

Models Comparison for Liver Cirrhosis Survival Prediction

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July 5, 2024

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1 Introduction

The liver is the **second largest organ** in the human body and **one of the most important for human health**. Cirrhosis is a progressive condition that puts both a person's liver and life at risk. [1]

Different models can be compared to determine **which one best predicts the likelihood of a patient to survive against the disease**.

2 Dataset

This study utilizes the Cirrhosis Prediction Dataset available on **Kaggle**[2], comprising data collected from the **Mayo Clinic trial in primary biliary cirrhosis** (*PBC*) of the liver conducted between 1974 and 1984.

The dataset includes various information such as Cholesterol, Triglycerides, and, crucially, the patient's **status**. In total, there are 418 observations with 20 attributes.

3 Data Visualization

3.1 Preliminary Adjustments

Before commencing with a complete dataset visualization, several **adjustments** were made for some features:

- All features of type "object" were converted to "**category**" (in order to plot barplots and use the describe function provided in pandas with specific characteristics for this type of features).
- The "ID" column was **dropped** as it is useless for the analysis, solely serving as an **identifier**.
- The "Stage" feature, originally represented as *float64*, was converted to **categorical**, since it can be considered the **name** of the current liver condition.
- Age, initially reported in **days**, was converted to years using the formula: $\text{round}(\frac{x}{365}, 0)$.

This was just made for visualization reasons.

- Status **C** was converted to "High chance", Status **CL** was converted to "Transplant needed" and Status **D** was converted to "Low chance" (again, still just for visualization reasons).

3.2 Plot Analysis

By looking at the **heatmap** of the numerical features (Figure 1),

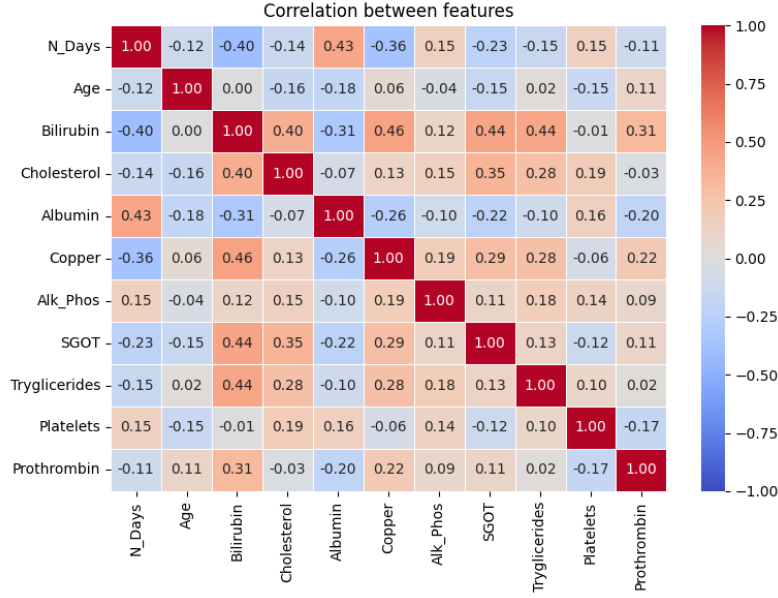


Figure 1: Heatmap of all numerical features.

one can see that there is **no strong positive/negative correlation** between them. For this reason, we cannot drop features based on their correlation, indeed no couples contain the **same type of information**.

Figure 2 demonstrates the **imbalanced distribution** of the dataset labels.

