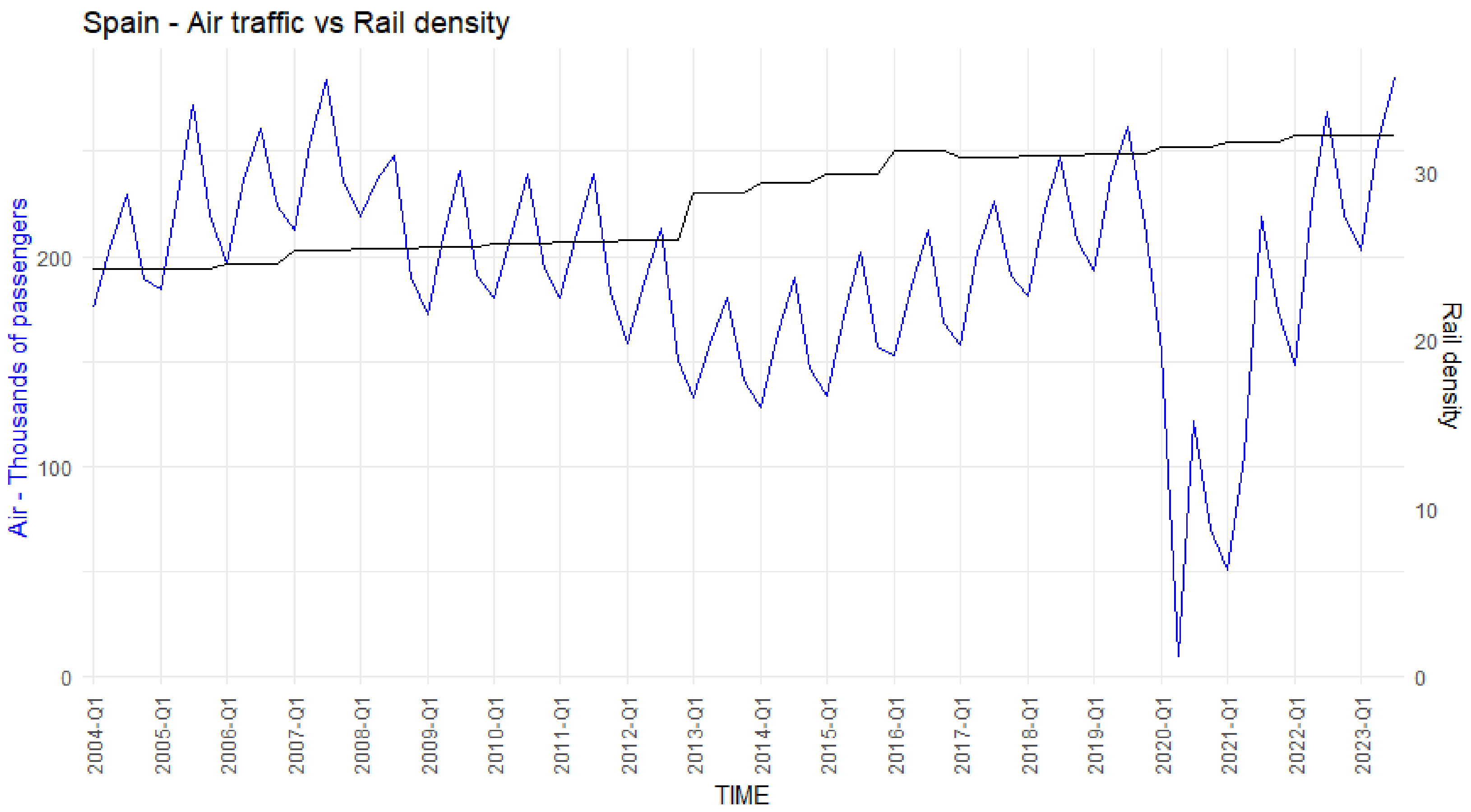
Rail density - Spain



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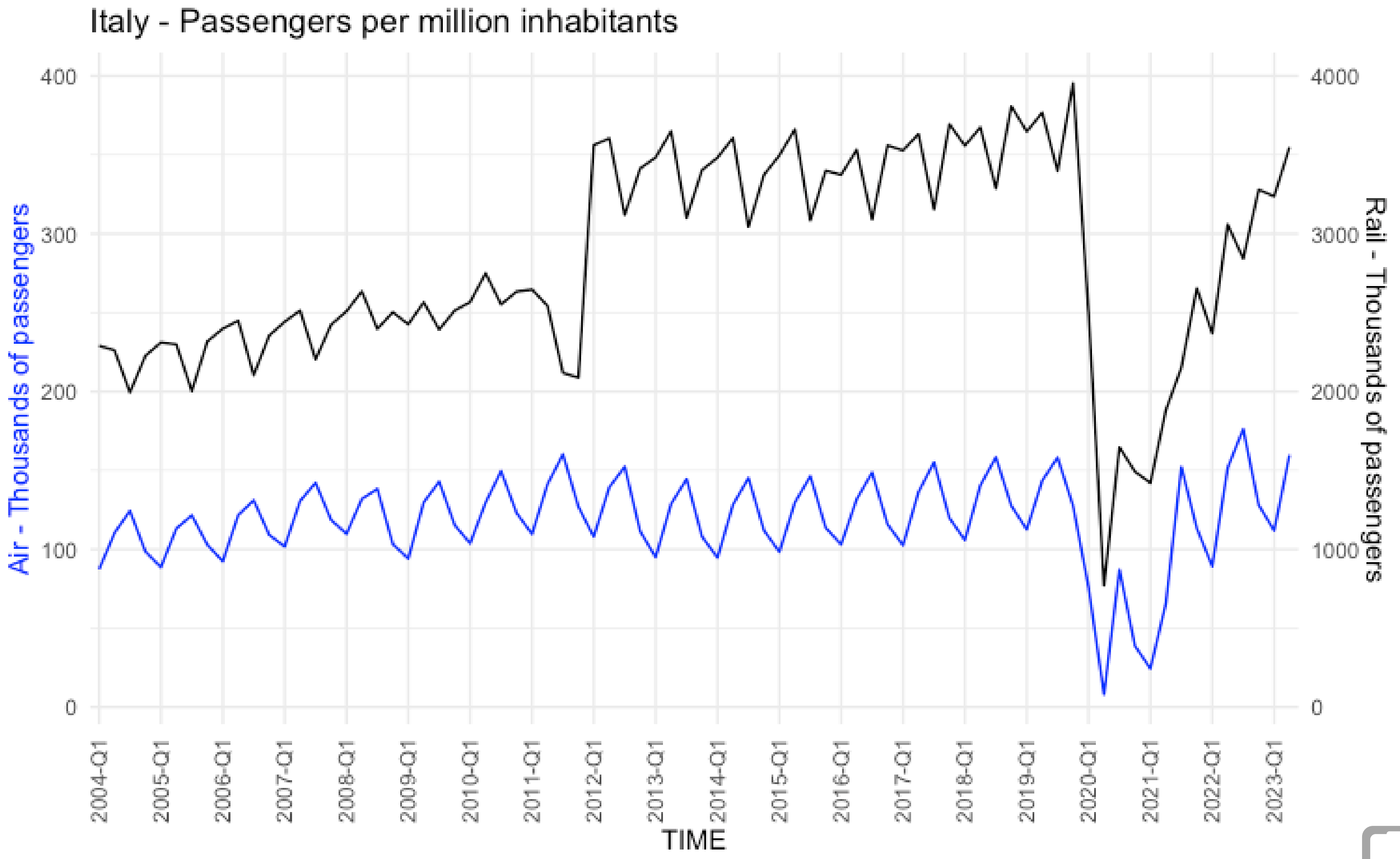
Railway traffic - Italy

Nov 2011: Prime Minister Monti - reform programme and austerity measures to adress **Italy's debt crisis**.

Nov 2011: Trenitalia Frecciarossa introduces trains with four levels of service, together with a reduction of prices

Apr 2012: Italo begins operations with the new high-speed trains.



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Railway traffic - Italy

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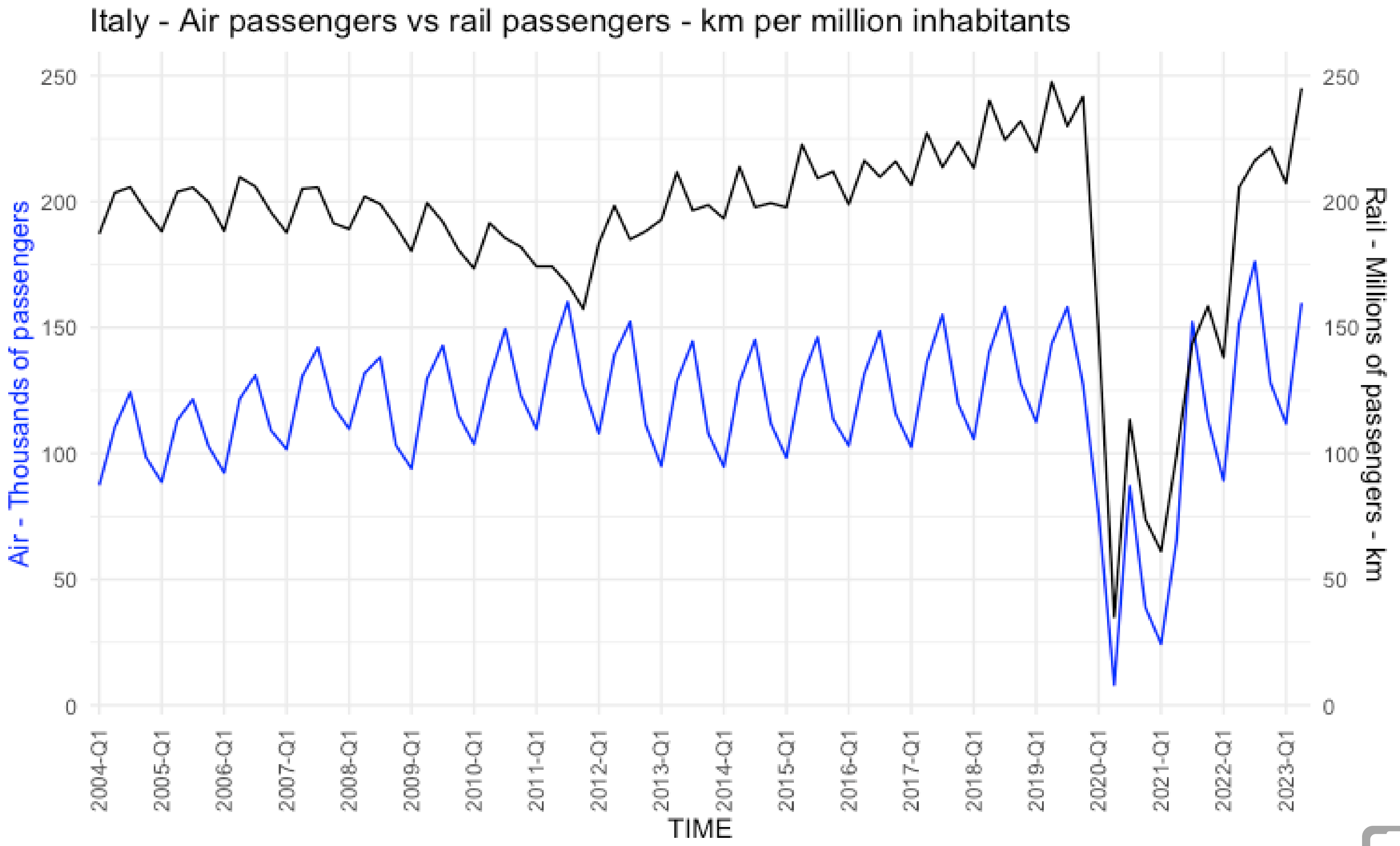

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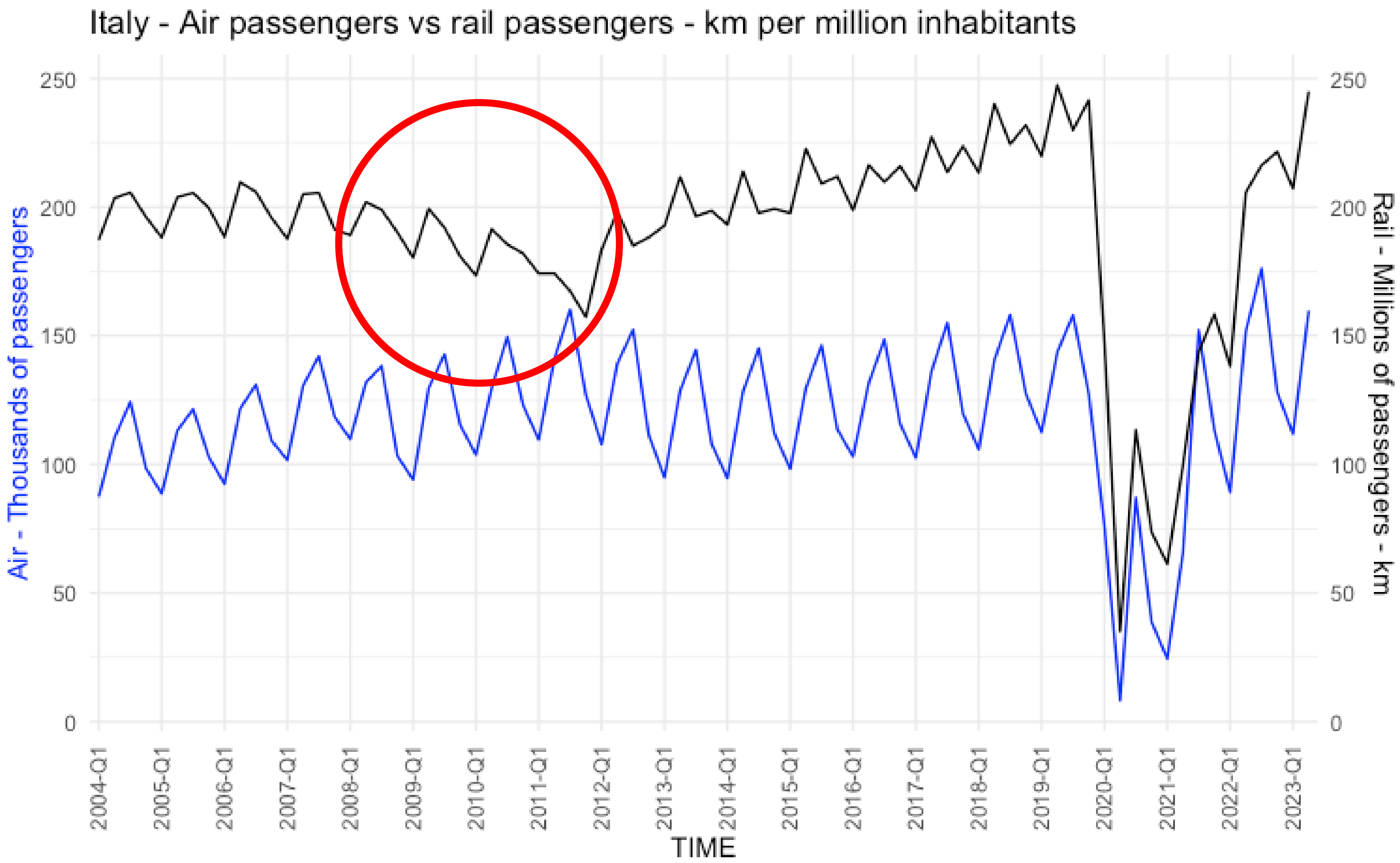
Railway traffic - Italy



- **2008** Global Financial crisis
- **2011** Italy’s debt crisis

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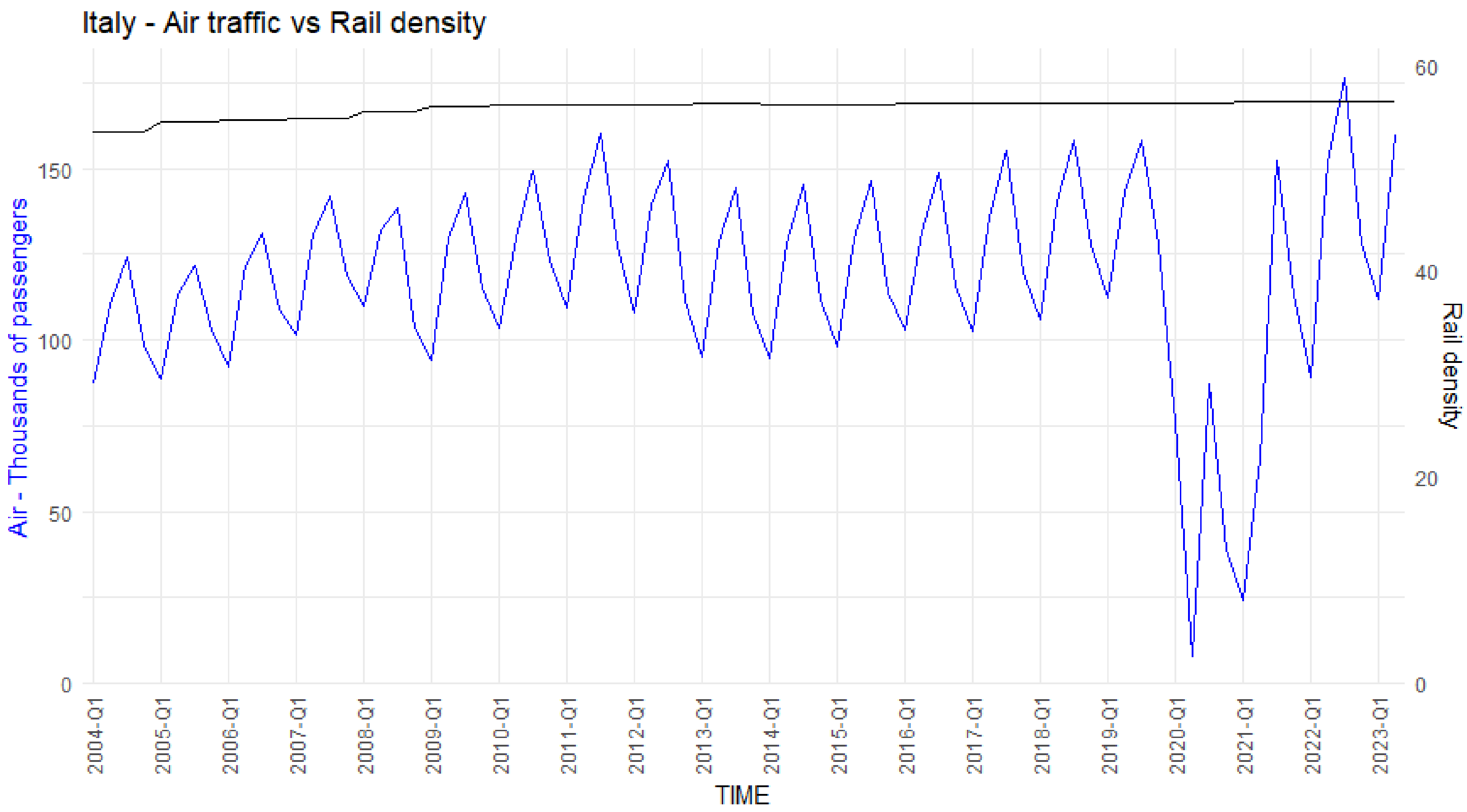
Rail density - Italy



