

FEDERAL STATE AUTONOMOUS EDUCATIONAL INSTITUTE  
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ITMO UNIVERSITY

Report on learning practice # 2  
Analysis of multivariate random variables

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## Non-parametric estimation of PDF for MRV

Figures 1 – 9 depict non-parametric estimations in form of histogram and using kernel density function for the chosen random variables.

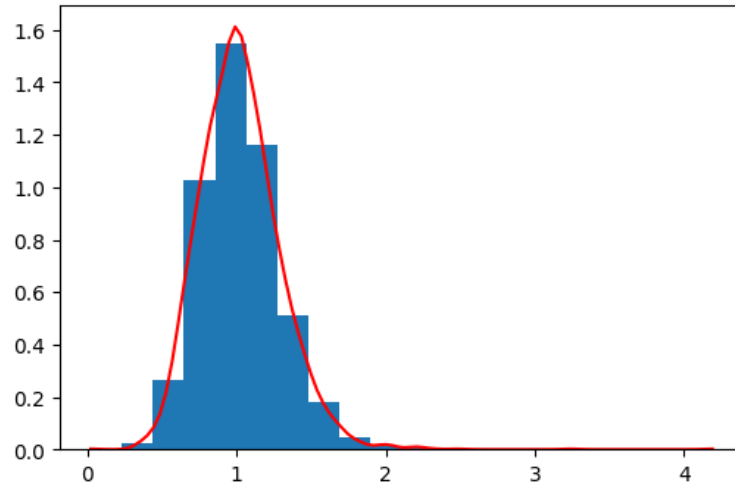


Figure 1 – Non-parametric estimation of PDF in form of histogram and using kernel density function for “Reproduction rate”

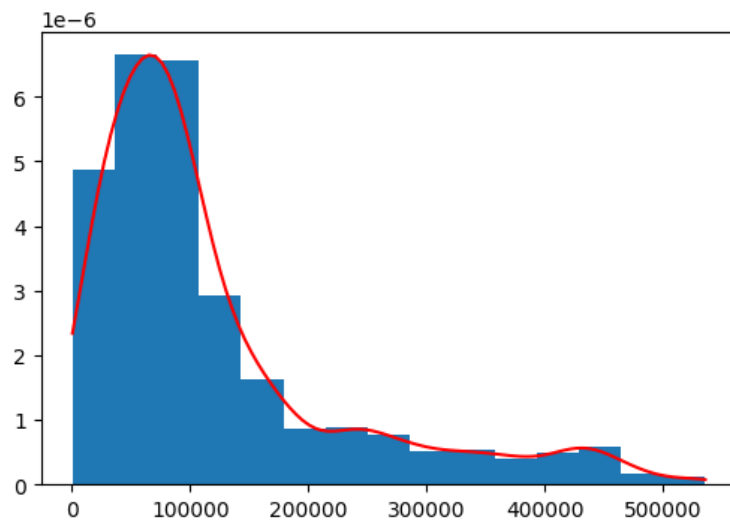


Figure 2 – Non-parametric estimation of PDF in form of histogram and using kernel density function for “Total cases per million”

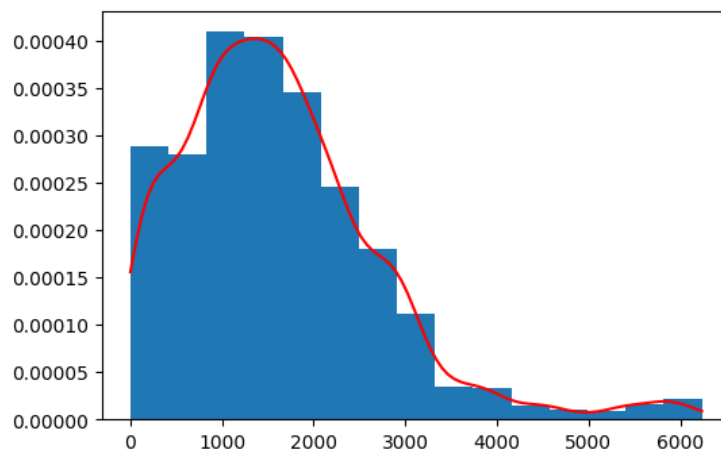


Figure 3 – Non-parametric estimation of PDF in form of histogram and using kernel density function for “Total deaths per million”

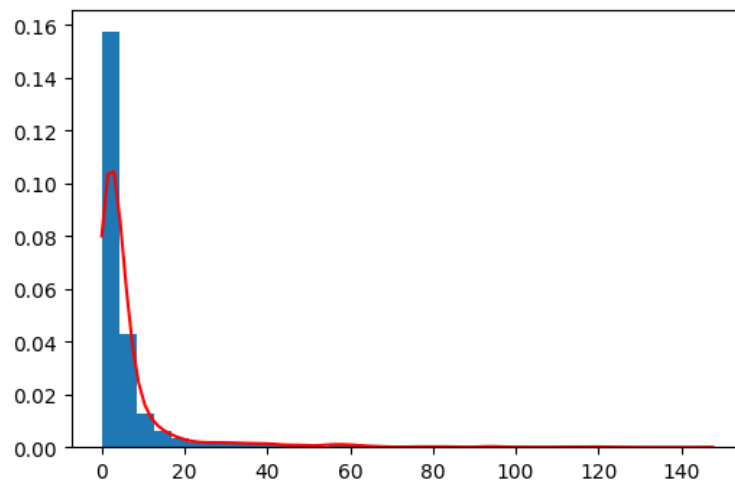


Figure 4 – Non-parametric estimation of PDF in form of histogram and using kernel density function for “New tests smoothed per thousand”

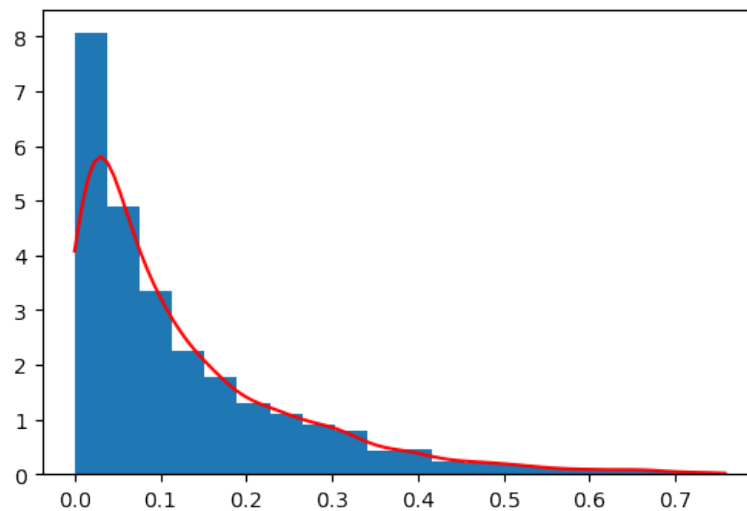


Figure 5 – Non-parametric estimation of PDF in form of histogram and using kernel density function for “Positive rate”

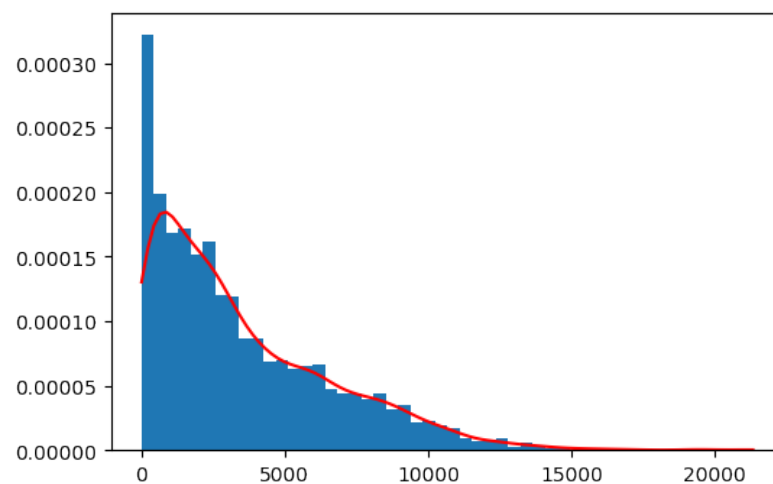


Figure 6 – Non-parametric estimation of PDF in form of histogram and using kernel density function for “New vaccinations smoothed per million”

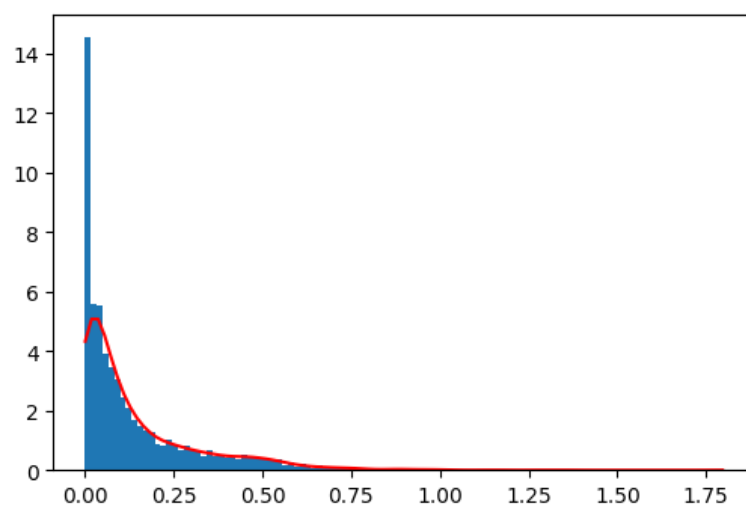


Figure 7 – Non-parametric estimation of PDF in form of histogram and using kernel density function for “New people vaccinated smoothed per hundred”