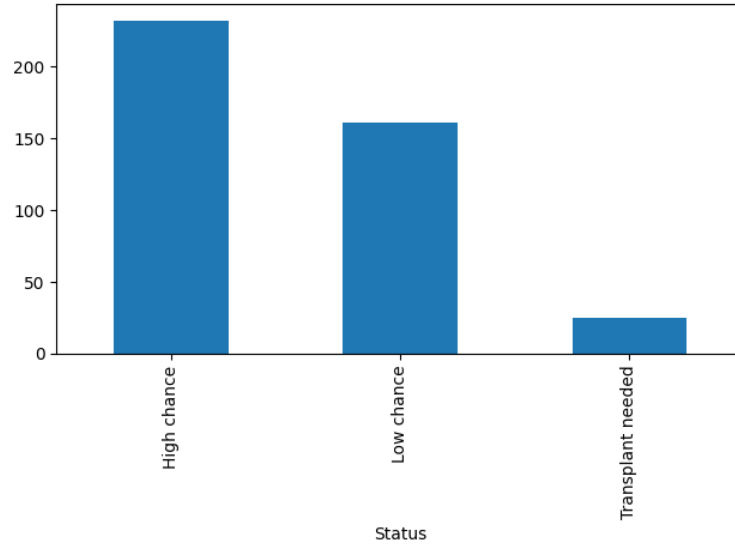


Figure 2: Distribution of patient statuses.

This is an important information not only for the **correct implementation of the pipelines** (imputing missing values, re balancing) but also to decide **how we will evaluate their performances** to select the best at predicting the correct chance of survival of the patient.

4 Preprocessing

The Train set showed lots of *NaN* values, but due to the low number of observation found, removing all of them was not a possible option in order to **maintain a substantial number of information**.

In order to replace *NaN* values in numerical features with plausible values, a **CustomKNNImputer** with **different values of k -neighbours** was used. The imputing was done also by dividing patients **by label** in order to create new values only considering **neighbours of the same class** (this can lead to more separate classes and better classification. Indeed by doing this we assure that, when we have an imbalanced problem, imputed values are **drawn from instances within the same class**, reducing the risk of **bias** introduced by imputing based on the **majority class**).

For categorical features, in order to replace *NaN* values with plausible values, a **CustomSimpleImputer** with "mode" (reported in python as *most_frequent*) was used. Also in this case, patients were divided by label.

Before deciding for the best **scaler**, it's important to analyze the **boxplots** (and so the distribution) of our numerical features one by one:

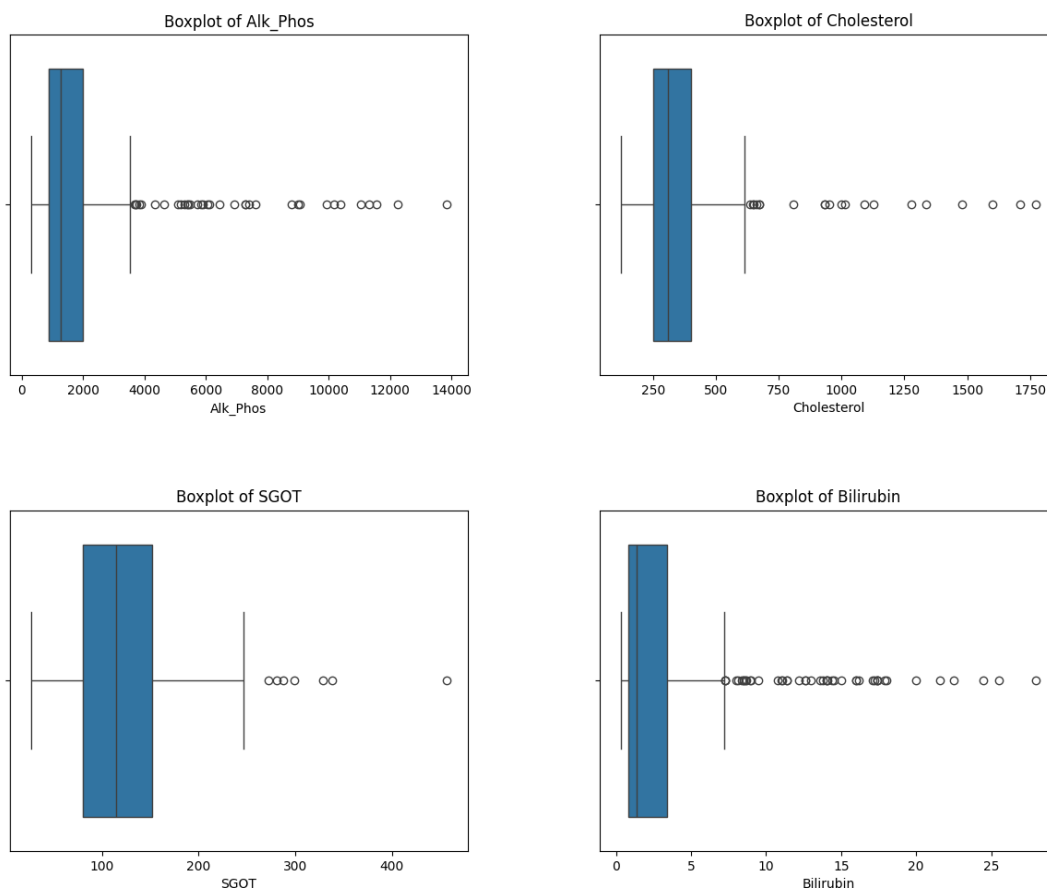


Figure 3: Boxplots of some numerical features.

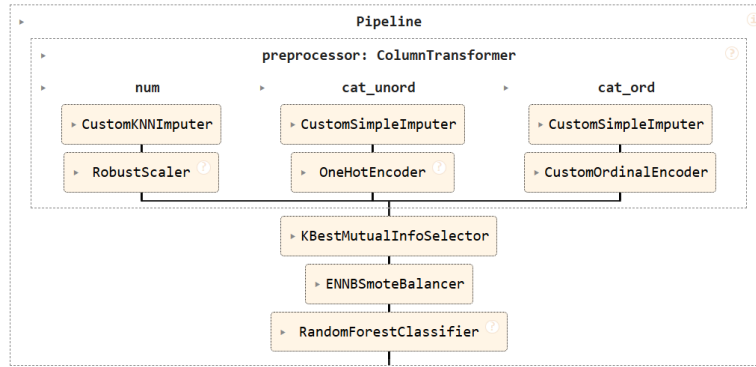
Given the relevant presence of outliers, the best choice would be to apply a **RobustScaler**.

Furthermore, in order to convert categorical features to numerical ones, **OneHotEncoding** and **CustomOrdinalEncoding** were used, respectively "Drug" was converted in "Drug_D-penicillamine" and "Drug_Placebo", while "Sex" became "Sex_M" and "Sex_F".

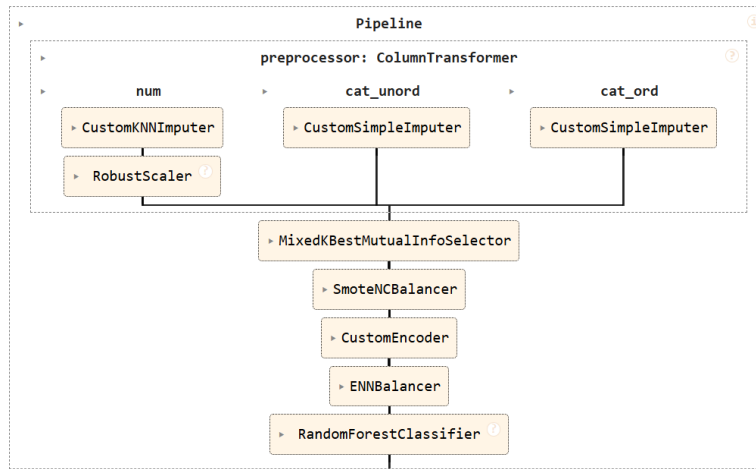
For the remaining categorical features, the CustomOrdinalEncoder implements an OrdinalEncoder for each feature, with sorting strategy that represent with high values **serious conditions** (the higher the values, the worse the condition). This step was possible by exploiting ad-hoc pipelines (**ColumnTransformers**) provided by the **imblearn** library.