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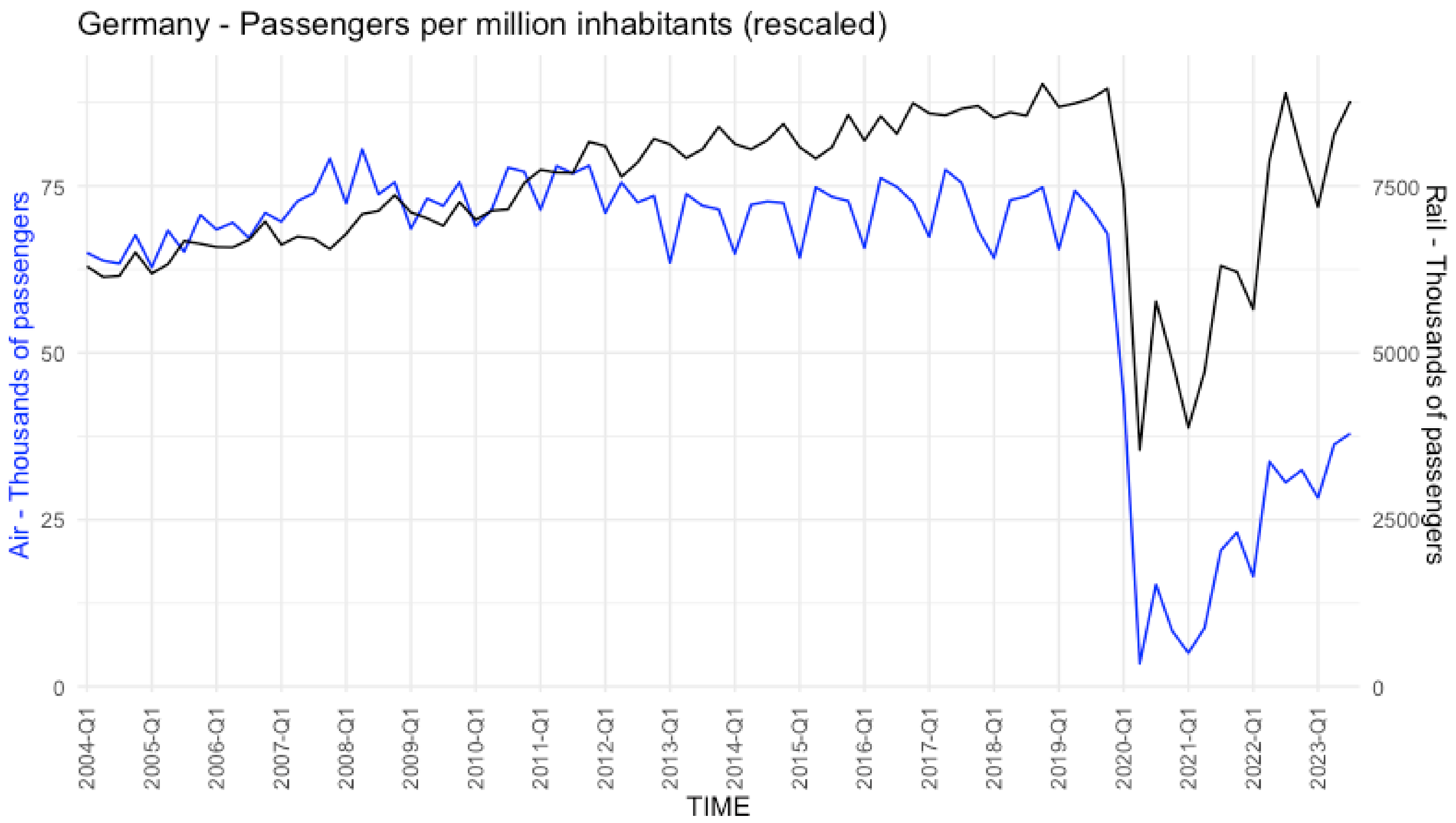
Railway traffic - Germany



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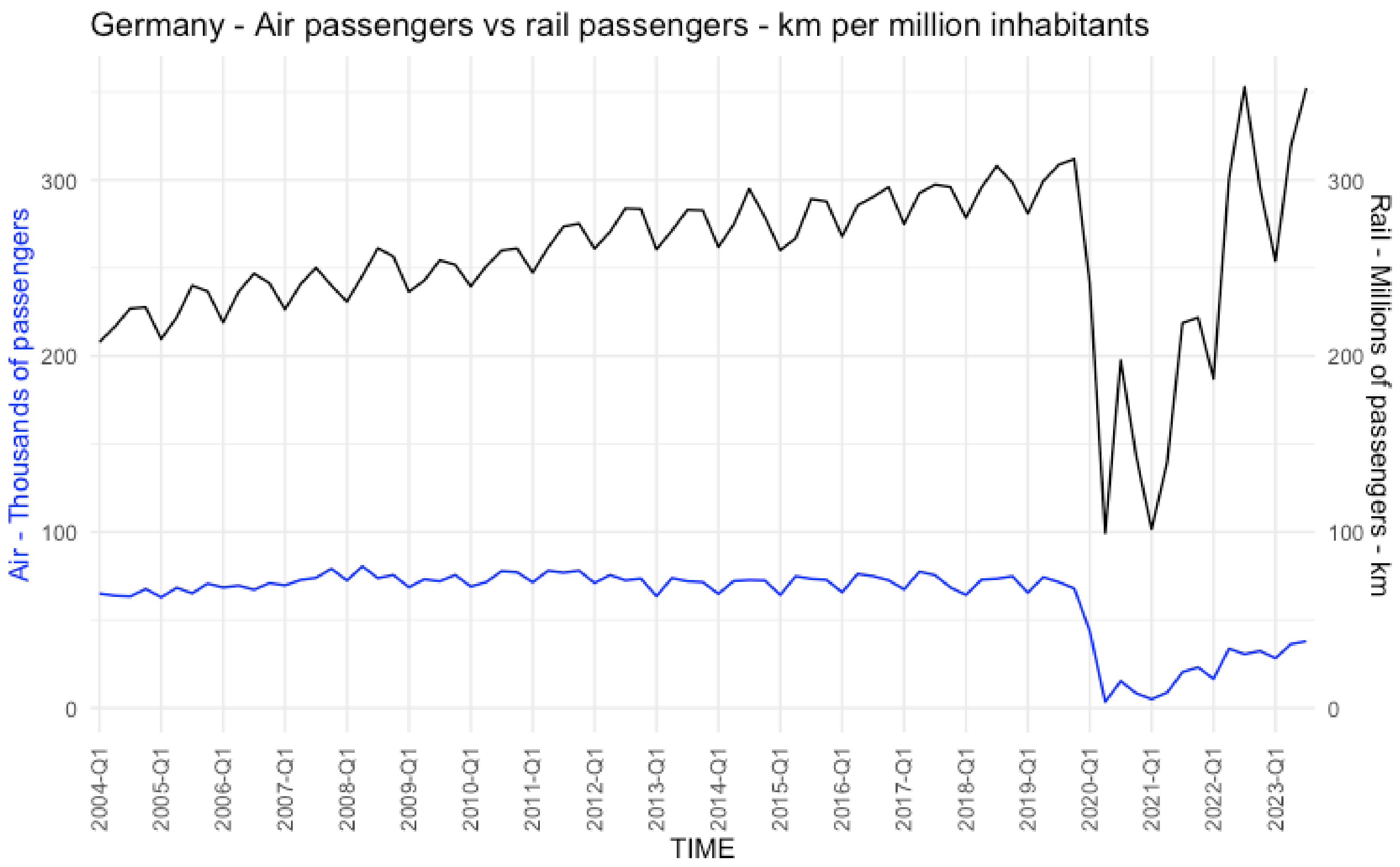
Railway traffic - Germany



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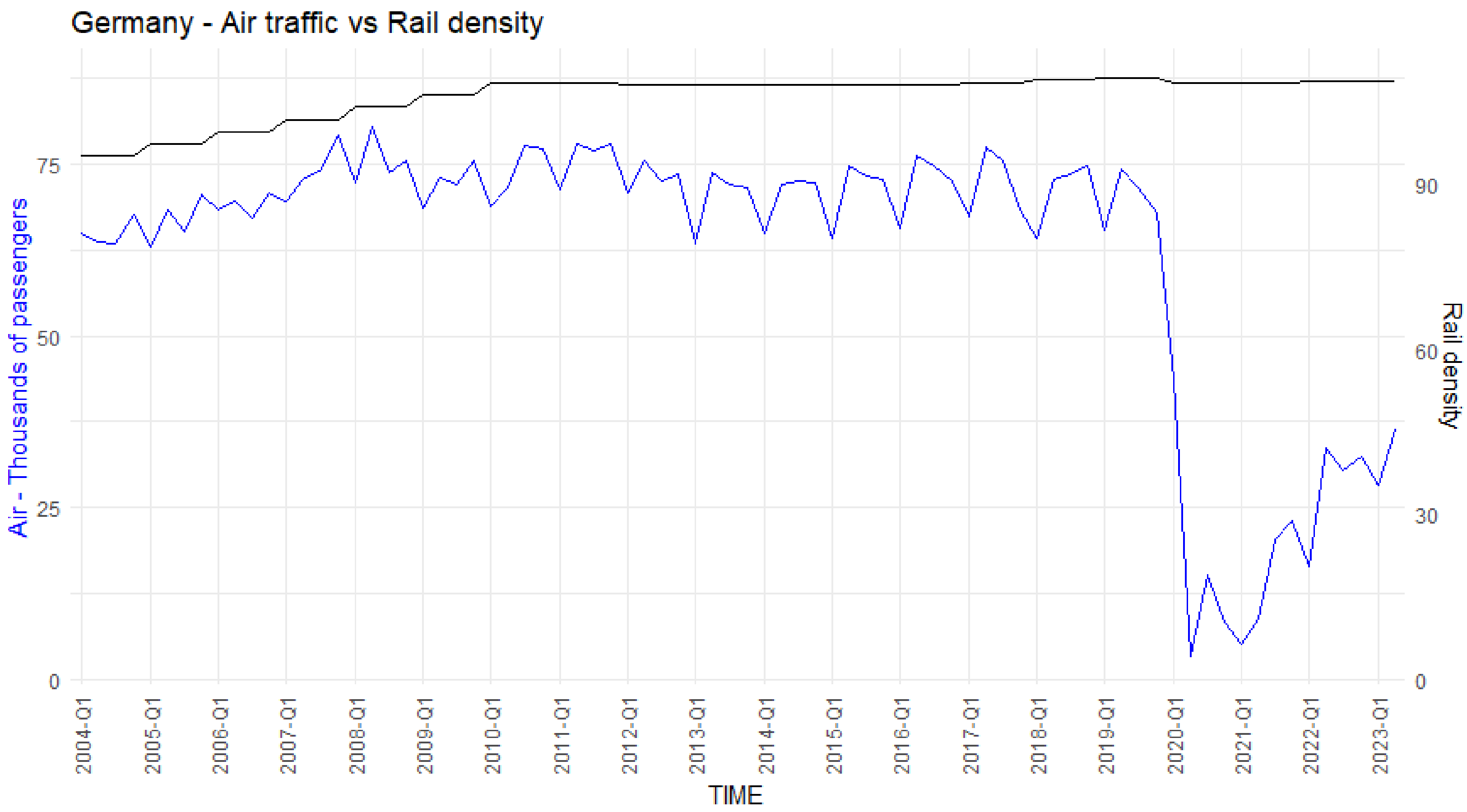
Rail density - Germany



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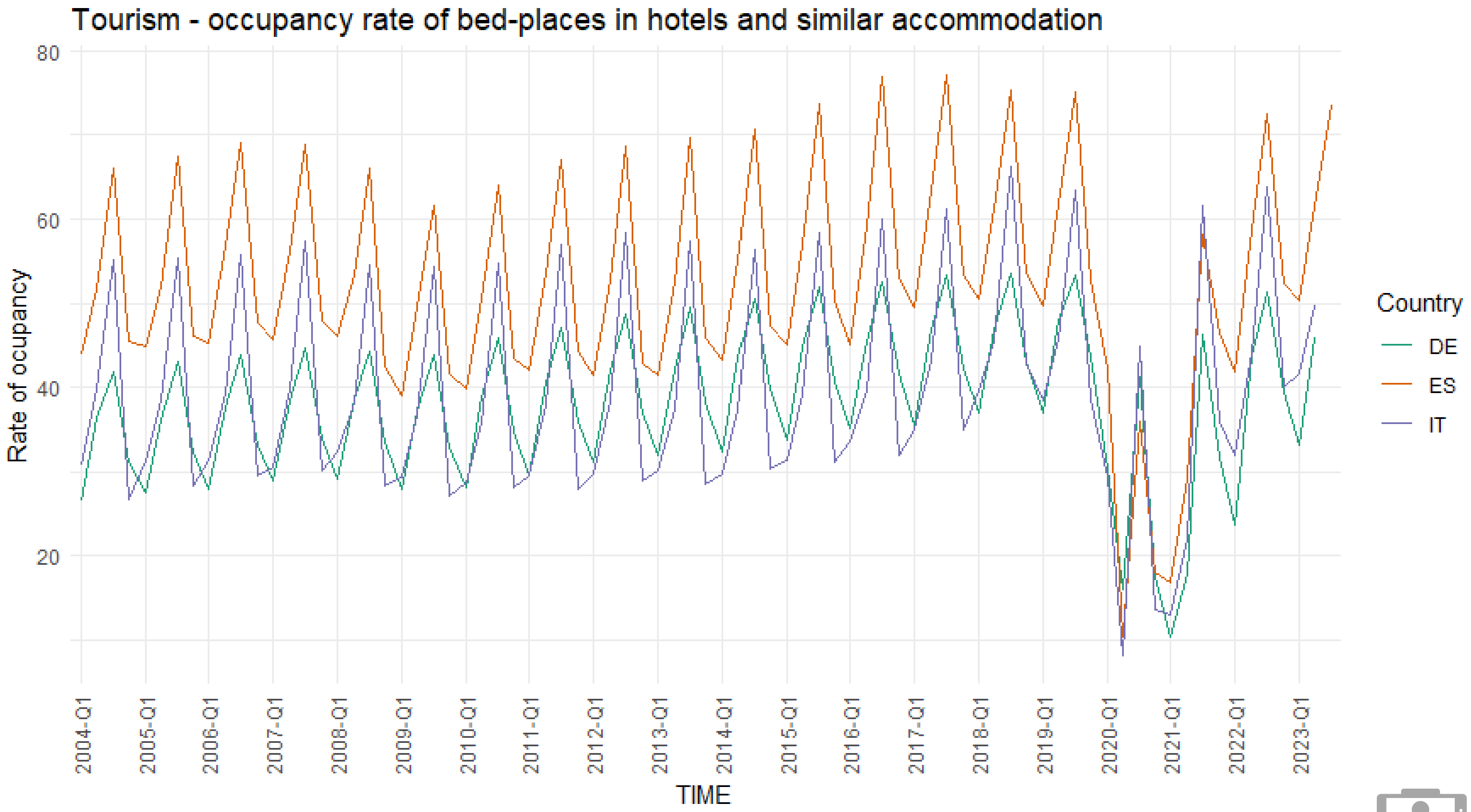
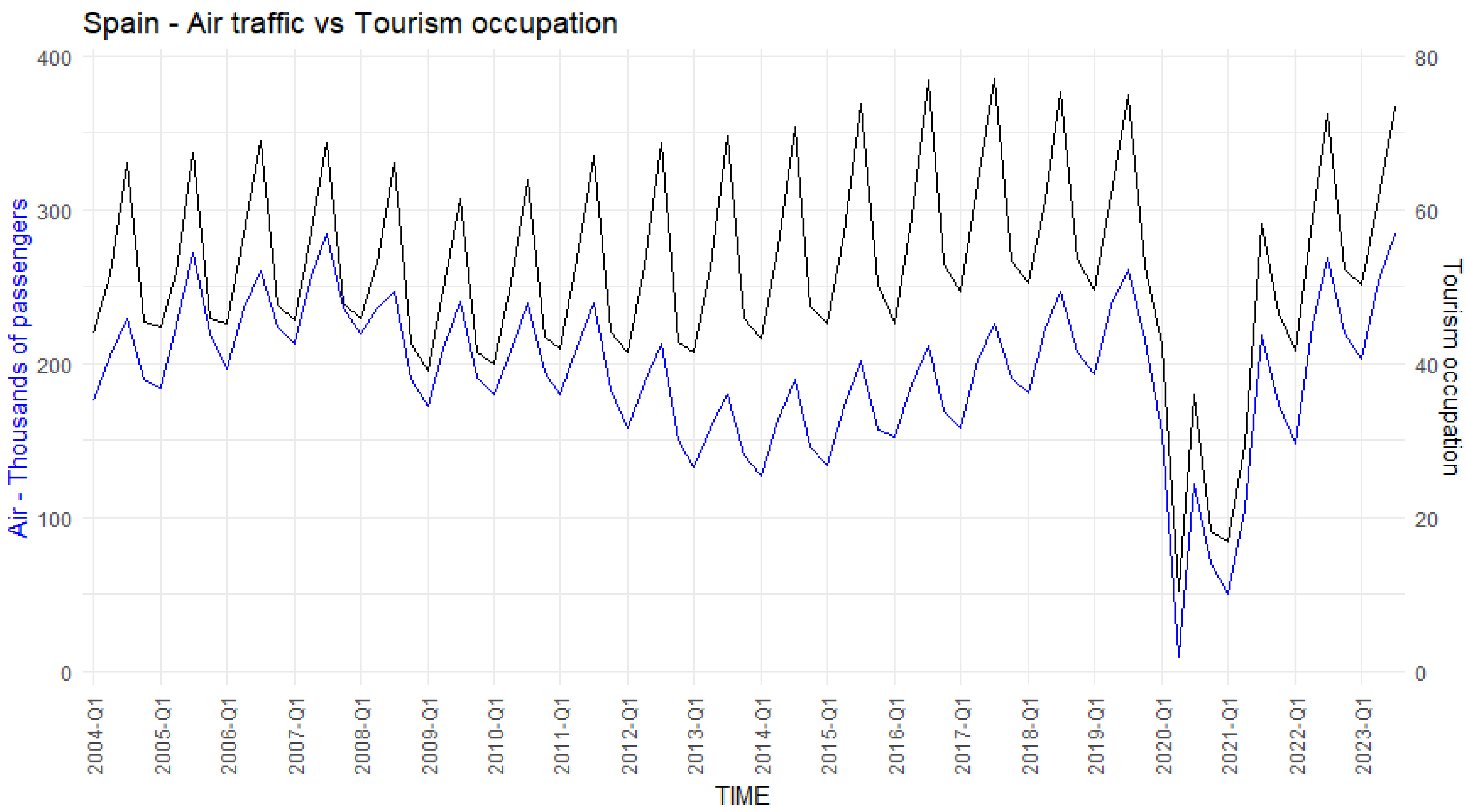
Tourism occupation

- Flights are usually related to travelling with touristic purposes. Is tourism by itself affecting air traffic?
- We used the occupancy rate of **bed-places** in hotels and similar accommodation from Eurostat.
- Monthly data grouped as the average by quarter.