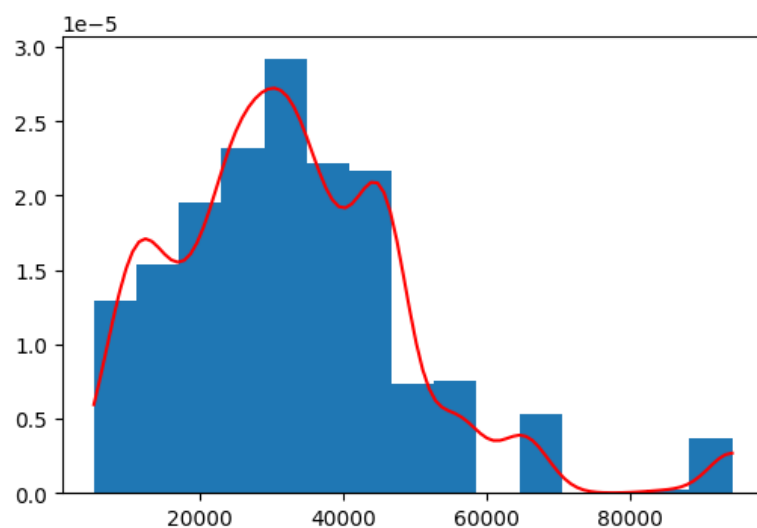


Figure 8 – Non-parametric estimation of PDF in form of histogram and using kernel density function for “GDP per capita”

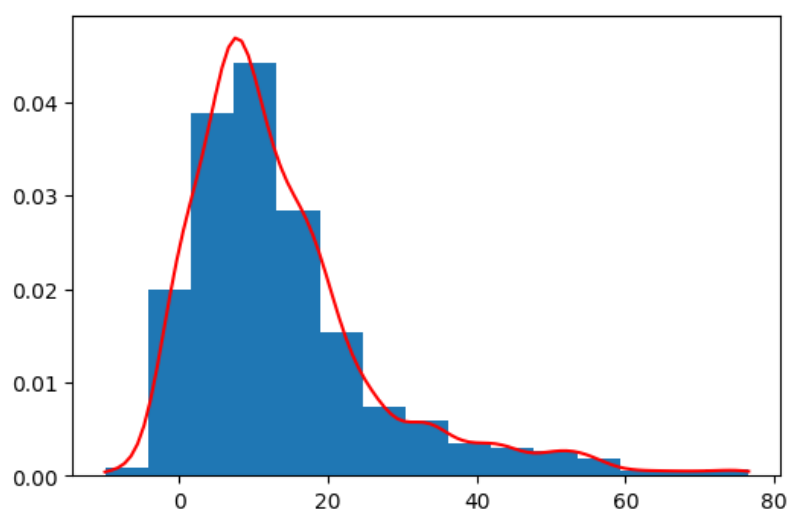


Figure 9 – Non-parametric estimation of PDF in form of histogram and using kernel density function for “Excess mortality cumulative”

Among given above-mentioned random variables, the first one is a target and the rest are predictors. Figures 10 – 17 show us joint probability density plots in form of histogram for variations between target and each predictor. Each image also contains points of different color. Colors represent data for different continents.

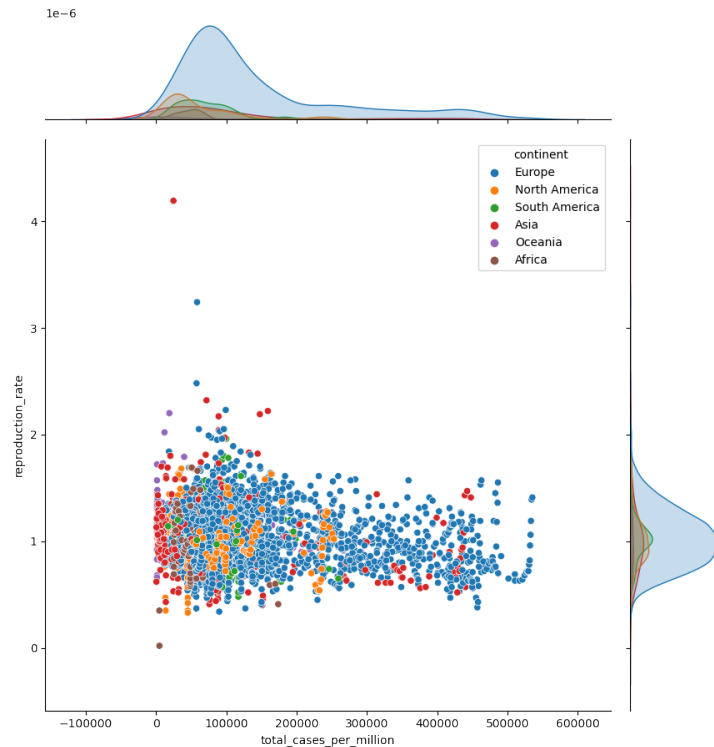


Figure 10 – Joint probability density plot in form of histogram between target “Reproduction rate” and predictor “Total cases per million”

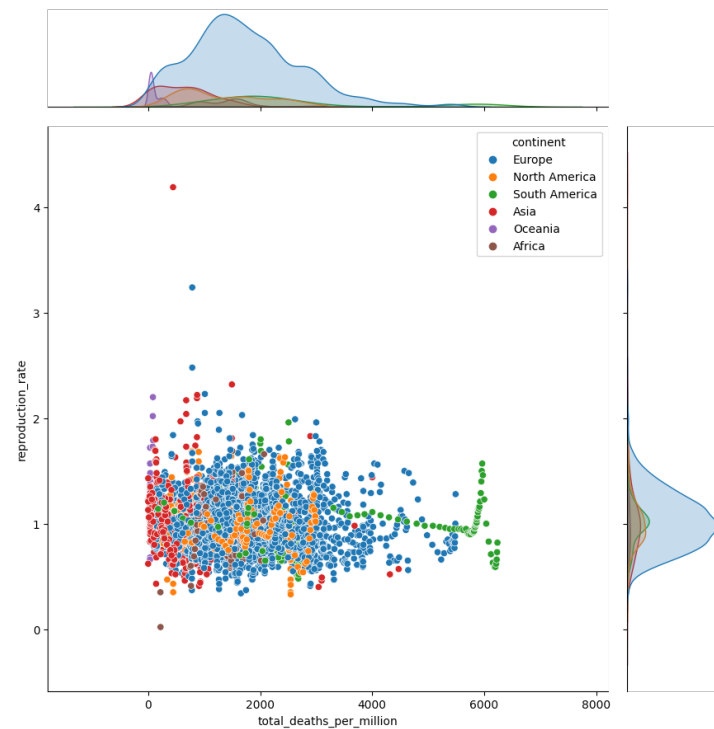


Figure 11 – Joint probability density plot in form of histogram between target “Reproduction rate” and predictor “Total deaths per million”

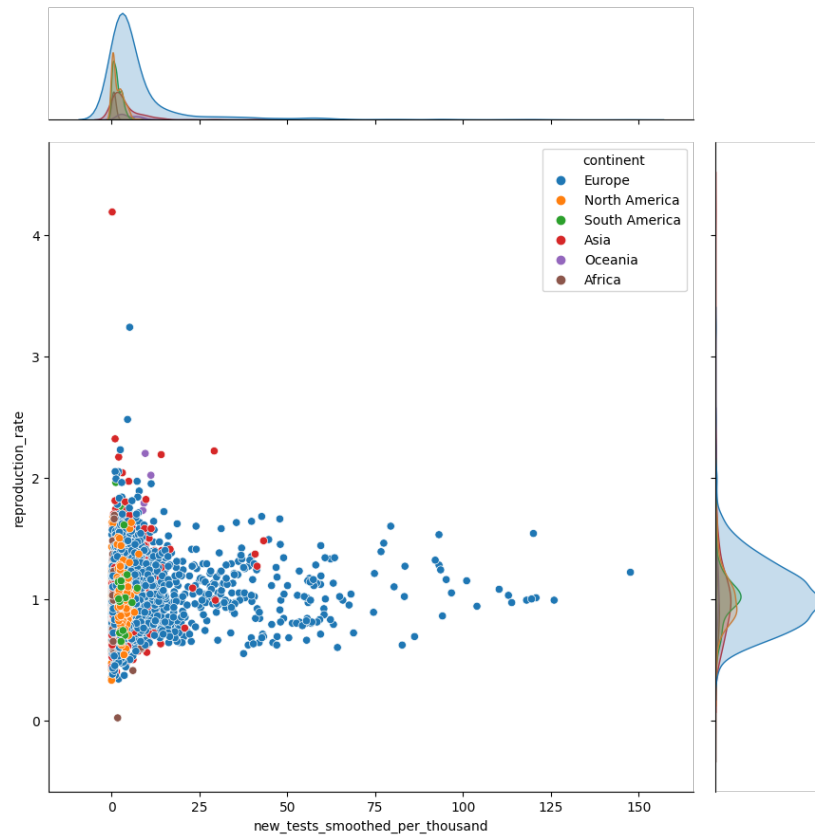


Figure 12 – Joint probability density plot in form of histogram between target “Reproduction rate” and predictor “New tests smoothed per thousand”

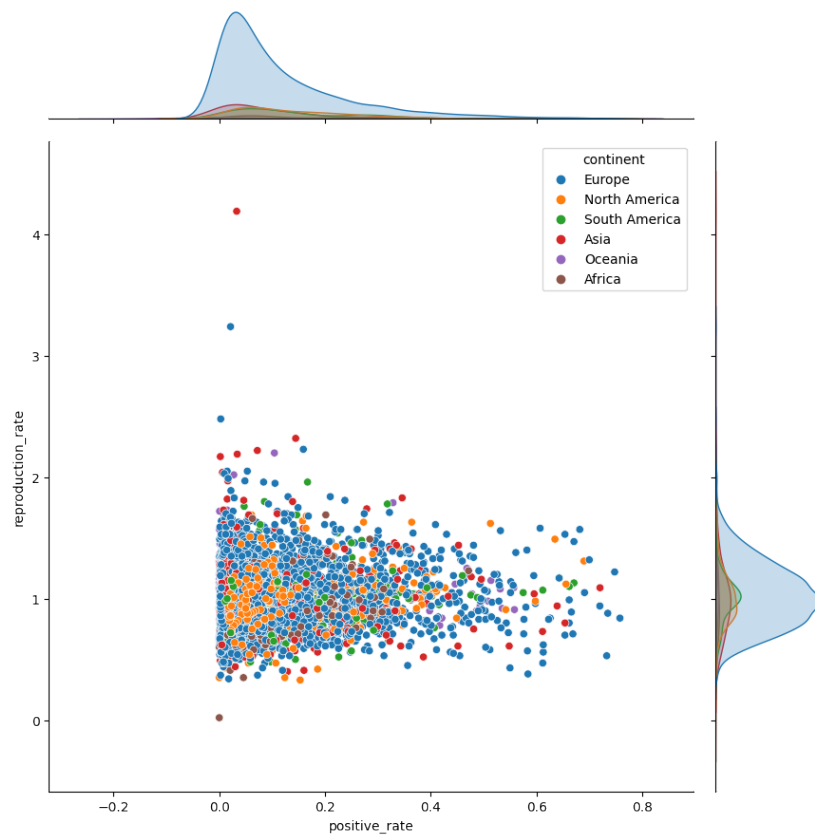


Figure 13 – Joint probability density plot in form of histogram between target “Reproduction rate” and predictor “Positive rate”

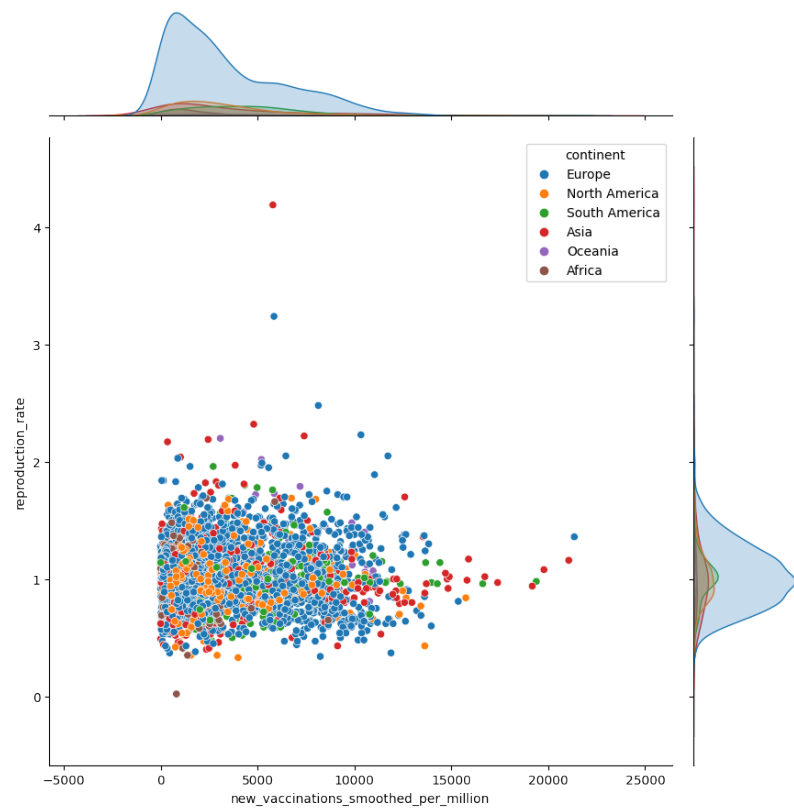


Figure 14 – Joint probability density plot in form of histogram between target “Reproduction rate” and predictor “New vaccinations smoothed per million”

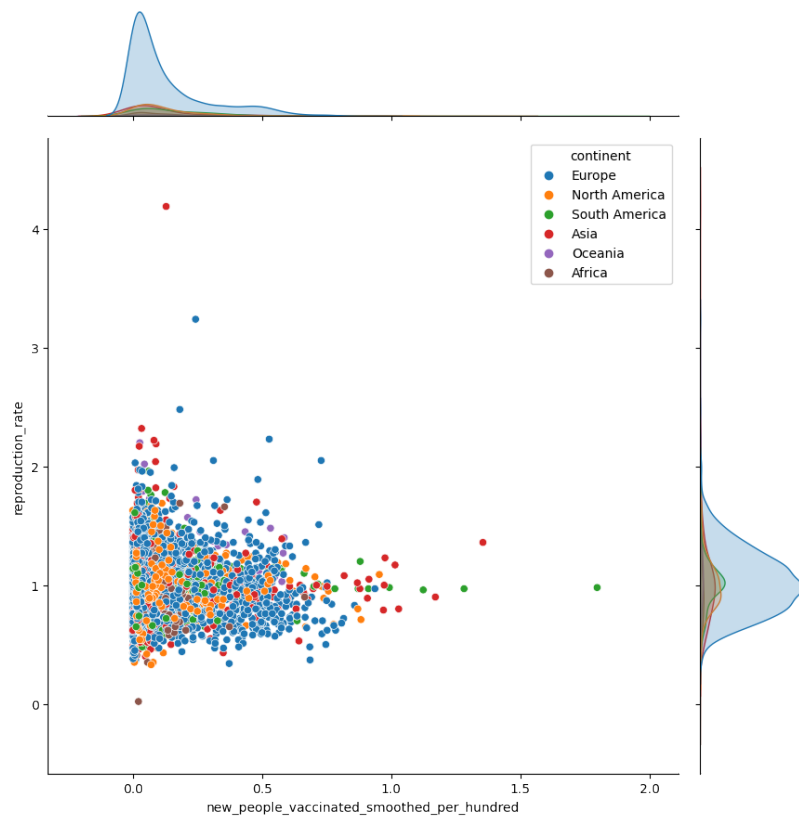


Figure 15 – Joint probability density plot in form of histogram between target “Reproduction rate” and predictor “New people vaccinated smoothed per hundred”

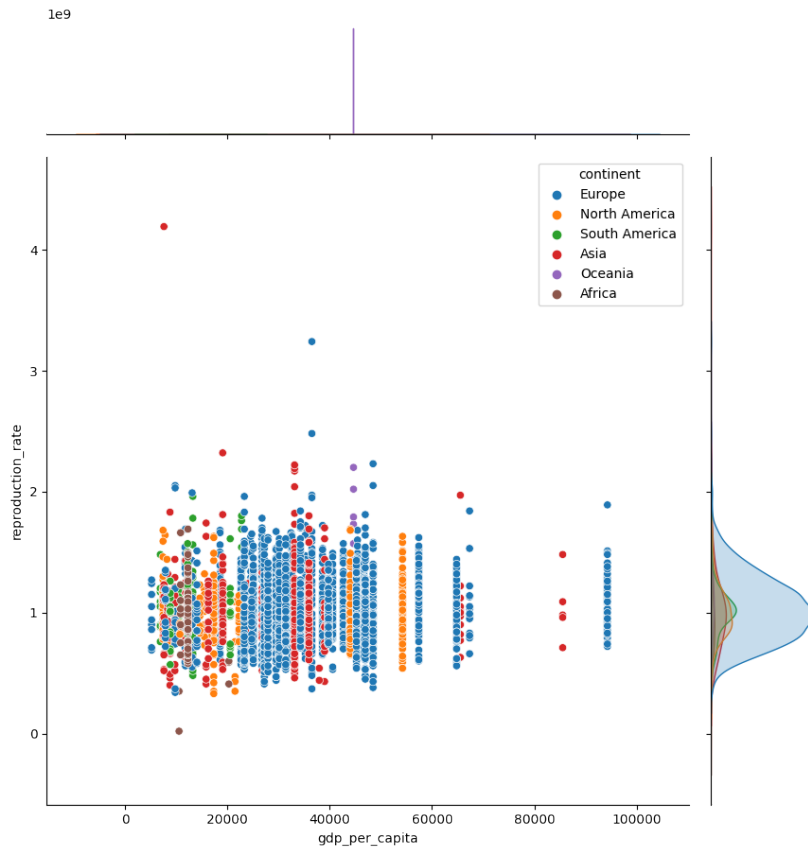


Figure 16 – Joint probability density plot in form of histogram between target “Reproduction rate” and predictor “GDP per capita”

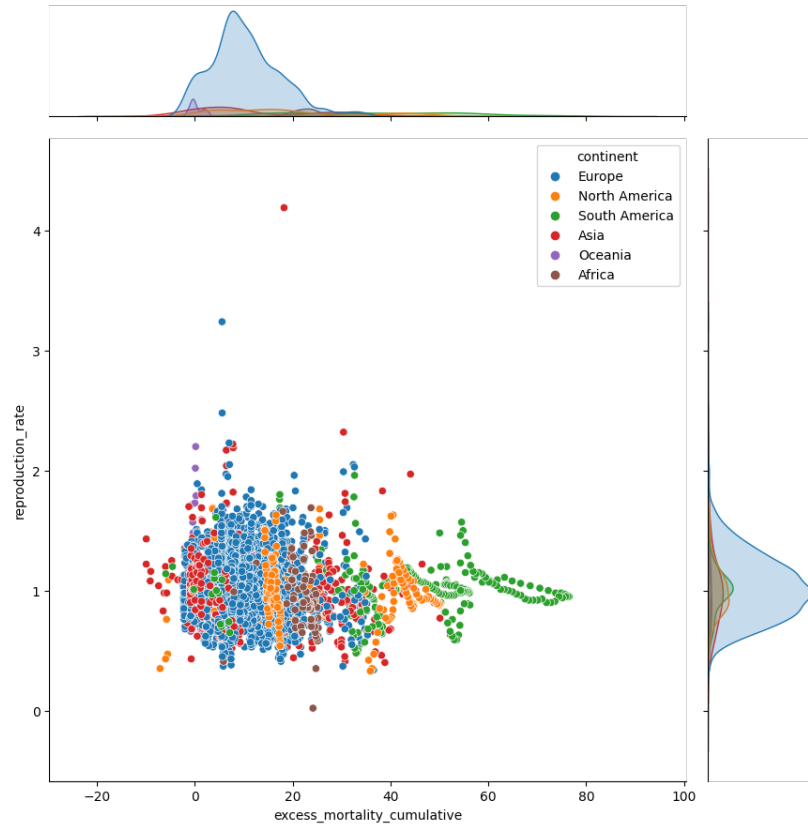


Figure 17 – Joint probability density plot in form of histogram between target “Reproduction rate” and predictor “Excess mortality cumulative”



Figures 18 – 25 show us joint probability density plots in form of kernel density function for variations between target and each predictor. Each image also contains lines of different color. Colors represent data for different continents.