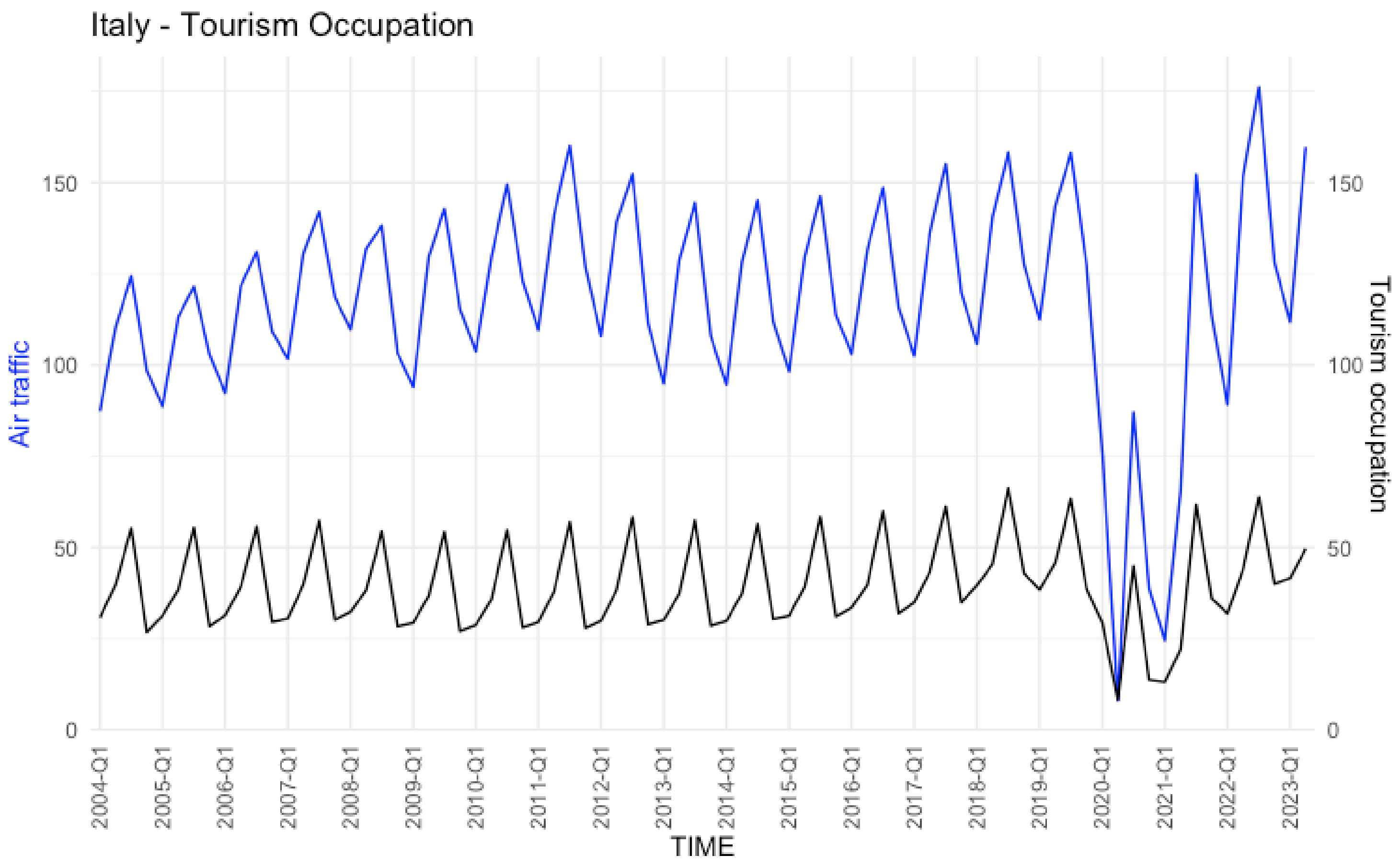
Tourism Occupation - Spain

- Kind of reminds the GDP plot (adding seasonality). Spain is a touristic country.
- Do we need both variables in this case? GDP is more robust, but we will see.



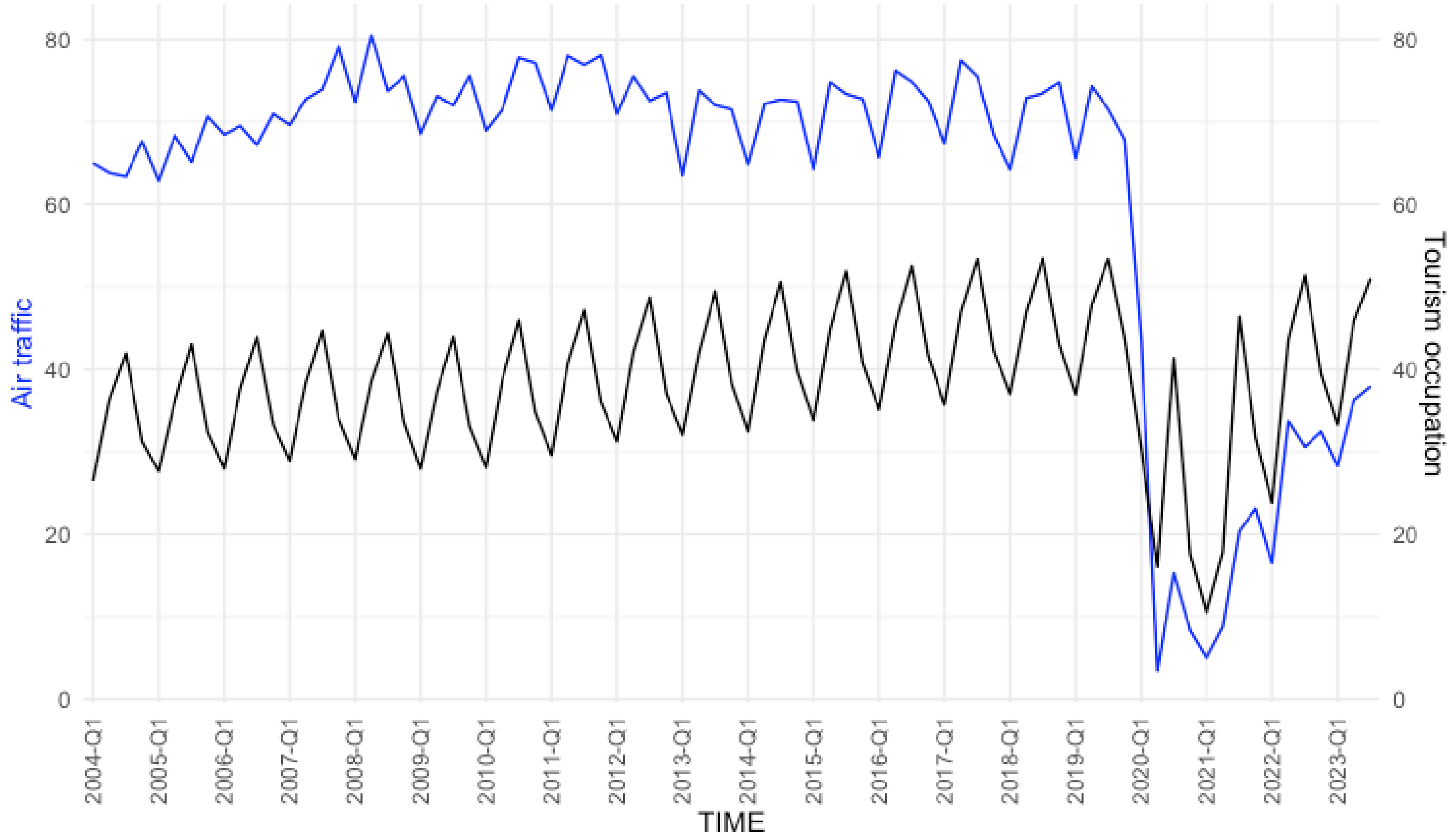
Tourism Occupation - Italy

- Seems a little flat, apart form seasonality.



Tourism Occupation - Germany

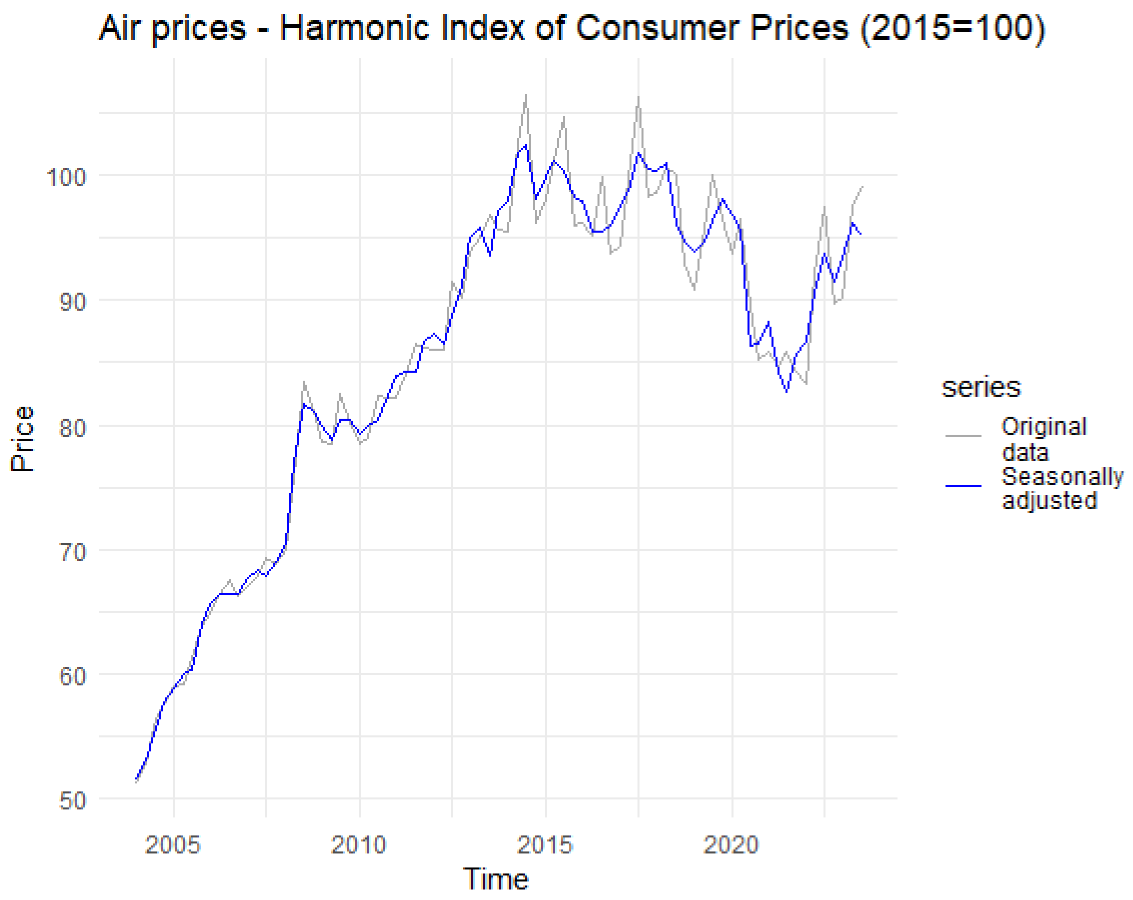
- No clear pattern.

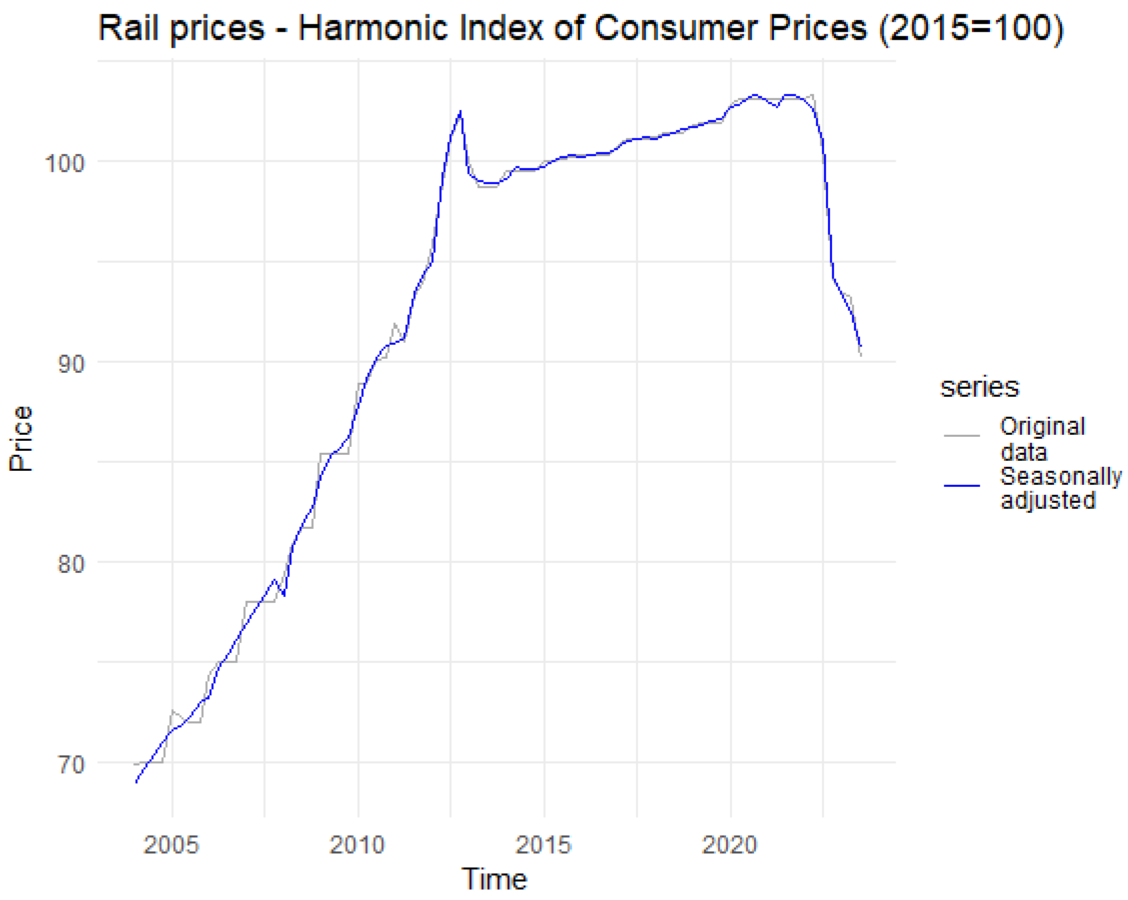


Time dependencies

- For the models that we are going to see next, we included explicit variables to account for **trend** and **seasonality**.
- Also, the type of models that we used aim to capture other kinds of type dependencies (more on this later).
- Since some of our potential predictors are also affected by seasonality, we considered a **seasonally adjusted version** of these variables. We used the **x11 decomposition** for this purpose.