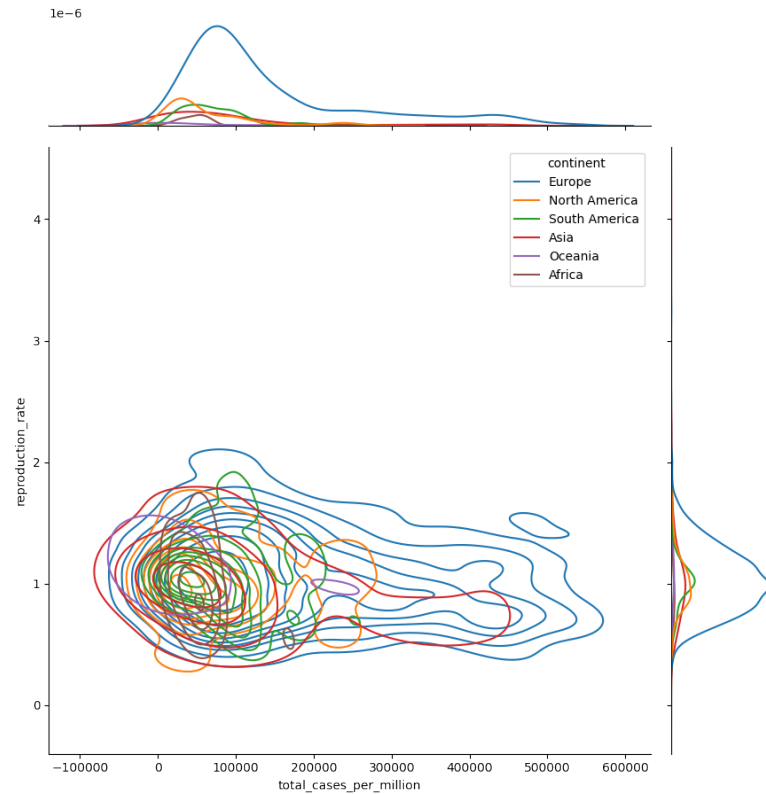


Figure 18 – Joint probability density plot in form of kernel density function between target “Reproduction rate” and predictor “Total cases per million”

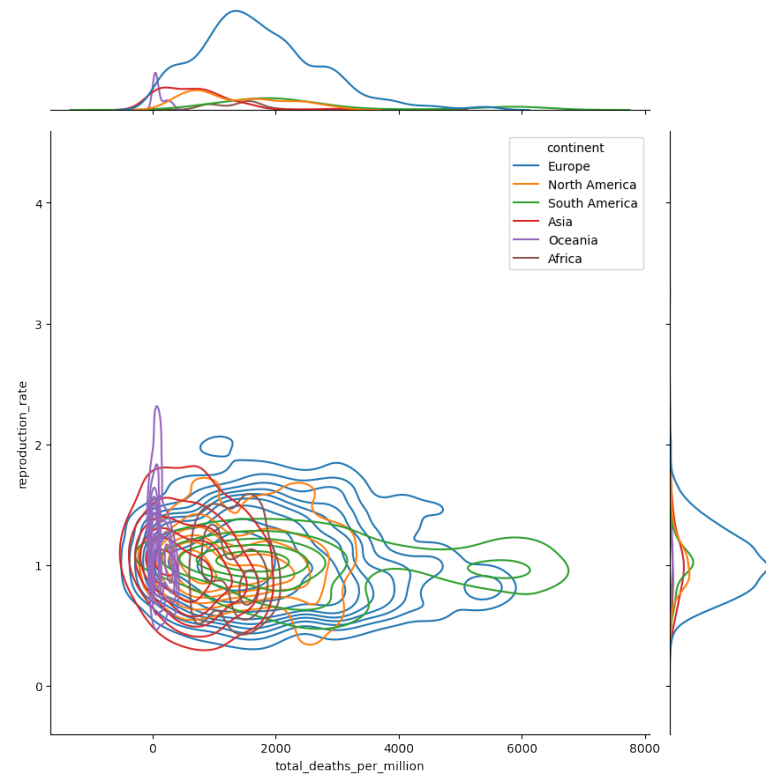


Figure 19 – Joint probability density plot in form of kernel density function between target “Reproduction rate” and predictor “Total deaths per million”

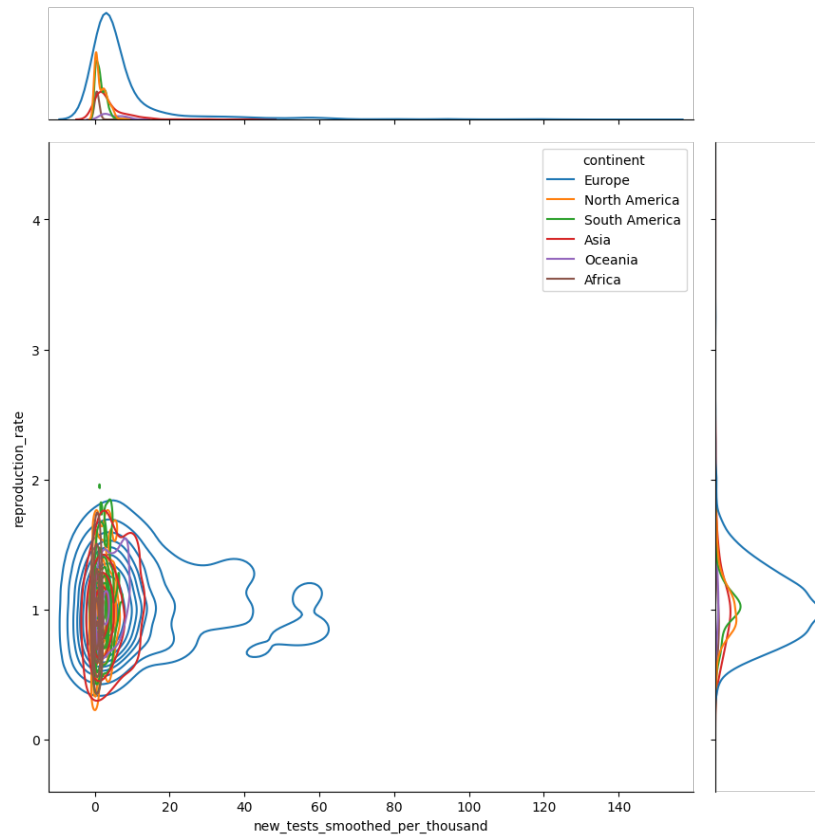


Figure 20 – Joint probability density plot in form of kernel density function between target “Reproduction rate” and predictor “New tests smoothed per thousand”

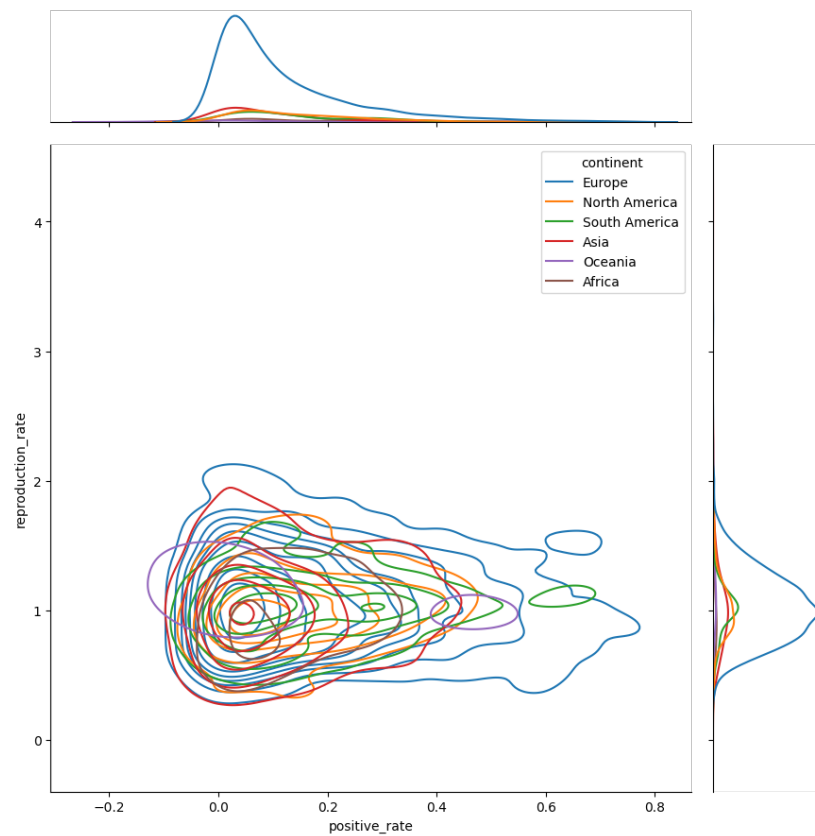


Figure 21 – Joint probability density plot in form of kernel density function between target “Reproduction rate” and predictor “Positive rate”