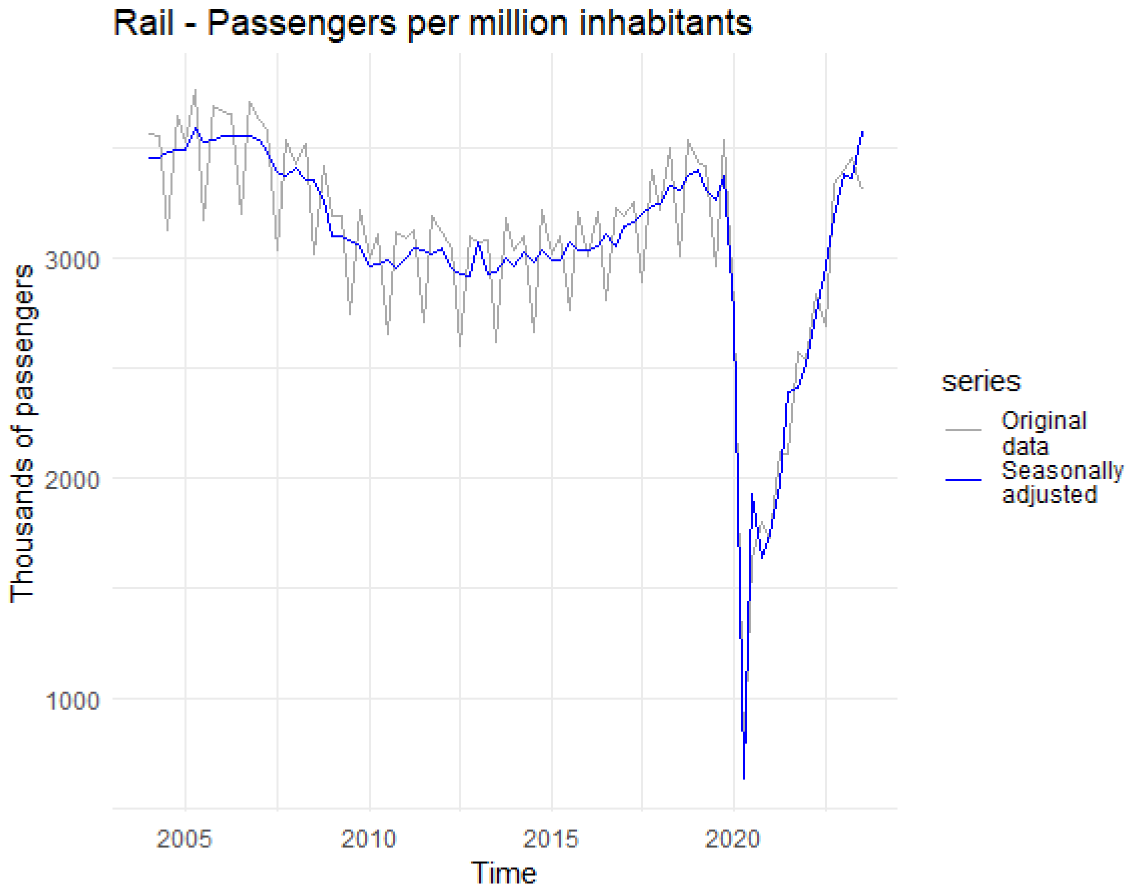
Seasonal adjustments

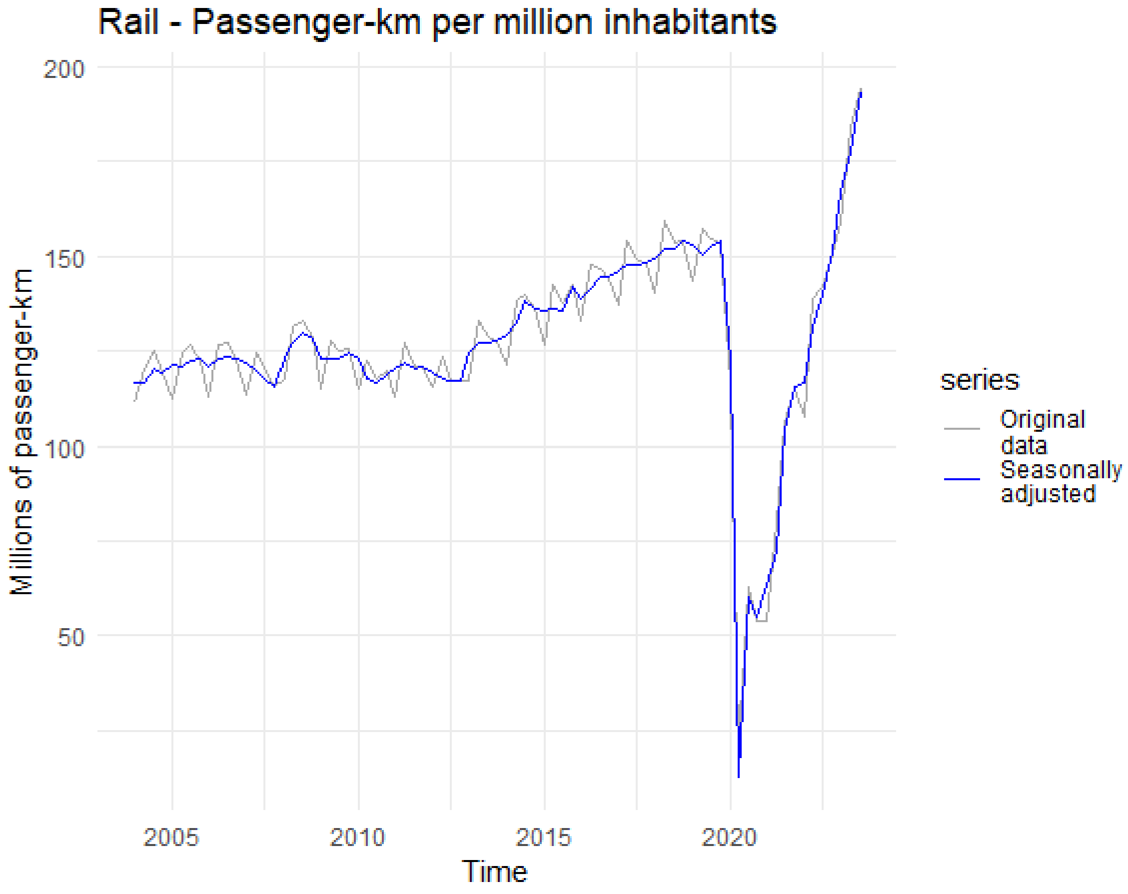




* Examples from Spain, but the same logic applies to the other countries

Seasonal adjustments





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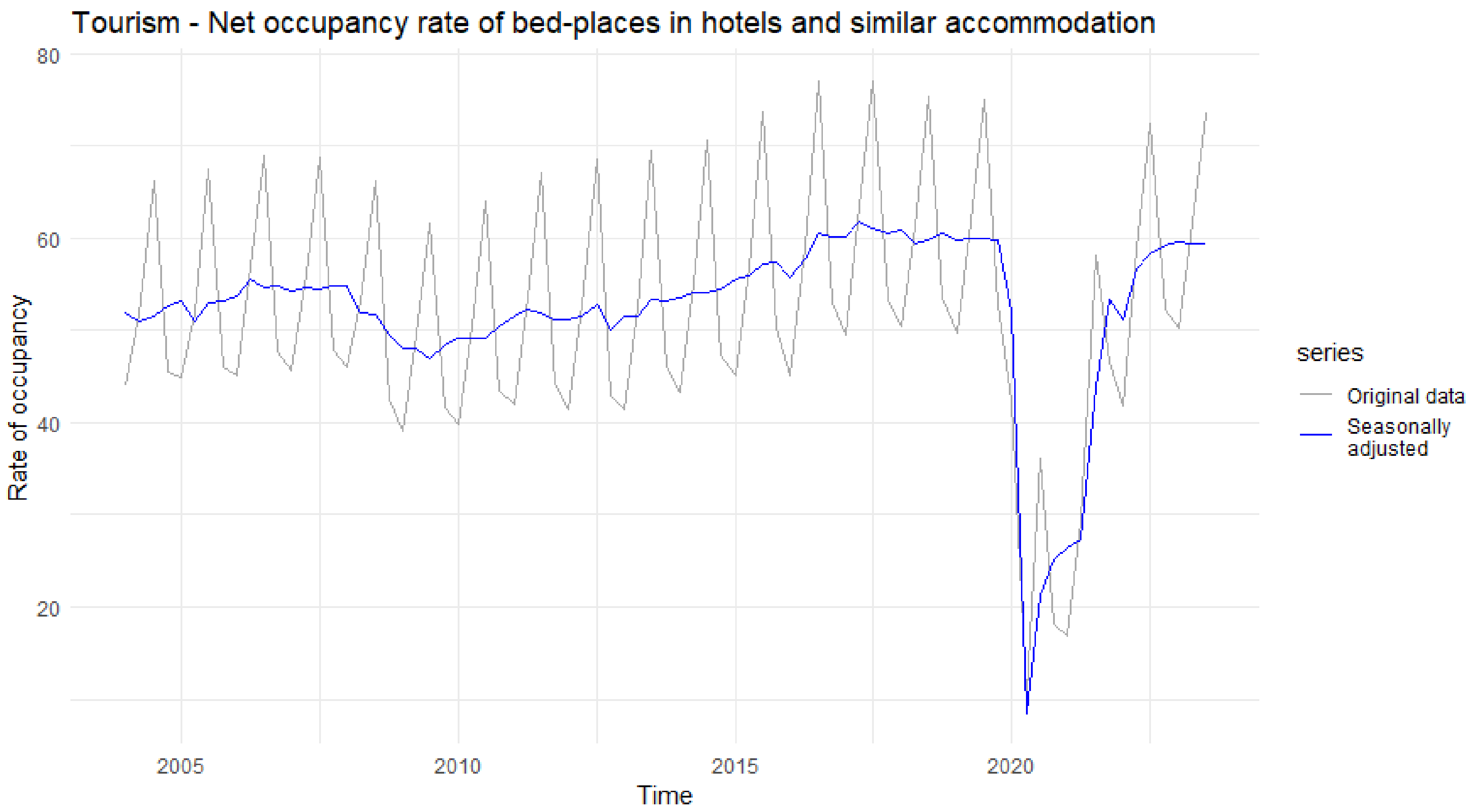
Seasonal adjustments



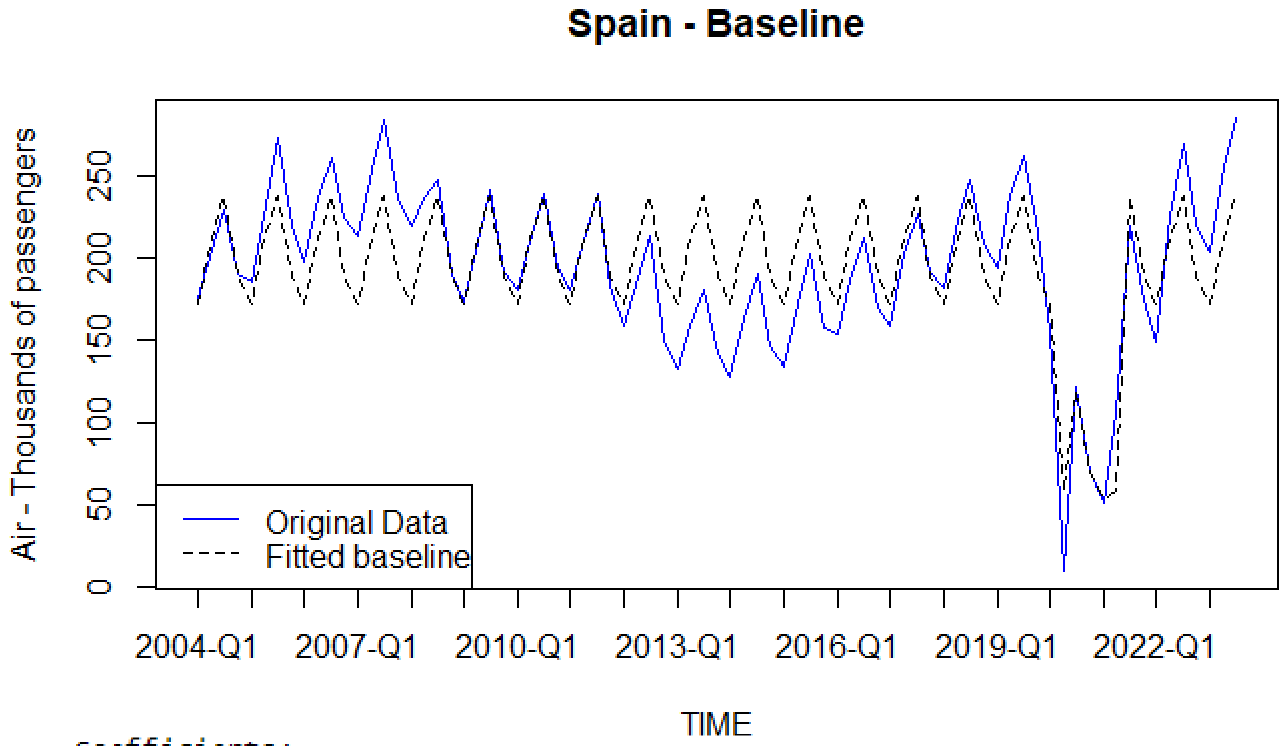
* Examples from Spain, but the same logic applies to the other countries

Statistical modeling

- We aim for a well-fitting model, but our primary goal is to **explain the data**.
- We avoided families of models that would be harder to interpret.
- We used an approach with two parts:
  - A **time-series linear model** to grasp the meaningful variables and understand our series.
  - A **dynamic regression with ARIMA errors** to capture the remaining time-dependencies (with the autoregression and the moving average components) and make an improvement in terms of fit
- To handle the bias-variance trade-off and avoid overfitting, we used the **LASSO and the best subset selection** approaches as feature selectors, along with information criteria.

Statistical modeling - Spain

- We started with a **very simple** linear model as a reference point. It only included the non-time-series predictors: **trend***, **quarter** (the seasonality), and **COVID restrictions**.
- These variables are **not explicit external factors**, except from COVID which we *know* that had an impact on air traffic.
- Therefore, this model serves as a **baseline** to compare and check how well our other (time-series) predictors explain the data.



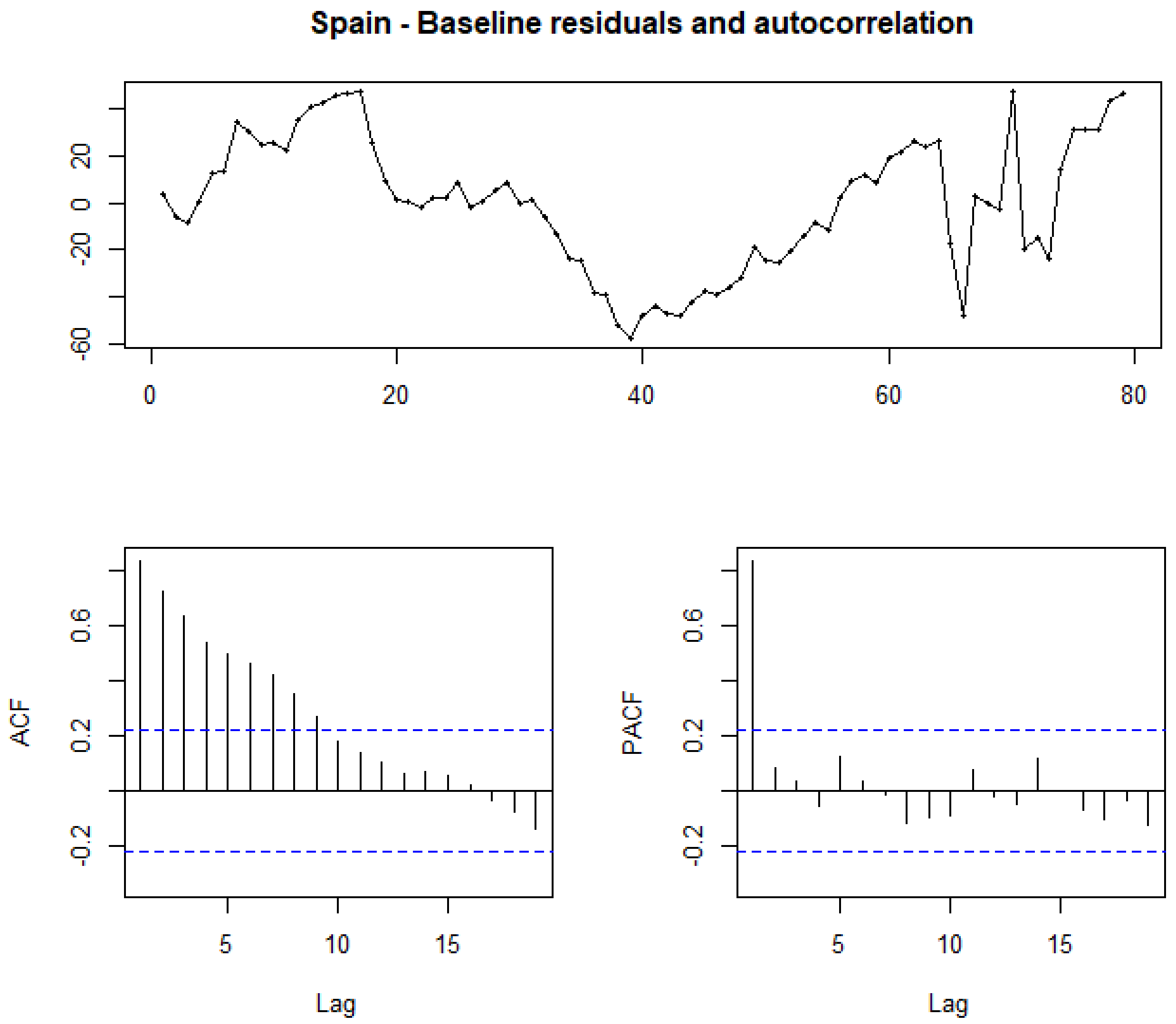

```
Coefficients:
                             Estimate Std. Error t value Pr(>|t|)    
(Intercept)                   171.754      6.559  26.186  < 2e-16 ***
QUARTERQ2                      39.082      9.487   4.120 9.89e-05 ***
QUARTERQ3                      66.198      9.195   7.199 4.45e-10 ***
QUARTERQ4                      16.919      9.316   1.816   0.0735 .  
COVID_AVG_RESTRICTIONS_FACTOR1 -153.236     21.674  -7.070 7.72e-10 ***
COVID_AVG_RESTRICTIONS_FACTOR2 -118.707     17.233  -6.889 1.68e-09 ***
```

AICc = 765.9
Adjusted R^2 = 0.65

* Trend was not significant for Spain, so we removed it

Statistical modeling - Spain

- It does not capture the time dependencies well.
- Hints of a pattern in residuals. **Not white noise.**
- Several of the first lags have a considerable **autocorrelation.**



Statistical modeling - Spain

- We tried both the standard version and the **seasonally adjusted version** of our predictors. The latter worked best.
- The Lasso regression and the best subset selection with adjusted R^2 and Cp as criteria resulted in the **same model**.
- The best subset selection with BIC as criterion, omitted the passenger-km variable.
- However, we may have **collinearity** issues.