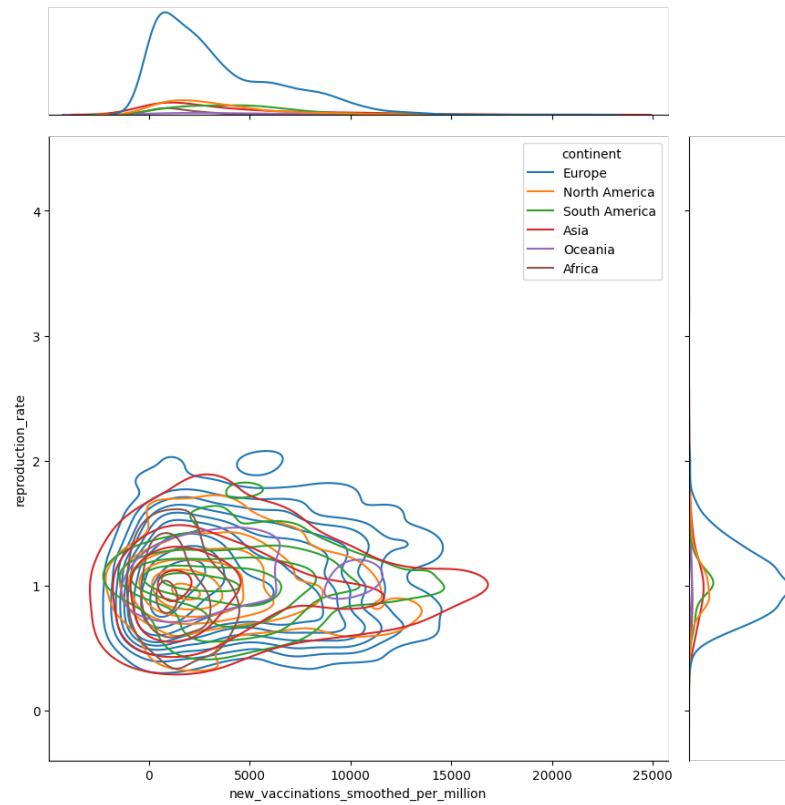


Figure 22 – Joint probability density plot in form of kernel density function between target “Reproduction rate” and predictor “New vaccinations smoothed per million”

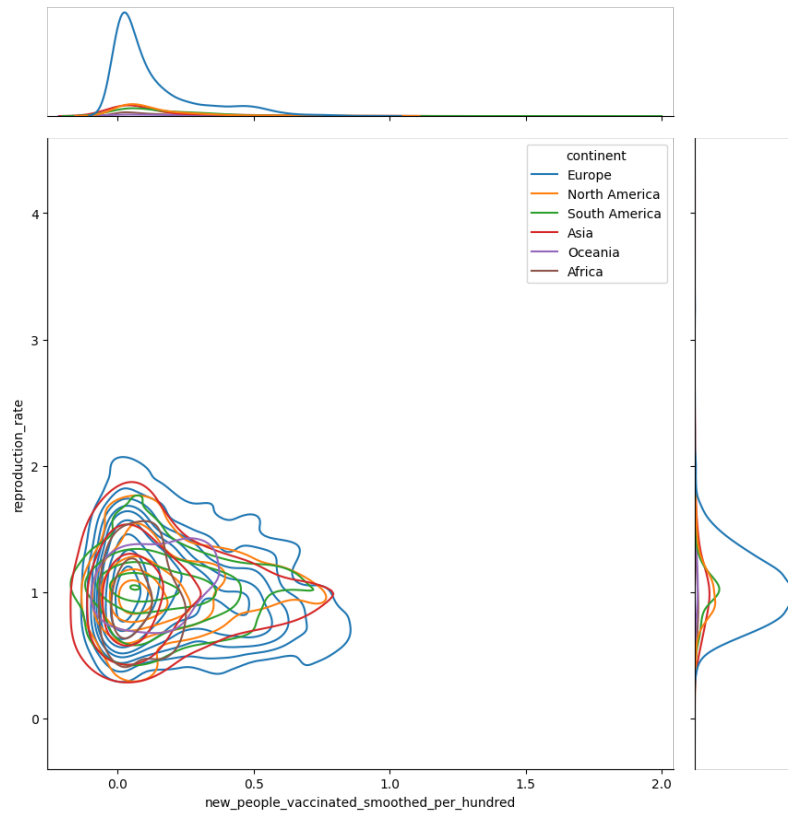


Figure 23 – Joint probability density plot in form of kernel density function between target “Reproduction rate” and predictor “New people vaccinated smoothed per hundred”

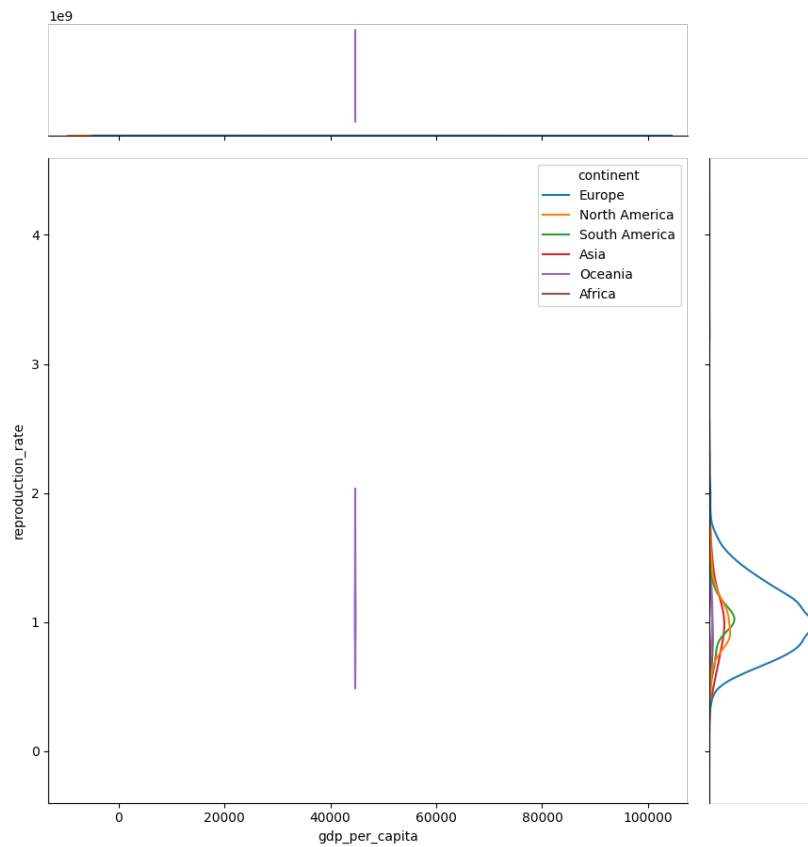


Figure 24 – Joint probability density plot in form of kernel density function between target “Reproduction rate” and predictor “GDR per capita”

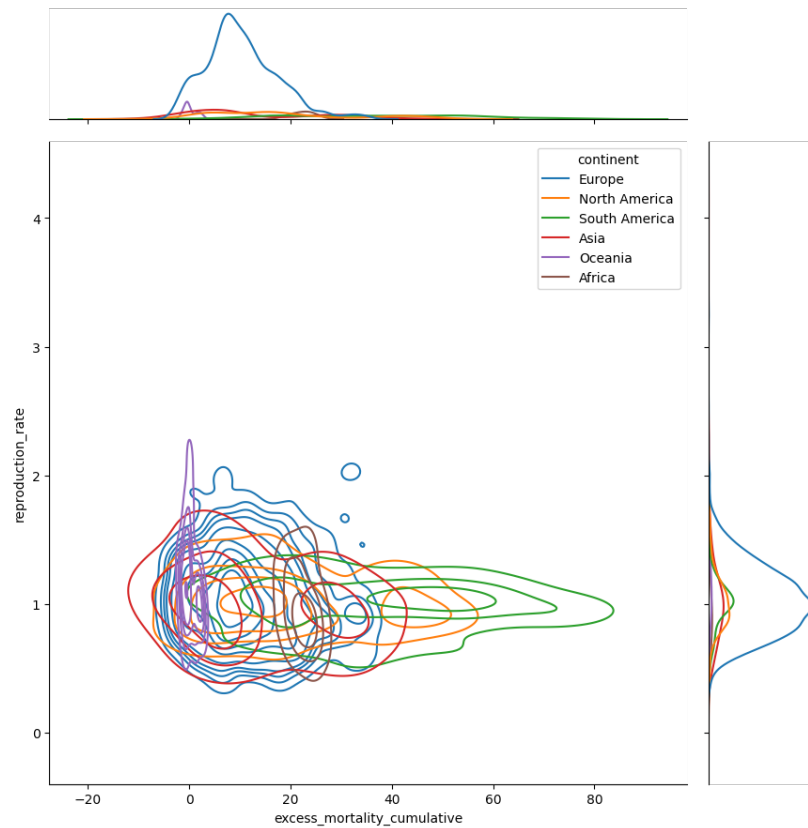


Figure 25 – Joint probability density plot in form of kernel density function between target “Reproduction rate” and predictor “Excess mortality cumulative”

The next Figure 26 depicts pairwise joint probability density histogram between five variables.

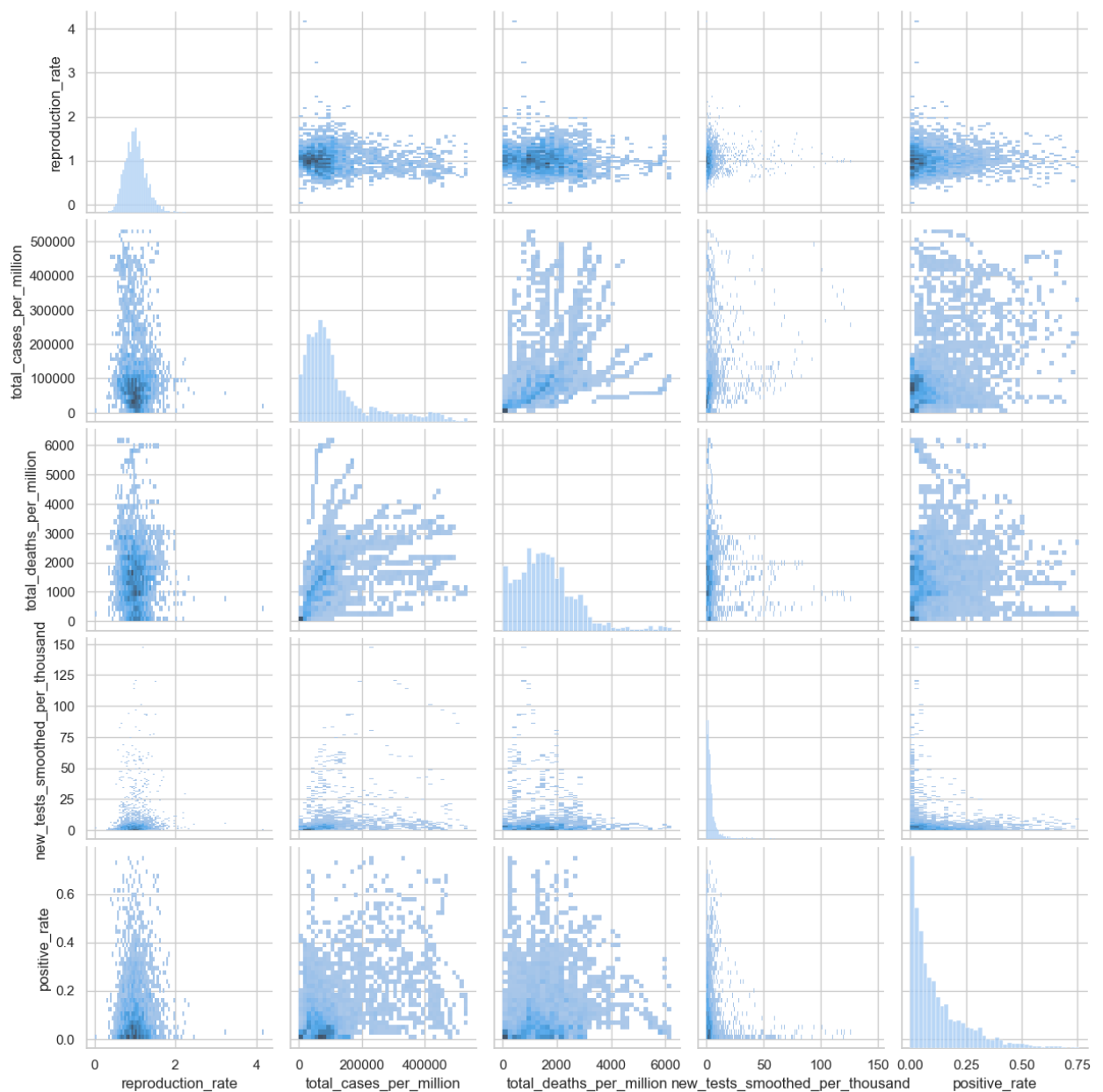


Figure 26 – Pairwise joint probability density between five random variables

#### Estimation of multivariate mean and variance

$X$	$E(X)$	$Var(X)$
Reproduction rate	1.023385	$7.484235 \cdot 10^{-2}$
Total cases per million	119878.364158	$1.217849 \cdot 10^{10}$
Total deaths per million	1617.485002	$1.206946 \cdot 10^6$
New tests smoothed per thousand	6.443801	$1.595720 \cdot 10^2$
Positive rate	0.123713	$1.702659 \cdot 10^{-2}$
New vaccinations smoothed per million	3508.352299	$1.004960 \cdot 10^7$

New people vaccinated smoothed per hundred	0.139452	$3.113892 \cdot 10^{-2}$
GDP per capita	32880.455968	$2.839982 \cdot 10^8$
Excess mortality cumulative	13.950828	$1.721878 \cdot 10^2$

Table 1 – Estimation of multivariate mathematical expectation and variance for the chosen variables

### Non-parametric estimation of conditional distributions, mathematical expectations and variances

Let condition  $C$  be *Reproduction rate* = 1.0. So, Figure 27 depicts distribution of variables under this condition. And Table 2 contains conditional mathematical expectation and conditional variance.

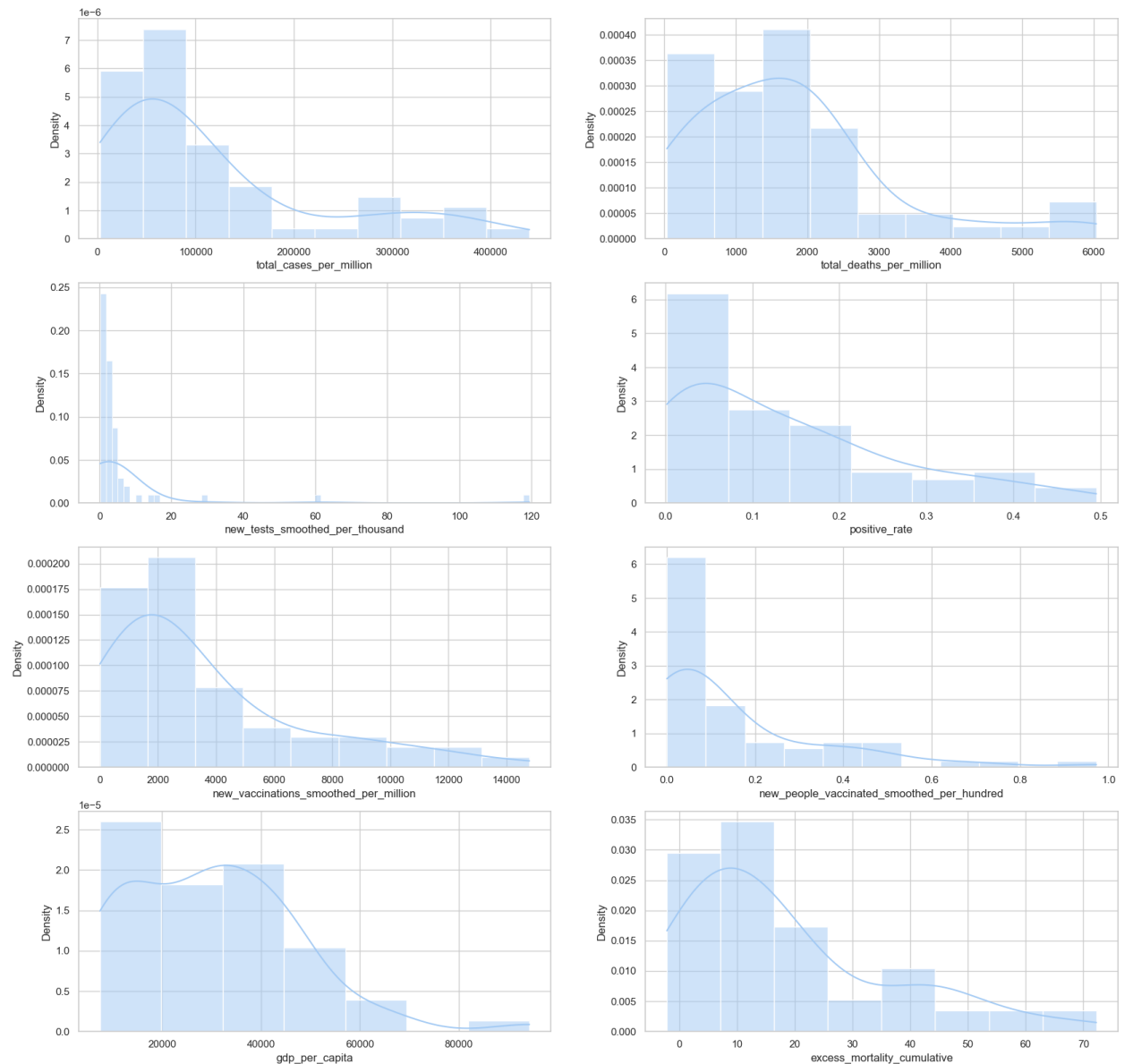


Figure 27 – Conditional distributions of variables

$X$	$E(X C)$	$Var(X C)$
Total cases per million	113775.970403	$1.250462 \cdot 10^{10}$
Total deaths per million	1743.478855	$1.921855 \cdot 10^6$
New tests smoothed per thousand	6.184790	$1.875900 \cdot 10^2$
Positive rate	0.135581	$1.613816 \cdot 10^{-2}$
New vaccinations smoothed per million	3569.225806	$1.184156 \cdot 10^7$
New people vaccinated smoothed per hundred	0.153016	$4.130244 \cdot 10^{-2}$
GDP per capita	30048.161435	$3.001686 \cdot 10^8$
Excess mortality cumulative	18.273065	$3.198207 \cdot 10^2$

Table 2 – Conditional mathematical expectation and conditional variance for predictors

### Estimation of pair correlation coefficients, confidence intervals for them and significance levels

Figure 28 shows pair correlation coefficients represented as a heatmap diagram. Table 3 contains information about confidence intervals for them and significance level.