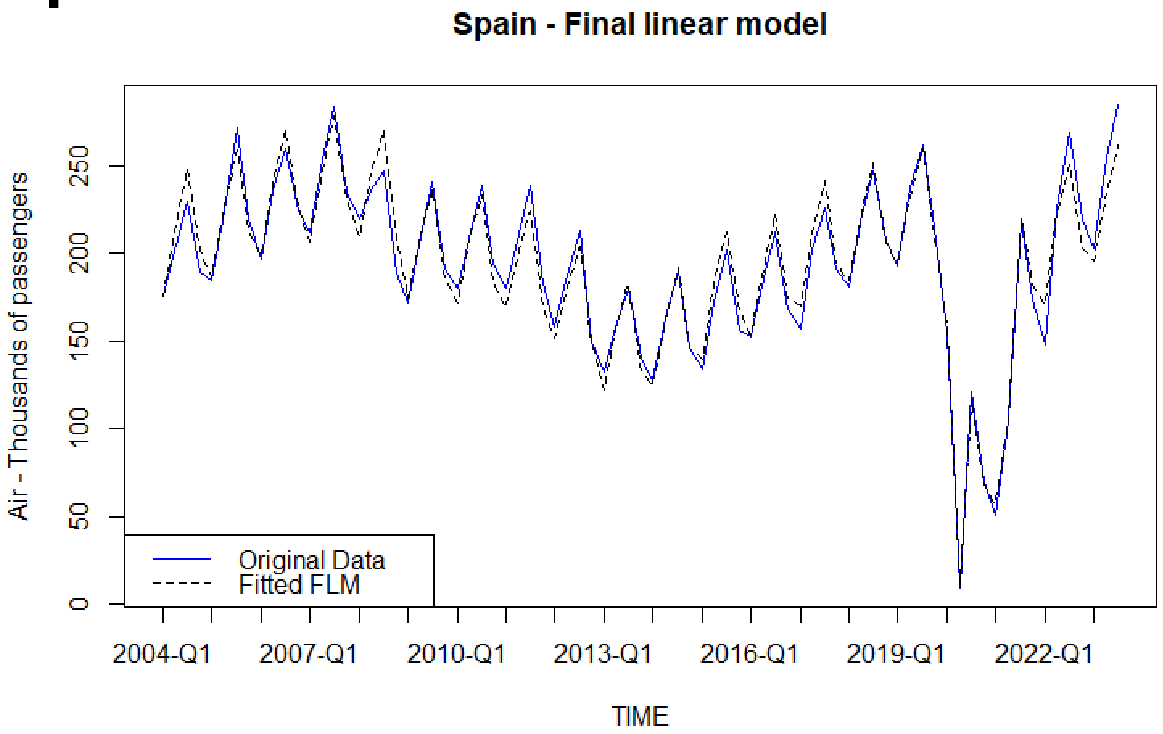
```
Coefficients:
                                  Estimate Std. Error t value Pr(>|t|)    
(Intercept)                      -250.5824    25.3484  -9.886 6.44e-15 ***
QUARTERQ2                          34.9441     3.1479  11.101  < 2e-16 ***
QUARTERQ3                          60.8337     3.0516  19.935  < 2e-16 ***
QUARTERQ4                          10.7901     3.0912   3.491 0.000839 ***
COVID_AVG_RESTRICTIONS_FACTOR1    -59.0041    12.0977  -4.877 6.50e-06 ***
COVID_AVG_RESTRICTIONS_FACTOR2    -61.2979    10.0742  -6.085 5.55e-08 ***
R_MIO_PKM_S_ADJ                     0.1979     0.1046   1.891 0.062707 .  
GDP_PC                             96.6077     4.8945  19.738  < 2e-16 ***
RAIL_DENSITY                       -6.2683     0.5126 -12.228  < 2e-16 ***
```

AICc = 595,5
Adjusted R^2 = 0.96

```
> vif(esPasBestSeasAdj)
                                  GVIF Df GVIF^(1/(2*Df))
QUARTER                       1.112085  3        1.017864
COVID_AVG_RESTRICTIONS_FACTOR 5.521797  2        1.532922
R_MIO_PKM_S_ADJ               5.902836  1        2.429575
GDP_PC                        1.740271  1        1.319193
RAIL_DENSITY                  1.973513  1        1.404818
```

Statistical modeling - Spain

- By **removing passenger-km,** the least significant variable from before (was even discarded by the BIC criterion), we **eliminate our collinearity** issues.
- Slightly worse AICc, but **more stable** model.




```
> vif(esPasBestSeasAdjVIF)
                                   GVIF Df GVIF^(1/(2*Df))
QUARTER                        1.106017  3        1.016936
COVID_AVG_RESTRICTIONS_FACTOR  1.456347  2        1.098541
GDP_PC                         1.313449  1        1.146058
RAIL_DENSITY                   1.274264  1        1.128833
```

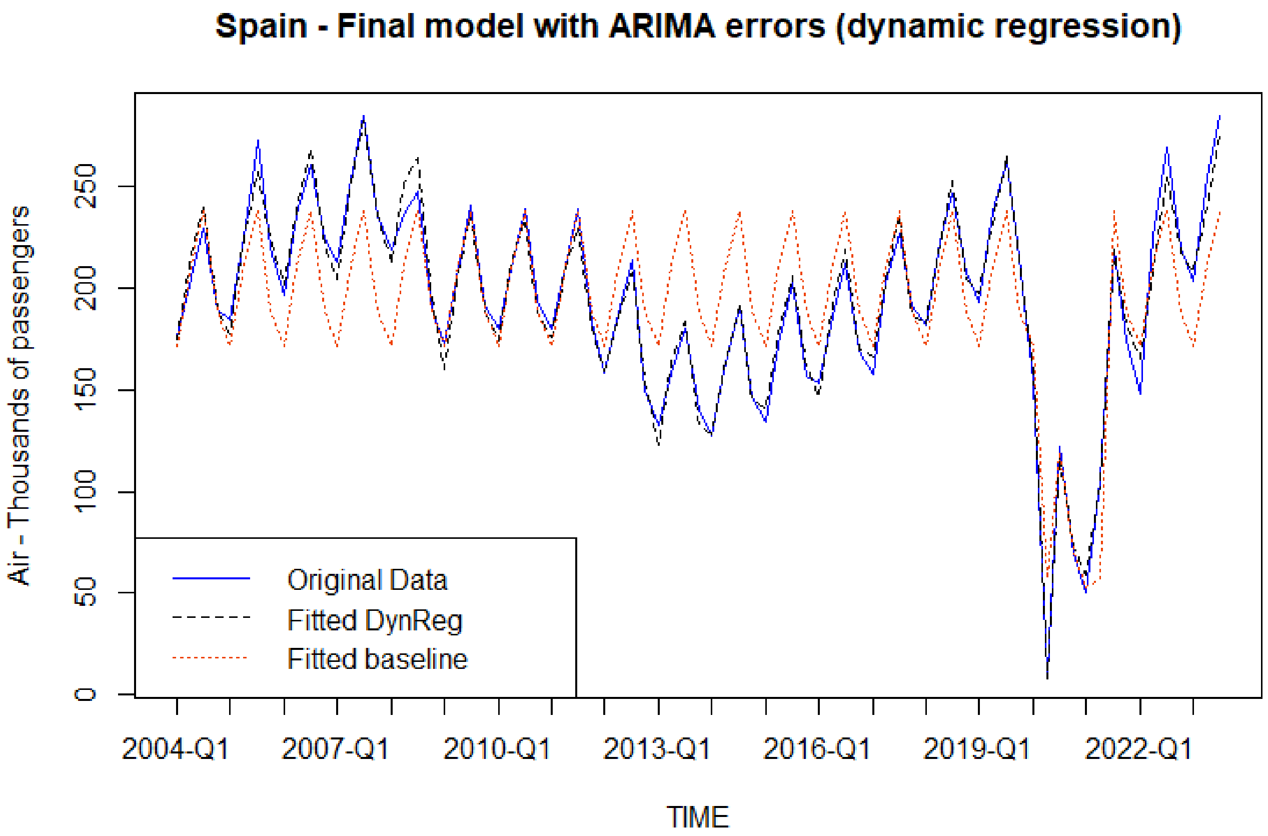
```
Coefficients:
                               Estimate Std. Error t value Pr(>|t|)
(Intercept)                   -268.2362    23.9914 -11.181  < 2e-16 ***
QUARTERQ2                       35.3268     3.1979  11.047  < 2e-16 ***
QUARTERQ3                       61.0889     3.1035  19.684  < 2e-16 ***
QUARTERQ4                       10.8359     3.1467   3.444 0.000967 ***
COVID_AVG_RESTRICTIONS_FACTOR1 -76.3896     8.0069  -9.540 2.37e-14 ***
COVID_AVG_RESTRICTIONS_FACTOR2 -76.5526     6.1453 -12.457  < 2e-16 ***
GDP_PC                         101.1924     4.3286  23.377  < 2e-16 ***
RAIL_DENSITY                    -5.6912     0.4193 -13.573  < 2e-16 ***
```

AICc = 596.8

Adjusted R^2 = 0.96

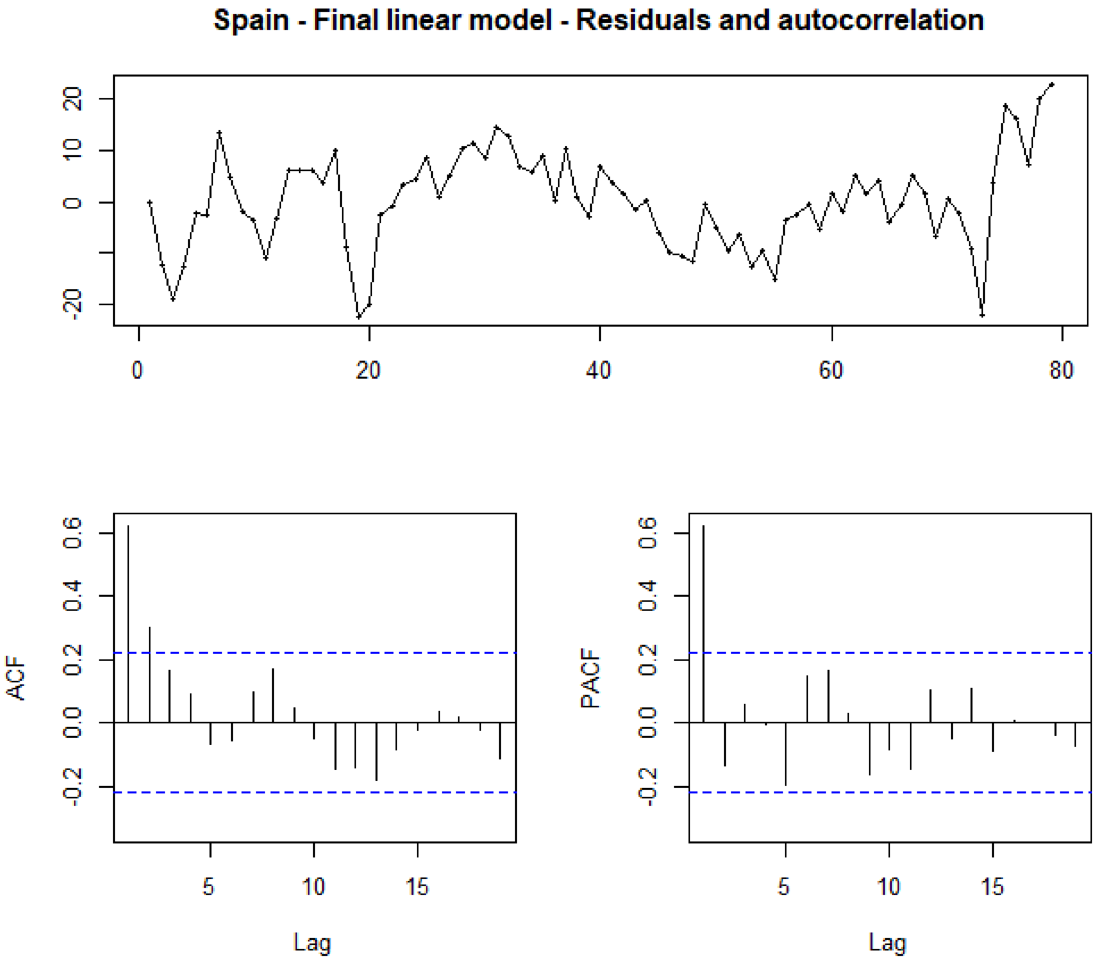
Statistical modeling - Spain

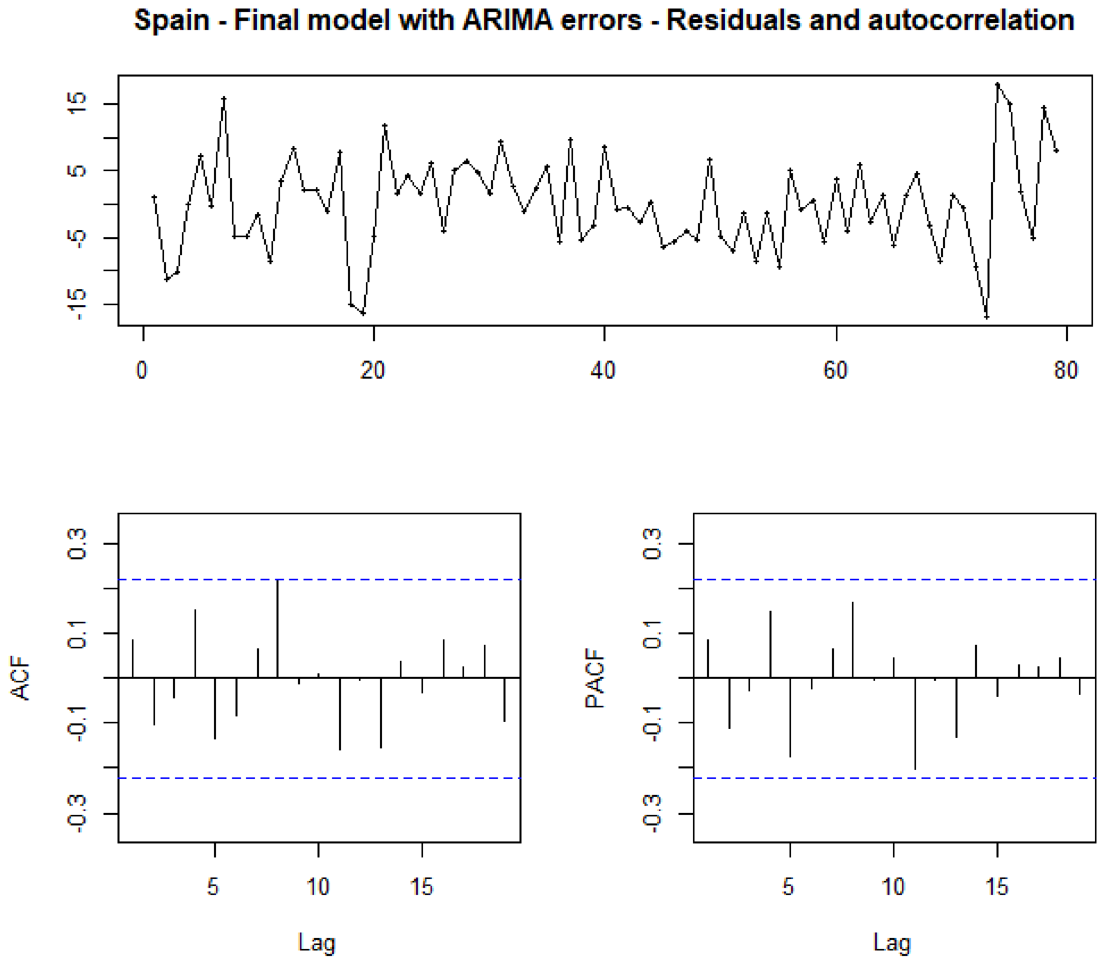
- The fit is already very good, but we could further improve it.
- We fitted a **dynamic regression with ARIMA errors** to account for the remaining time dependencies.
- If the goal were to make **forecasts**, this would be the model to pick.
- We used the auto.arima, which follows an algorithm to pick the best model parameters (p, d and q).
- Only resulted in one AR term.




```
Regression with ARIMA(1,0,0) errors

Coefficients:
          ar1  intercept  QUARTERQ2  QUARTERQ3  QUARTERQ4  COVID_AVG_RESTRICTIONS_FACTOR1  COVID_AVG_RESTRICTIONS_FACTOR2
       0.6795  -298.9944    34.8709    60.6412    11.1269                        -72.3212                        -75.2416
s.e.   0.0905    38.3523     1.6764     1.8806     1.6910                          6.6878                          7.3050
         GDP_PC  RAIL_DENSITY
       104.4569       -5.2695
s.e.     6.1166        0.8444

sigma^2 = 56.01:  log likelihood = -266.64
AIC=553.28   AICc=556.51   BIC=576.97
```

Statistical modeling - Spain





Statistical modeling - Spain

Insights:

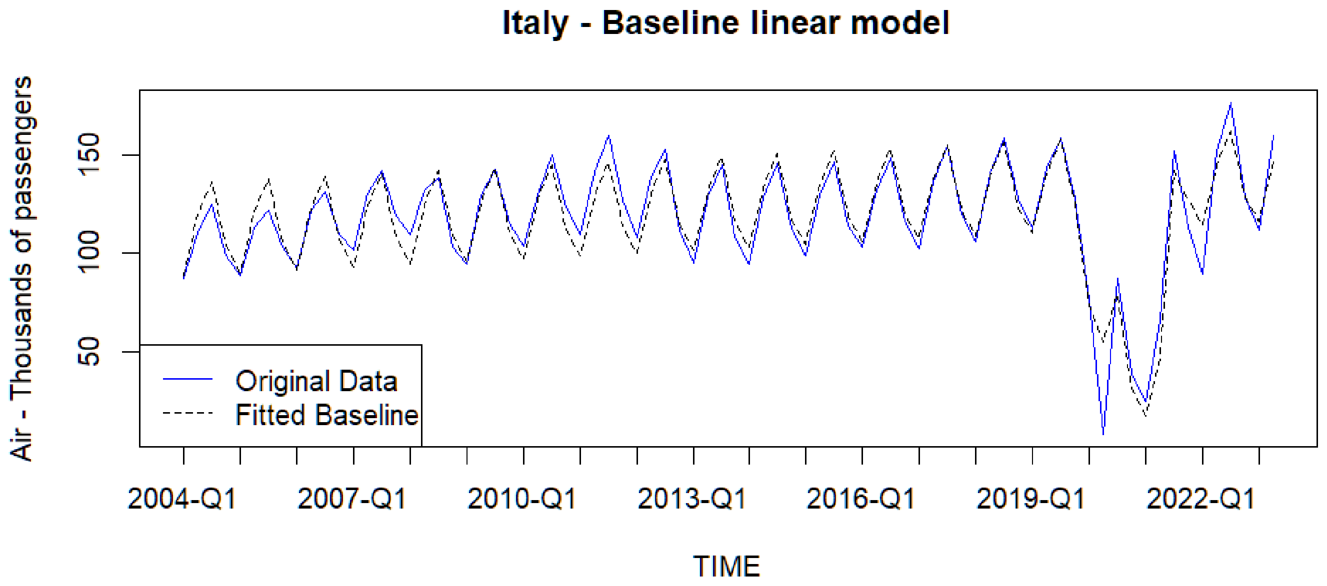
- There is indeed a strong seasonal component where Q3 (summer) is related to a greater air traffic.
- **GDP per capita dominates** what happens with air traffic in Spain.
- Then, to better understand this phenomenon, anybody interested would need to **unwrap** what happens with the **economic activity** in the country, which is not an easy task.
- **Are railways really competing with airplanes in Spain?**
- Interestingly, it seems that air traffic in Spain is **somewhat unresponsive to the variations in price** (of both air and rail trips), although it might be to soon to evaluate recent policies.