$X$	$Y$	Coefficient	Conf. interval	Signif. level
Total cases per million	Total deaths per million	0.3592	(0.3427, 0.4092)	0.000000
New vaccinations smoothed per million	Excess mortality cumulative	-0.0630	(-0.0963, -0.0298)	0.000202
New people vaccinated smoothed per hundred	Excess mortality cumulative	-0.0031	(-0.0363, 0.0302)	0.856135
GDP per capita	Excess mortality cumulative	-0.5742	(-0.6871, -0.6206)	0.000000
Total cases per million	New vaccinations smoothed per million	-0.3183	(-0.3629, -0.2965)	0.000000

Table 3 – Pair correlation coefficients confidence intervals and significance levels

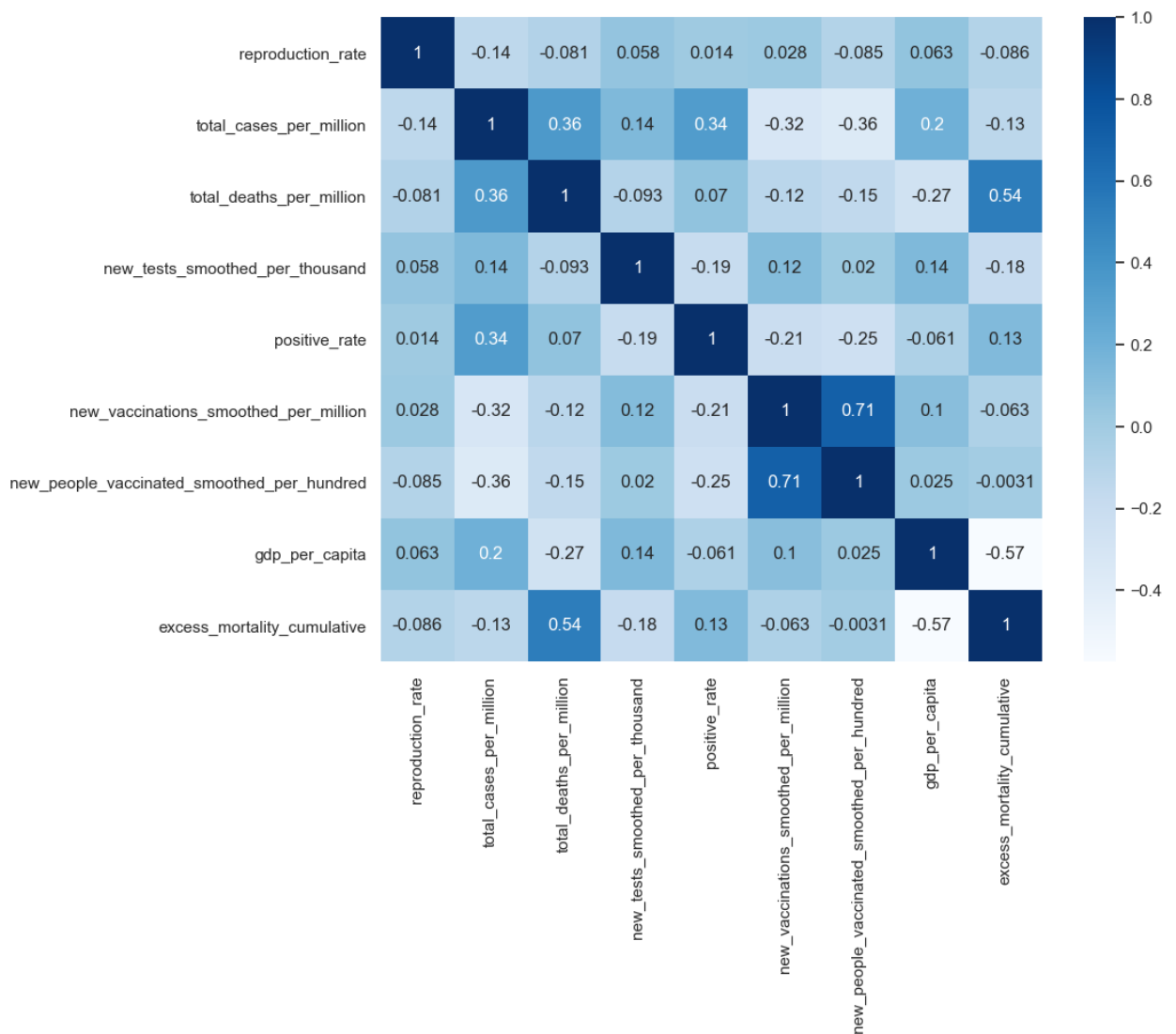


Figure 28 – Pair correlation coefficients

Let's highlight the most significant correlations in our data:

- new\_people\_vaccinated\_smoothed\_per\_hundred & new\_vaccinations\_smoothed\_per\_million: 0.71 (strong positive correlation);
- gdp\_per\_capita & excess\_mortality\_cumulative: -0.57 (average negative correlation);
- excess\_mortality\_cumulative & total\_deaths\_per\_million: 0.54 (average positive correlation);
- total\_deaths\_per\_million & total\_cases\_per\_million: 0.36 (average positive correlation)
- new\_people\_vaccinated\_smoothed\_per\_hundred & total\_cases\_per\_million: -0.36 (average negative correlation);
- positive\_rate & total\_cases\_per\_million: 0.34 (average positive correlation);
- new\_vaccinations\_smoothed\_per\_million & total\_cases\_per\_million: -0.32 (average negative correlation);
- total\_deaths\_per\_million & gdp\_per\_capita: -0.27 (average negative correlation);

The remaining correlations have a small dependence and their contribution is insignificant.



## Task formulation for regression, multivariate correlation

Training a model for predicting “Reproduction rate” based on “Total cases per million”, “Total deaths per million”, “New tests smoothed per thousand”, “Positive rate”, “New vaccinations smoothed per million”, “New people vaccinated smoothed per hundred”, “GDP per capita”, “Excess mortality cumulative” variables.

## Regression model, multicollinearity and regularization

We have built regression model. Table 4 consist of metrics obtained after fitting ordinal regression model.

Metric	Value
Mean Absolute Error	0.192338
Mean Squared Error	0.653560
R2 Score	0.063770
Mean Absolute Percentage Error	20.379919

Table 4 – Ordinal regression model metrics

After that we have applied Lasso regularization to model (with  $\alpha = 0.1$ ). Table 5 consist of metrics obtained after fitting Lasso-regression model.

Metric	Value
Mean Absolute Error	0.193504
Mean Squared Error	0.067059
R2 Score	0.039364

Table 5 – Lasso-regression model metrics

Finally, a LARS regression was used. Table 6 shows its metrics.

Metric	Value
Mean Absolute Error	0.192338
Mean Squared Error	0.065356
R2 Score	0.063770

Table 6 – LARS model metrics

Also  $2^{nd}$  degree polynomial regression models was fitted.

## Quality analysis for regression model

Figure 29 illustrates real values and values predicted by linear model for “Reproduction rate” variable. Figure 30 contains Quantile-Quantile plot for this model. Distribution of residuals for linear model is depicted at Figure 31. Table 7 contains confident intervals for regression coefficients for linear regression.

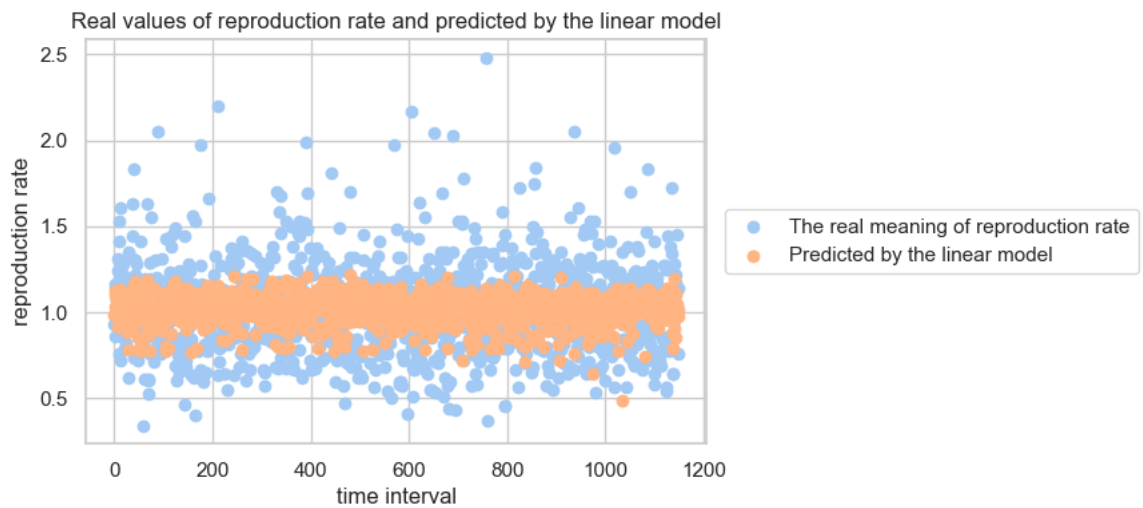


Figure 29 – Real and predicted points by linear model

Figure 32 illustrates real values and values predicted by polynomial model for “Reproduction rate” variable. Figure 33 contains Quantile-Quantile plot for this model.