Statistical modeling - Italy

- Baseline linear model including the non-time-series predictors: **trend**, **quarter** (the seasonality), and **COVID restrictions**.

- All parameters revealed to be significant.

- Good initial fit, because the timeseries exhibits a linear trend and consistent seasonality.

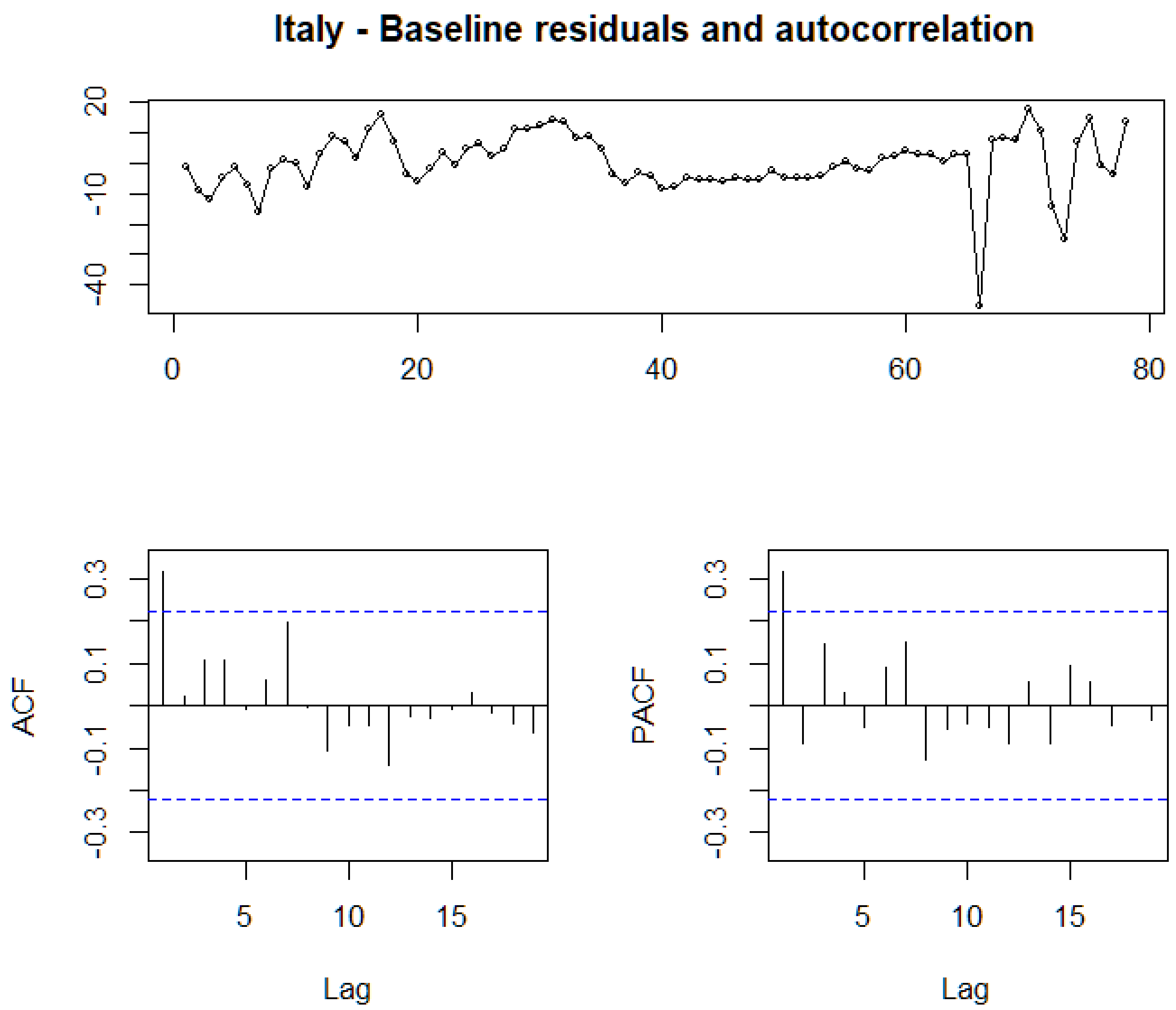



```
Coefficients:
                       Estimate Std. Error t value Pr(>|t|)
(Intercept)            88.23299    2.94349  29.976  < 2e-16 ***
TREND                   0.35478    0.05299   6.695 4.01e-09 ***
QUARTERQ2              30.26003    3.10193   9.755 8.33e-15 ***
QUARTERQ3              46.95004    3.14107  14.947  < 2e-16 ***
QUARTERQ4              13.83893    3.14224   4.404 3.62e-05 ***
COVID_AVG_RESTRICTIONS -47.76766   2.53122 -18.871  < 2e-16 ***
```

AICc = 587
Adjusted R^2 = 0.89

Statistical modeling - Italy

- Hints for autocorrelation in the first lag.
- Durbin-Watson test reveals significant positive autocorrelation (0.317179)
- **Not white noise.**



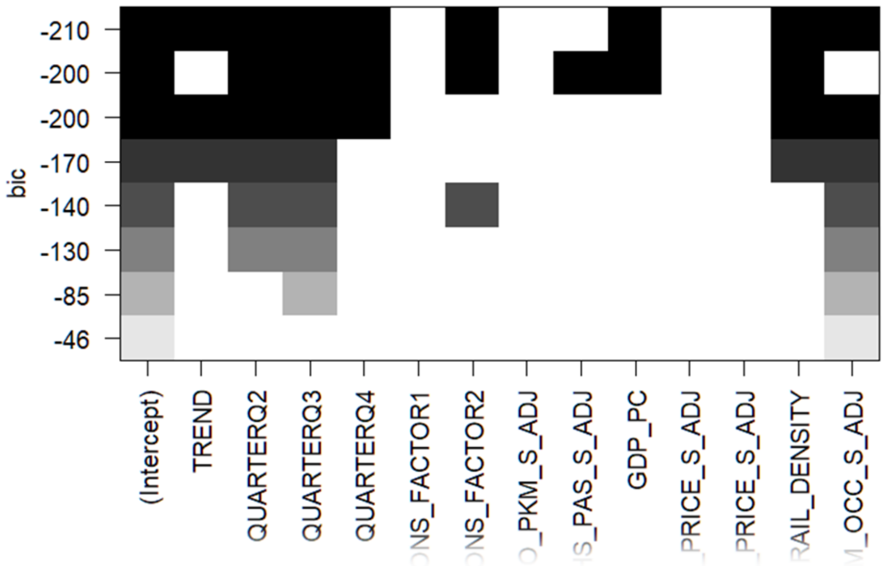
Statistical modeling - Italy

- Again, the model fitted on **seasonally adjusted** parameters outperformed the standard model.

- In this case, the **best subset selection** with Adjusted R-squared/Cp/BIC criteria gave the **same output variables**.

- Best subset selection with seasonally adjusted parameters **doesn't give a model with strong collinearity issues**, opposite to Lasso and non-seasonally adjusted models.

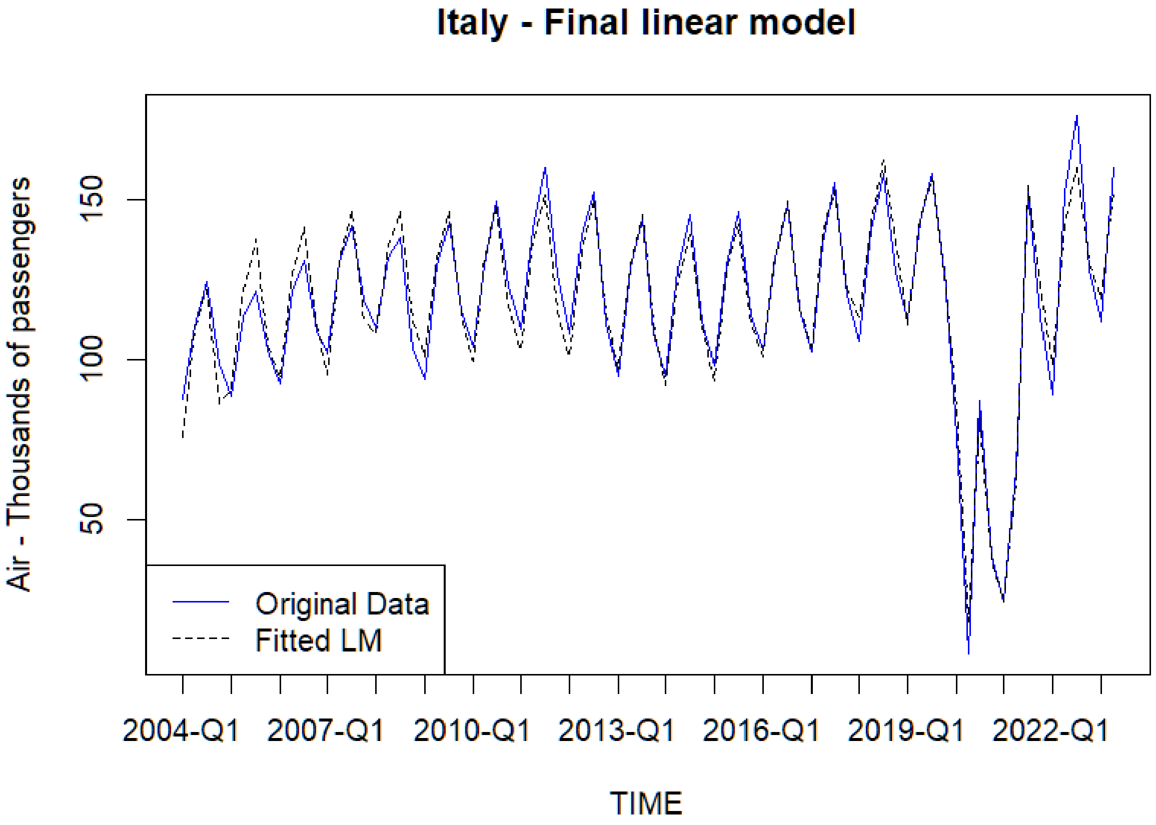
BIC criterion for variable selection



VIF for variables selected by Best Subset Selection

```
        TREND                        QUARTERQ2          QUARTERQ3
     7.471362                         1.495720           1.490548
    QUARTERQ4 COVID_AVG_RESTRICTIONS_FACTOR2             GDP_PC
     1.491282                         7.460806           2.251836
 RAIL_DENSITY                TOURISM_OCC_S_ADJ
     4.237445                         7.988296
```

Statistical modeling - Italy



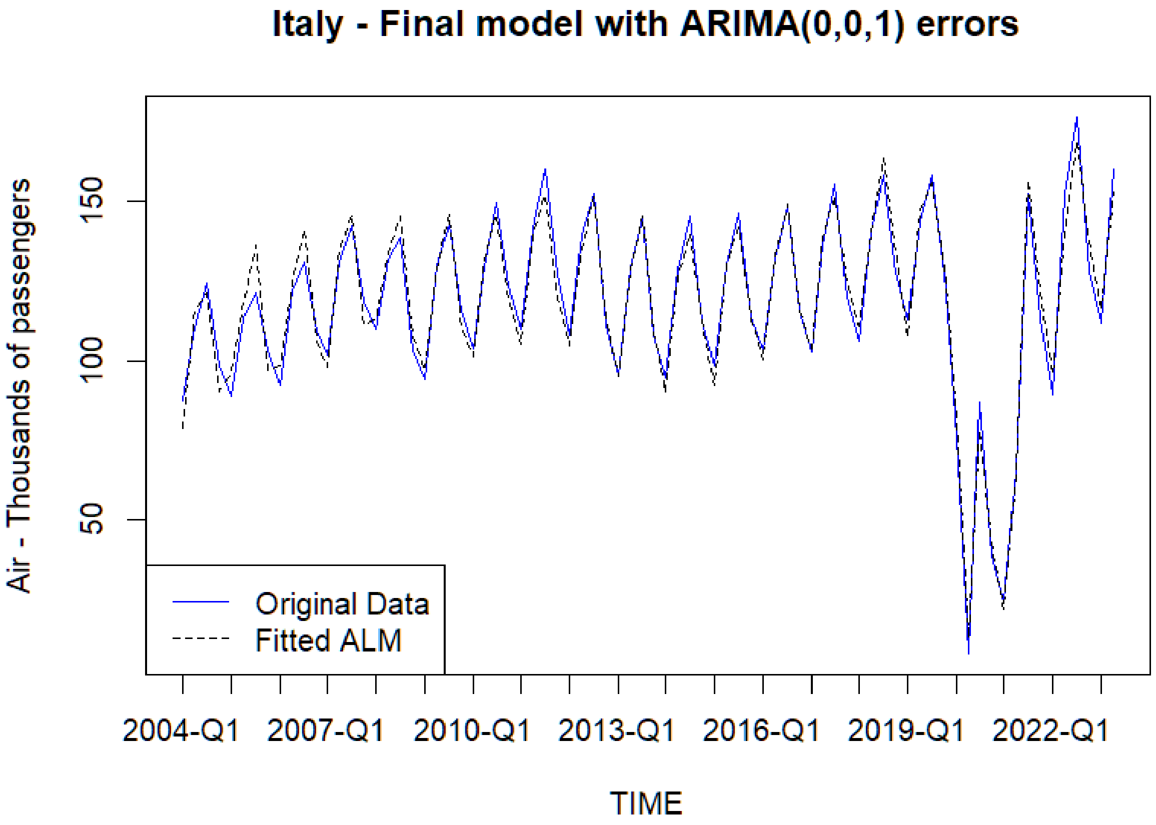

```
Coefficients:
                             Estimate Std. Error t value Pr(>|t|)
(Intercept)                 -914.9477   108.6292  -8.423 3.37e-12 ***
TREND                         -0.3657     0.0862  -4.243 6.75e-05 ***
QUARTERQ2                     32.2511     1.9888  16.217  < 2e-16 ***
QUARTERQ3                     47.2478     2.0196  23.395  < 2e-16 ***
QUARTERQ4                     14.8015     2.0201   7.327 3.38e-10 ***
COVID_AVG_RESTRICTIONS_FACTOR2 -30.3433   7.9184  -3.832 0.000277 ***
GDP_PC                        13.0589     3.2675   3.997 0.000159 ***
RAIL_DENSITY                  15.2253     1.7853   8.528 2.16e-12 ***
TOURISM_OCC_S_ADJ              2.0743     0.3153   6.579 7.65e-09 ***
```

AICc = 521
Adjusted R^2 = 0.95

Improvement in both Adjusted R^2 and AICc compared to the Baseline linear model.

All variables are **significant**.

Statistical modeling - Italy




```
Coefficients:
         ma1  intercept    TREND  QUARTERQ2  QUARTERQ3  QUARTERQ4  COVID_AVG_RESTRICTIONS_FACTOR1
      0.5830  -842.0428  -0.3016    32.1497    47.2816    14.8166                         -2.2340
s.e.  0.0898   127.3523   0.0931     1.4249     1.9104     1.4663                          4.8105
      COVID_AVG_RESTRICTIONS_FACTOR2   GDP_PC  RAIL_DENSITY  TOURISM_OCC_S_ADJ
                            -31.5783  14.8646       13.6623             2.0518
s.e.                          7.4756   3.9893        2.1237             0.2898

sigma^2 = 30.22:  log likelihood = -237.89
AIC=499.78   AICc=504.58   BIC=528.06

Training set error measures:
                      ME    RMSE      MAE        MPE     MAPE      MASE       ACF1
Training set -0.04303326 5.09513 4.225892 -0.7438481 4.465491 0.1600268 0.01668633
```