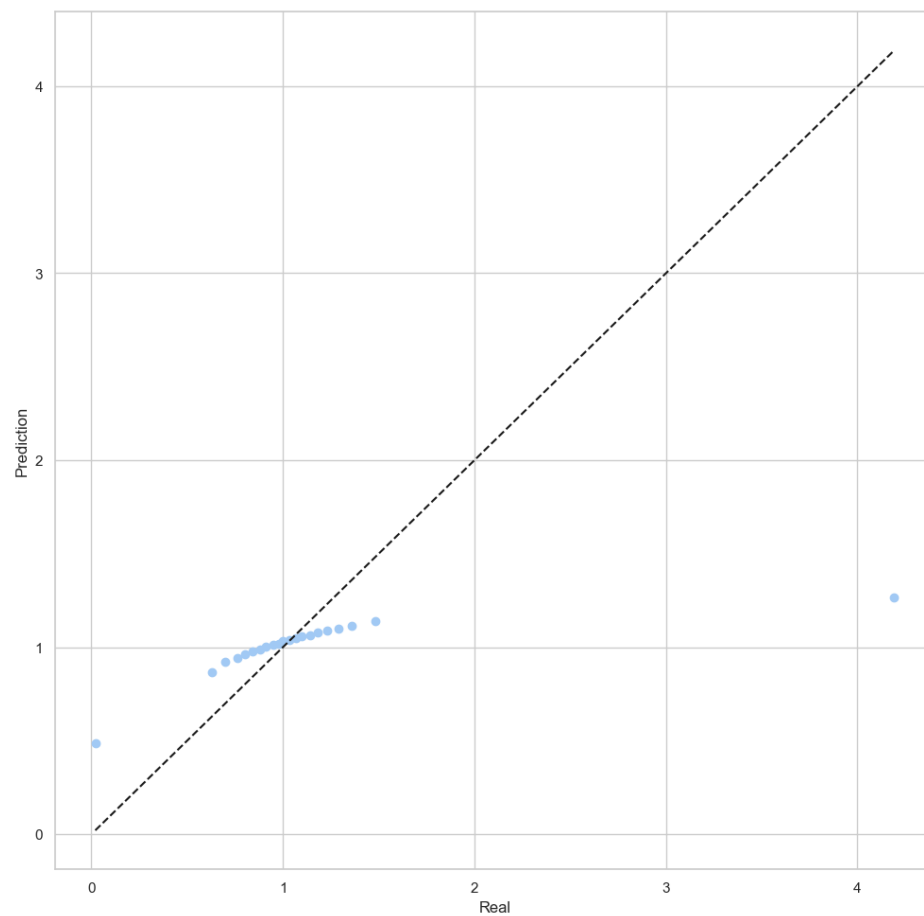


Figure 30 – QQ-plot for linear model

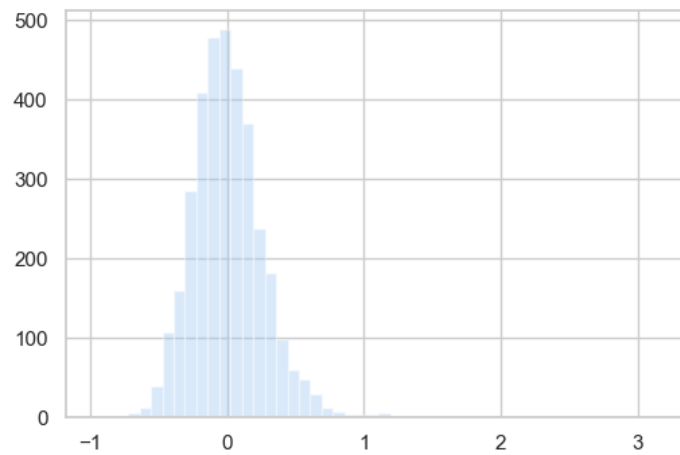


Figure 31 – Distribution of residuals for linear model

Let's apply the Anderson test to check the distribution of residuals for normality:

Statistic: 14.264

significance level: critical values

15.0: 0.575, data does not look normal (reject H0)

10.0: 0.655, data does not look normal (reject H0)

5.0: 0.786, data does not look normal (reject H0)

2.5: 0.917, data does not look normal (reject H0)

1.0: 1.091, data does not look normal (reject H0)

We also apply Kolmogorov-Smirnov Test and Cramer–Von Mises Test to check the distribution of residuals for normality:

Kolmogorov-Smirnov Test: 0.00001

Cramer–Von Mises Test: 0.00000

So, residuals are not distributed normally.

$X$	Interval left	Interval right
Total cases per million	$-8.315253 \cdot 10^{-7}$	$-3.065669 \cdot 10^{-7}$
Total deaths per million	$7.420195 \cdot 10^{-5}$	$1.260864 \cdot 10^{-4}$
New tests smoothed per thousand	$4.017558 \cdot 10^{-3}$	$7.307548 \cdot 10^{-3}$
Positive rate	$5.893598 \cdot 10^{-1}$	$9.321734 \cdot 10^{-1}$
New vaccinations smoothed per million	$1.731372 \cdot 10^{-5}$	$3.541832 \cdot 10^{-5}$
New people vaccinated smoothed per hundred	$-2.714395 \cdot 10^{-1}$	$6.117958 \cdot 10^{-2}$
GDP per capita	$1.425285 \cdot 10^{-5}$	$1.633377 \cdot 10^{-5}$
Excess mortality cumulative	$8.211649 \cdot 10^{-3}$	$1.238924 \cdot 10^{-2}$

Table 7 – Confidence interval of regression coefficients

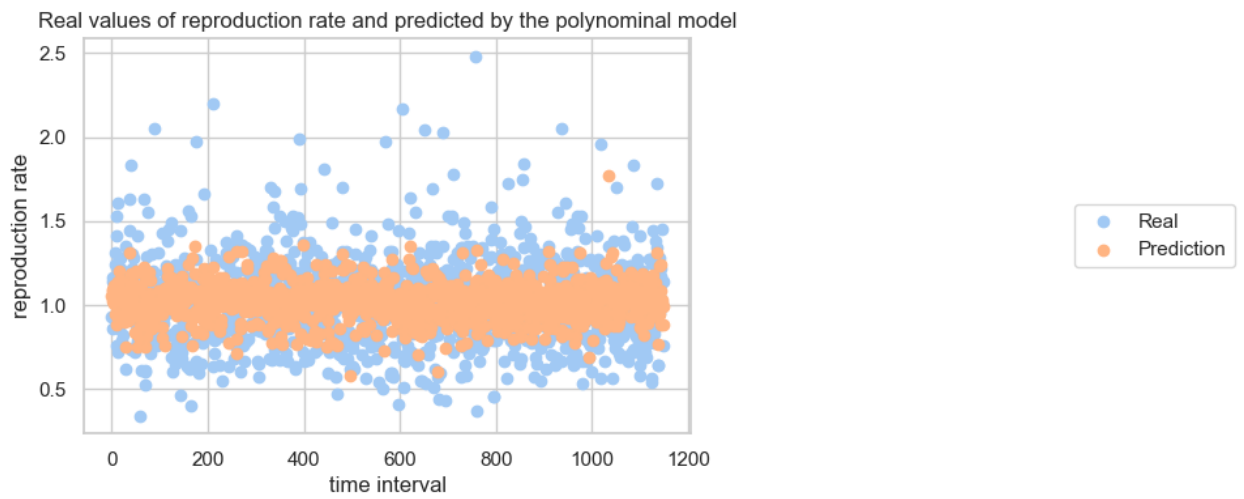


Figure 32 – Real and predicted points by polynomial model

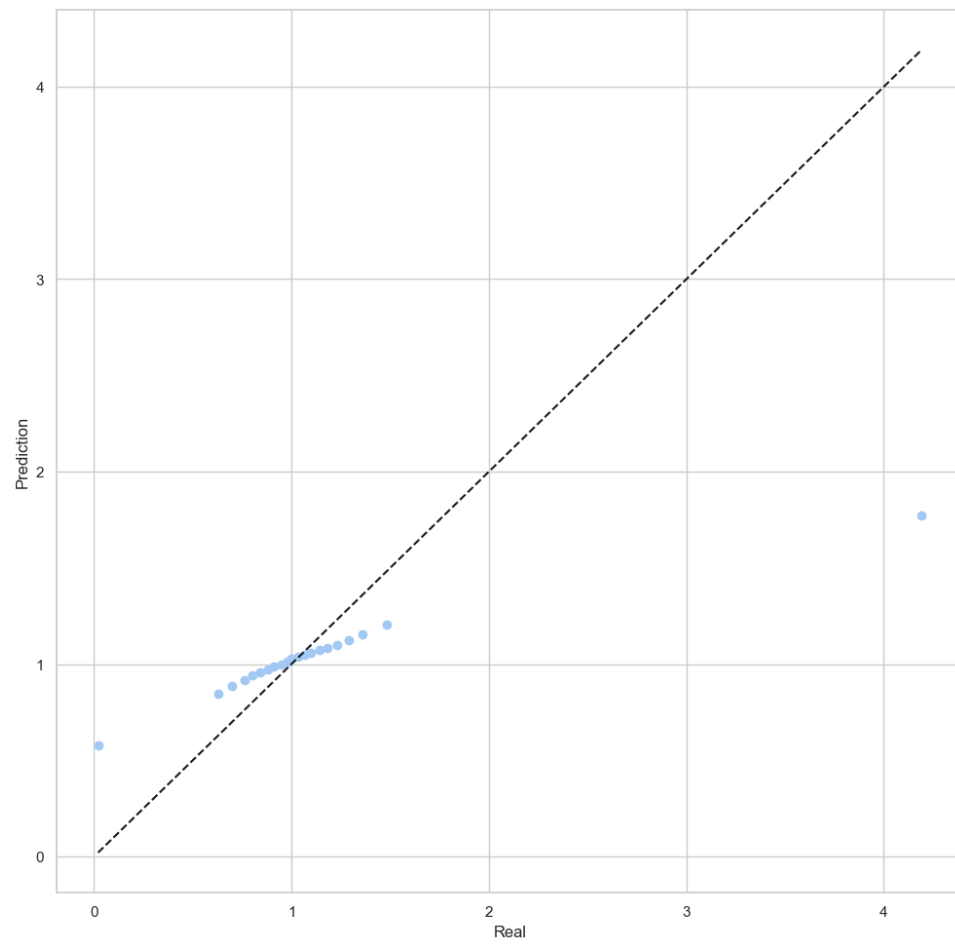


Figure 33 – QQ-plot for polynomial model

## **Appendix**

[https://github.com/D3lph1/methods-and-models-for-multivariate-data-analysis/blob/master/Lab%202/lab\\_2\\_notebook.ipynb](https://github.com/D3lph1/methods-and-models-for-multivariate-data-analysis/blob/master/Lab%202/lab_2_notebook.ipynb)