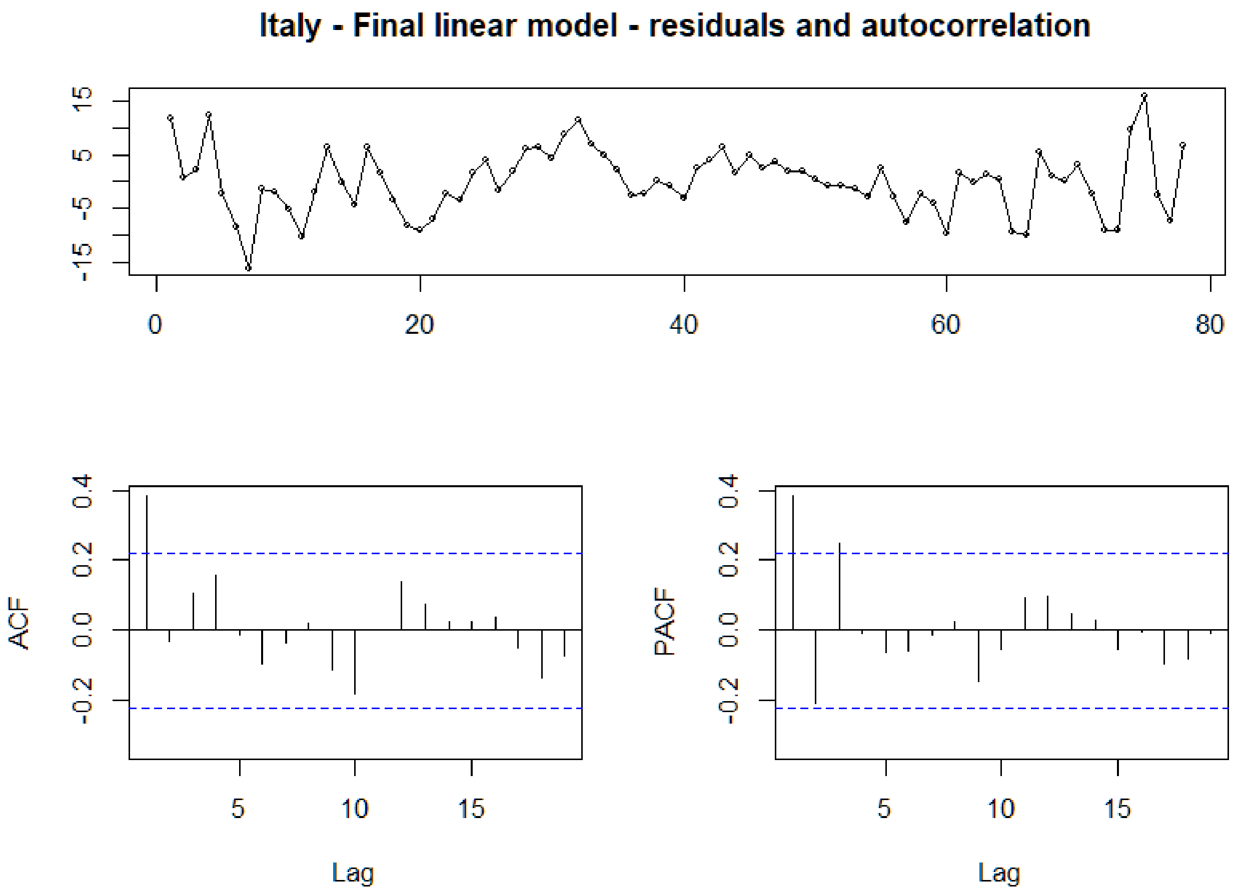
AICc = 504

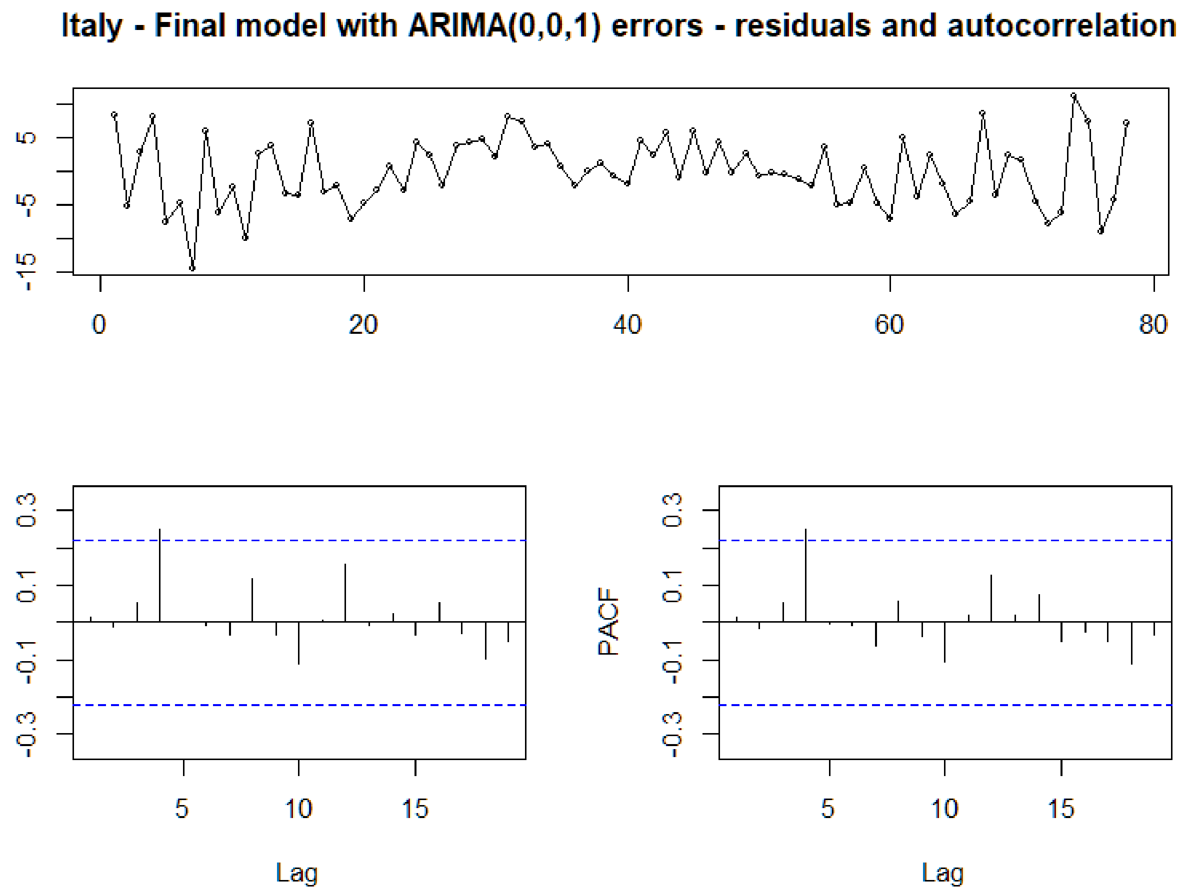
Improvement in AICc compared to the Baseline and previous linear models.

Presence of moving average component with one lag (**ma1**).

Good fit to the data.

Statistical modeling - Italy





Durbin-Watson Test statistic: 1.91

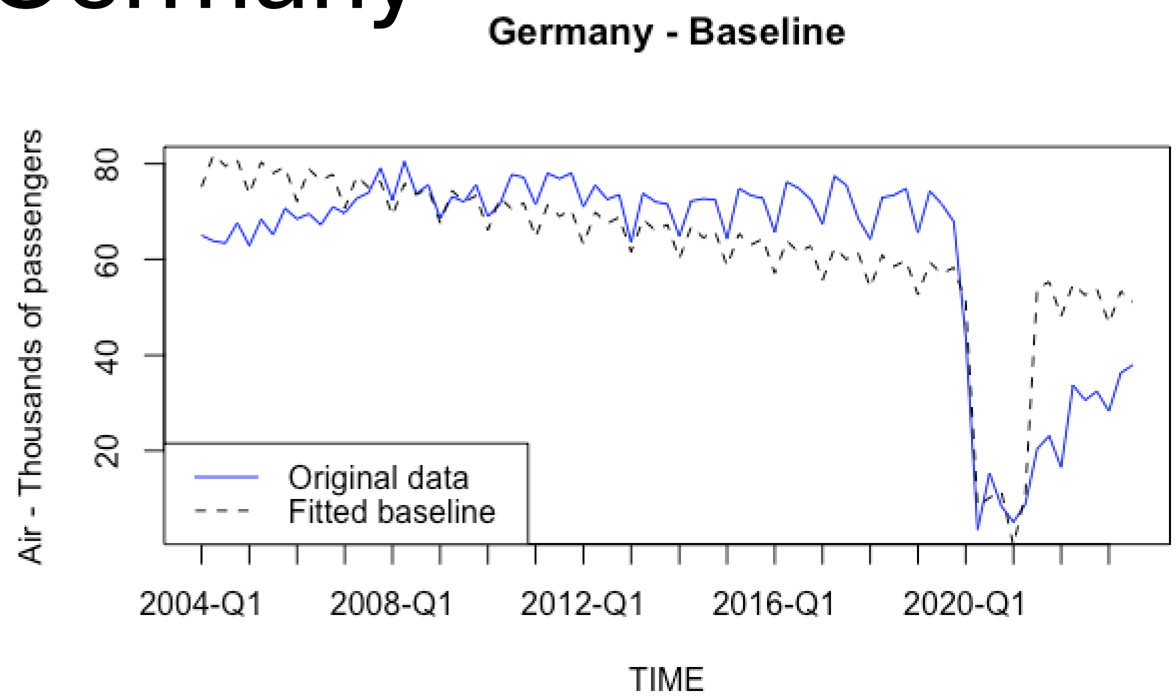
Statistical modeling - Italy

Insights:

- Variables **Trend** and **Rail Density** should be further inspected to understand their counterintuitive effects on the number of air passengers.
- **COVID restrictions** played a very clear role in the variations of air traffic, specially when these measures were mandatory and not only recommended.
- Naturally, there’s also a strong impact of **Quarter 3** (Summer) in air traffic.
- Along with the previous, also the **GDP** variable has a very relevant impact, once again revealing what we could only assume: the **economic activity** in Italy plays an important role, from various angles, in determining the number of people taking domestic flights.
- Like in Spain, **Air price** and **Rail price** are not considered into the best models, as well as other rail-related parameters, showing a certain independence between air and rail traffic. This aligns with the **lack of train discounts campaigns** in Italy.

Statistical modelling – Germany

- Simple linear model
  predictors: trend, seasonality (quarter), COVID restrictions
- Shows different significance among the parameters
- Doesn't do a good job in fitting original data



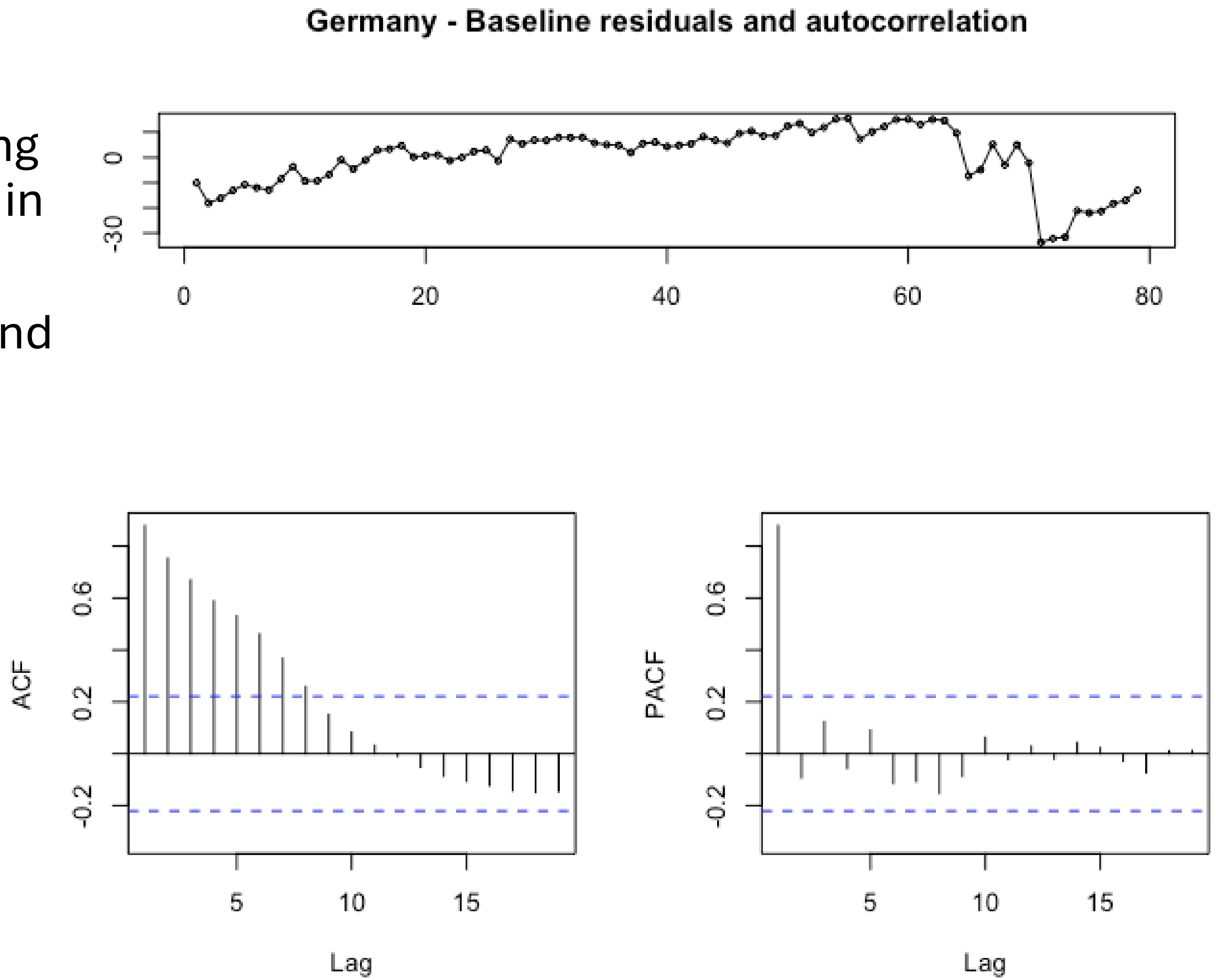

```
Coefficients:
                               Estimate Std. Error t value Pr(>|t|)
(Intercept)                    75.50162    3.64659  20.705  < 2e-16 ***
TREND                          -0.37593    0.06353  -5.917 1.02e-07 ***
QUARTERQ2                       7.12405    3.87203   1.840   0.0699 .
QUARTERQ3                       5.19452    3.89830   1.333   0.1869
QUARTERQ4                       6.79517    3.94826   1.721   0.0895 .
COVID_AVG_RESTRICTIONS_FACTOR1 -45.36527   7.47373  -6.070 5.43e-08 ***
COVID_AVG_RESTRICTIONS_FACTOR2 -49.43946   9.05257  -5.461 6.40e-07 ***
---
```

AICc = 630.0249

Adjusted R^2 = 0.6398

Statistical modelling – Germany

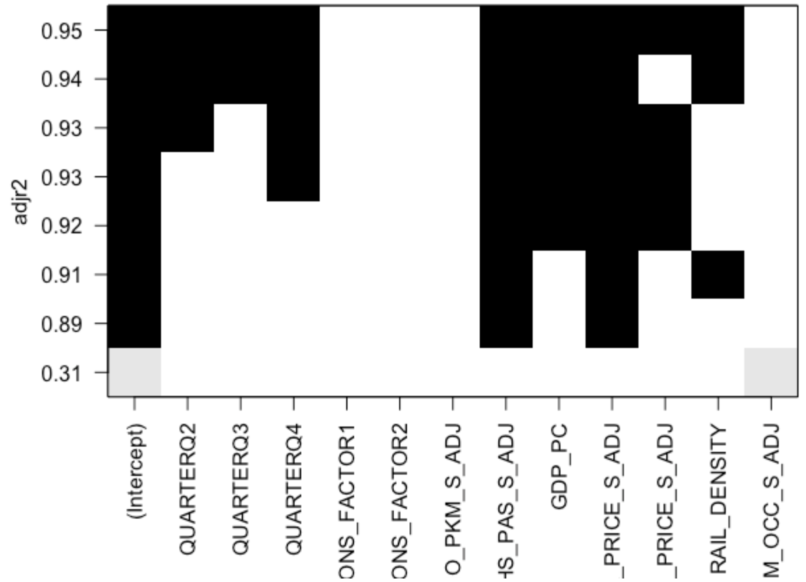
- Not white noise
- Durbin-Watson test indicated a strong evidence of positive autocorrelation in the residuals
- The model doesn't capture some trend or pattern

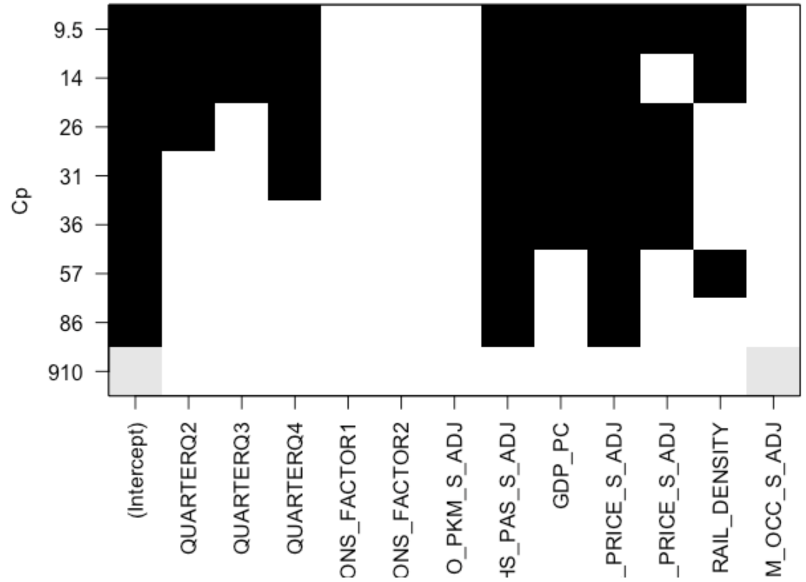


Statistical modelling – Germany

- Season adjustment of the predictor improved the results of our models
- In order to choose predictors to our models we used **Lasso Regression** and **best subset selection**
- We got different results:
    - Lasso Regression: *COVID restrictions* is a significant variable
    - Best subset selection: *COVID restrictions* are **not** significant

```
        (Intercept)                           QUARTERQ2                           QUARTERQ3
        18.44629067                          5.35120298                          4.39043329
          QUARTERQ4 COVID_AVG_RESTRICTIONS_FACTOR1 COVID_AVG_RESTRICTIONS_FACTOR2
         6.26882216                         -4.42910200                         -1.07183948
     R_MIO_PKM_S_ADJ                     R_THS_PAS_S_ADJ                              GDP_PC
         0.00000000                          0.01269306                         -8.93349731
      AIR_PRICE_S_ADJ                     RAIL_PRICE_S_ADJ                        RAIL_DENSITY
        -0.82920904                          0.40183777                          0.62945452
   TOURISM_OCC_S_ADJ
         0.00000000
```





Statistical modelling – Germany

- After comparing the results we found not much difference (AICc: 487.3263, 489.6472; R^2: 0.9419, 0.9425)
- We decided to keep the COVID restriction variable and look closely later
- However, collinearity problem was found

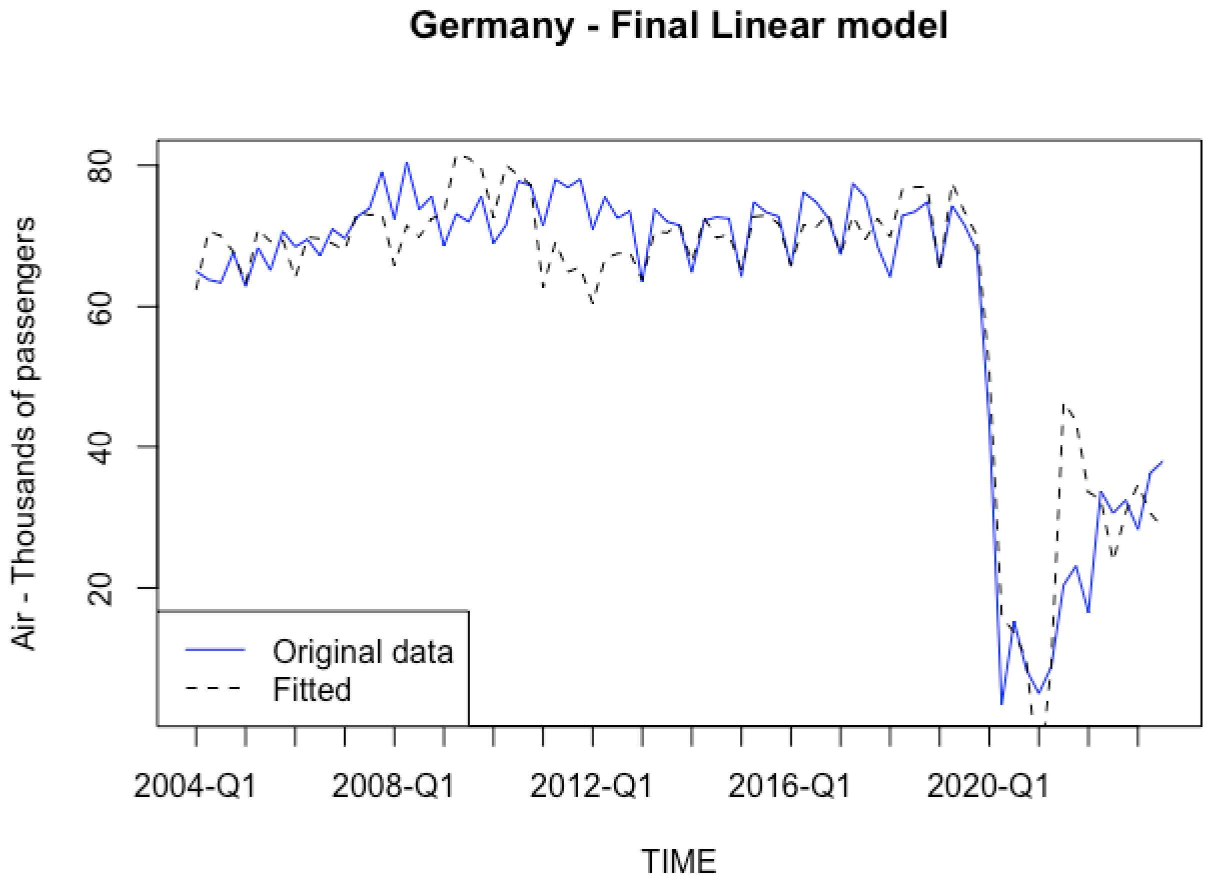
```
> vif(dePasBestSeasAdjVIF)
                                GVIF Df GVIF^(1/(2*Df))
QUARTER                     1.053874  3        1.008784
COVID_AVG_RESTRICTIONS_FACTOR 1.242625  2        1.055808
AIR_PRICE_S_ADJ             5.646416  1        2.376219
RAIL_PRICE_S_ADJ            2.821449  1        1.679717
GDP_PC                      8.489331  1        2.913646
```

Statistical modelling – Germany

Best linear model

- Better fit than the baseline
- Higher Adjusted R^2
- All the coefficients are significant

```
Coefficients:
                              Estimate Std. Error t value Pr(>|t|)
(Intercept)                    82.2528    18.7003   4.398 3.81e-05 ***
QUARTERQ2                       6.7174     2.2662   2.964  0.00415 **
QUARTERQ3                       5.4693     2.2777   2.401  0.01900 *
QUARTERQ4                       5.7419     2.3071   2.489  0.01520 *
COVID_AVG_RESTRICTIONS_FACTOR1 -36.8018    4.4453  -8.279 5.60e-12 ***
COVID_AVG_RESTRICTIONS_FACTOR2 -50.2180    5.3416  -9.401 4.88e-14 ***
AIR_PRICE_S_ADJ                -0.6874     0.1083  -6.349 1.88e-08 ***
RAIL_PRICE_S_ADJ                1.5185     0.1398  10.863  < 2e-16 ***
GDP_PC                        -10.6349     3.6496  -2.914  0.00479 **
---
```

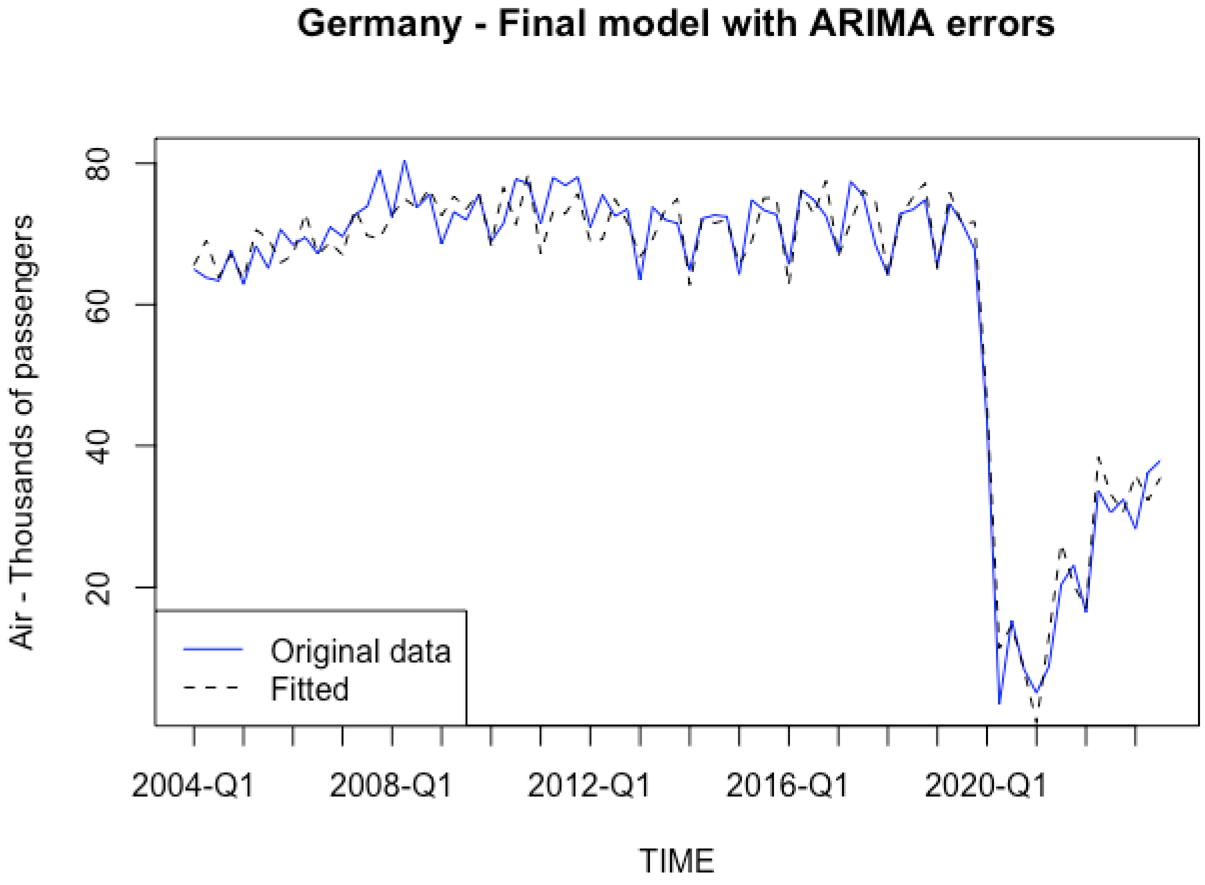


AICc = 547.685 Adjusted R^2 = 0.8776

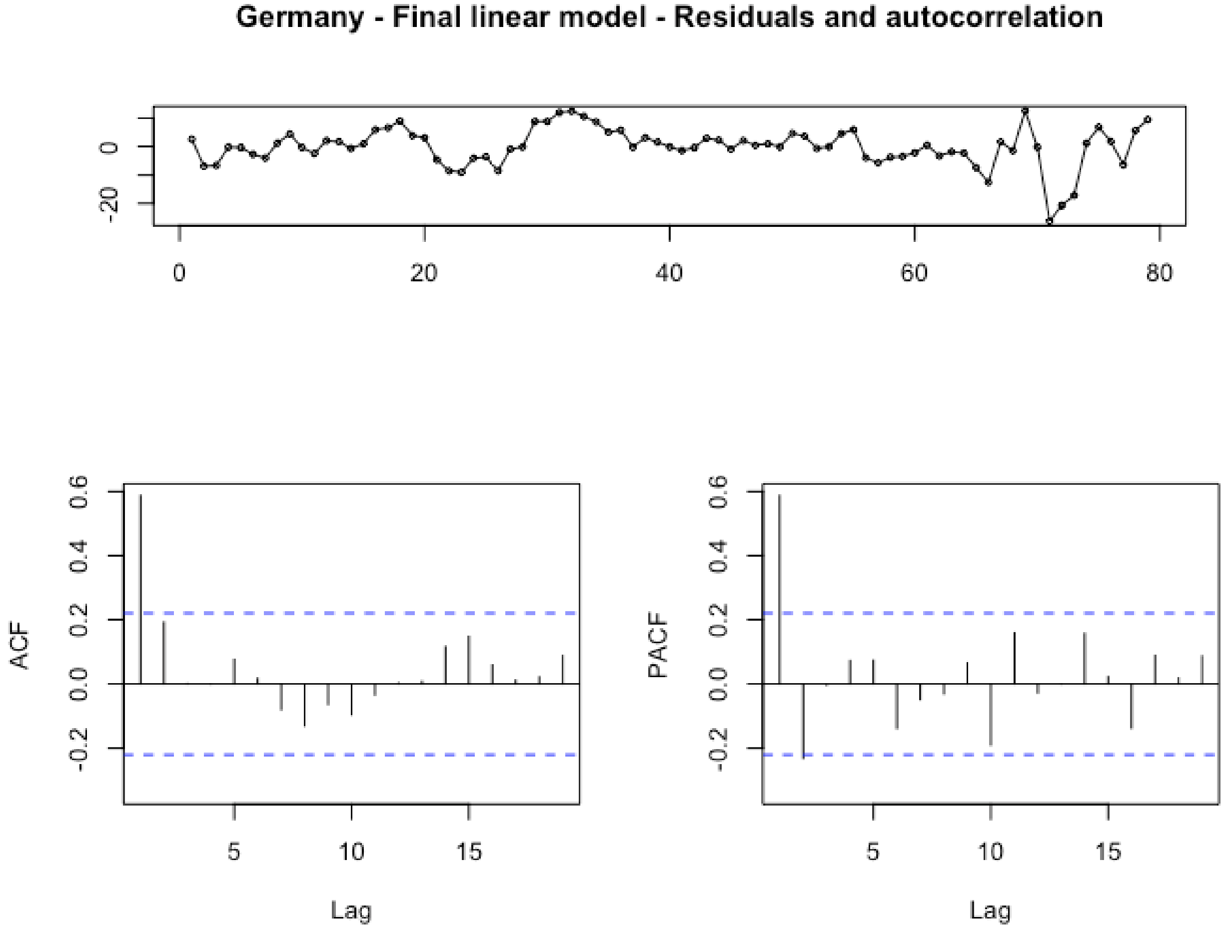
Statistical modelling – Germany

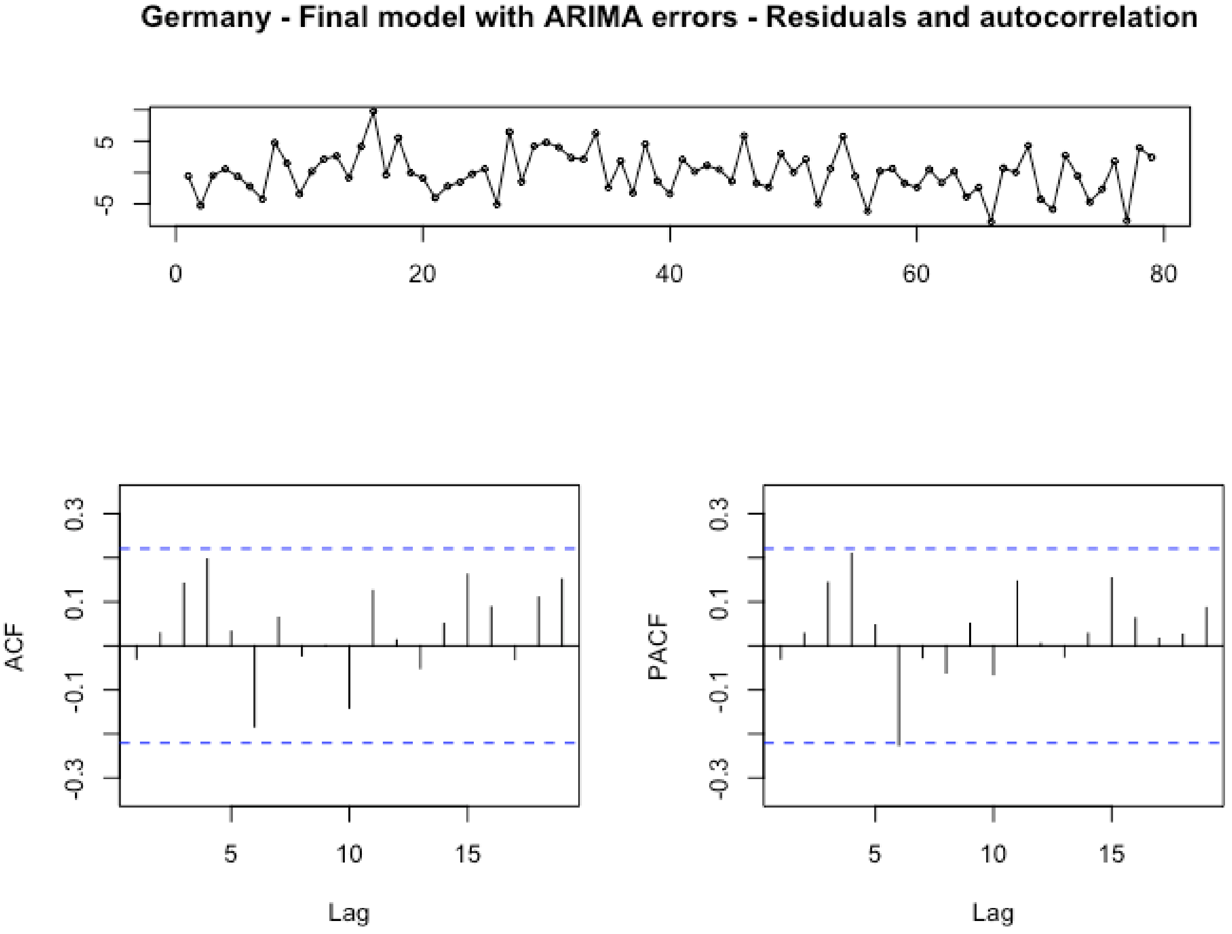
- Trying to improve using the **dynamic regression with ARIMA errors**
- Significantly better results
- ARIMA model indicates 2 moving average terms

```
Regression with ARIMA(0,0,2) errors

Coefficients:
         ma1     ma2  intercept  QUARTERQ2  QUARTERQ3  QUARTERQ4
      0.8419  0.5667    91.2717     6.0826     5.2767     7.0453
s.e.  0.1329  0.1779    43.5443     0.9789     1.0905     1.0363
      COVID_AVG_RESTRICTIONS_FACTOR1  COVID_AVG_RESTRICTIONS_FACTOR2  R_THS
                             -5.6173                         -7.9761
s.e.                          4.1083                          4.3874
        GDP_PC  AIR_PRICE_S_ADJ  RAIL_PRICE_S_ADJ  RAIL_DENSITY
      -14.5304          -0.5848            0.8329       -0.0168
s.e.    3.1695           0.1127            0.2020        0.5227

sigma^2 = 14.34:  log likelihood = -210.73
AIC=449.46   AICc=456.02   BIC=482.63
```



Statistical modelling – Germany





Statistical modelling – Germany

Insights:

- Somehow, Germany seems to have **reverted the tendency** to travel more by plane as GDP per capita grows (negative coefficient). **Why could this be?**
- **COVID restrictions** brought a negative effect.
- Unlike in Spain and Italy, air traffic in Germany depends on the **prices of both rail and air travel**. Interestingly enough, rail price has a stronger impact than air price.
- There is a **seasonality** present in the data, however it is smaller comparing to Spain and Italy (that can be seen from the plots as well).

Discussion

- Policymakers are trying to react (not only in these countries), **but is it enough?**

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France calls for minimum price on European flights

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Breaking news • Donald Trump does not have presidential immunity, rules US court

Measures deemed too timid to curb air traffic

But in general, associations and environmental NGOs point to the lack of ambitious structural measures to reduce air traffic-related CO2 emissions.

r example, issued a decree in May banning domestic flights when a train f less than 2.5 hours is possible. This measure is considered "anecdotal" by dvocates, as it concerns only a handful of routes out of the hundred or so

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When flight-shaming took off in 2018, it aimed to make people feel change their travel habits by highlighting the huge emissions we ge

Air travel cur expected to

But such a ra realistically r away.

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Train services must meet certain conditions to replace flights

ervices on the same route must be frequent, timely and ne needs of passengers who would otherwise travel by se in passenger numbers.

e able to make outbound and return train journeys on hours at their destination.

The end of budget flights? France pushes for minimum ticket prices in Europe

But many are wondering if these proposals are not just symbolic gestures. In particular, there is debate as to whether the suggested minimum prices are high enough to have a serious effect. Beaune has not fixed a figure for the minimum price and said that he "doesn't want to see ticket prices increase tenfold either."

Discussion

- For railway policies to make an impact on air traffic, its usage should be widely spread and deeply rooted. It **may not be easy** in all cases.
- When people are economically active, they tend to travel. It is essential to create **true alternatives** to airplanes if policymakers want to reduce their impact on the environment. Perhaps, **structural measures are needed**.
- Although there are elements in common, air traffic does not respond equally to the same factors in different countries. **There is no silver bullet.**

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DIPARTIMENTO MATEMATICA

Thank you