Furthermore, different pipelines were tested:

- both Unordered and Ordered categorical features encoded before re-sampling:



- both Unordered and Ordered categorical features encoded after over sampling.



For the feature selection **mutual information** was used, applied to a **SelectKBest** strategy with various values of K.

The **KBestMutualInfoSelector** was created in order to select a fixed `random_state` in order to **replicate the results** (since in sklearn it's not possible to pass the value while using the mutual information as a score function).

In the **MixedKBestMutualInfoSelector** class of the pipeline, there is a combination of `mutual_info_classif` for numerical features, while for categorical features, that cannot be analyzed with the same function (not implemented), there is an **handwritten implementation of the mutual information**.

Another important thing that is done inside the class is to leave **at least one feature for both numerical and categorical**, since SMOTENC needs at least one categorical feature (instead if there were only numerical, the other pipeline is preferred).

PCA was not tested since it's not **recommended when dealing with encoded features**.

To balance instances, a double balancing technique was used. The undersampling technique was the **EditedNearestNeighbour**, with sampling strategy to decrease the number of instances in the "High chance" class, along with different values of `n_neighbors`.

This method was used since it can not only decrease the number of instances, but it's also capable to **separate** classes in the process, by deleting instances that may be close while being in different classes. This was done with the goal to delete instances of the High chance class that may make more difficult to classify the others.

The only problem with that approach is that there is no way to control **how much instances are deleted** (due to how it's implemented), differently from the other approaches.

The oversampling approach was done in order to increase the number of instances in the Transplant needed class. Given the SMOTENC (SMOTE for numerical and categorical) approach for a pipeline, the other one has a **BorderlineSMOTE** approach, since it can increase the chance to classify better instances which are considered hard to classify, by increasing the number of instances at the "border". All the methods were also used by comparing different values of *n_neighbors*.

This distinction was done to try and test what happens when applying a classic SMOTE approach against a specific type of SMOTE for mixed data type.

Indeed SMOTENC creates instances with a **coherent** value based on the feature, while BorderlineSMOTE, like SMOTE, creates values by **interpolating** with existing values (for instance, if Sex is represented by 0 and 1, SMOTENC may create 1 or 0, while Borderline SMOTE a value also in between, which is **meaningless** in this case)

Overall, the goal of the whole sampling approach was to **decrease the number of instances of the majority class down to the closest class in terms of instances, then increasing the lowest up to the closest**. e.g.) Suppose:

- Starting labels: Low chance = 100, High chance = 200 and Transplant needed = 20;
- Final result: 100 for all the classes.

This decision was driven by the fact that only applying oversampling could have caused **over fitting**, since creating too much synthetic values may lead the model to learn the **noise in the data rather than the underlying patterns**.

5 Models Definition and Evaluation

In order to conduct the experiments, four different models were used:

- RandomForest;
- KNNNeighbour;
- ADABOOST with naive Bayes classifier;
- Logistic regression.

All the models were optimized using the **Randomized Cross Validation** method.

Also it was important to decide the scorer in order to classify the best classifier, and the decision was to choose the classifier that improved the *f1_weighted* score. This was done to **penalize** classifiers that did not achieve good performances in classifying the Transplant needed class, which is actually the hardest given the very low number of instances.

The hardest decision was made when choosing **how many folds** were needed in order to obtain a significant amount of information to perform statistical analysis (that could be considered **valid**) on the results. Indeed most of the tests may not be **efficient** when using few values, but on the contrary, a confusion matrix with not so many instances may be **useless to compare performances**.

The chosen method was the **Kruskal-Vallis** test (combined with the **Wilcoxon** test if statistically relevant differences were found between groups), which is a **non-parametric** test, that can be used to compare three or more independent distributions, and has as only assumption to have **5 or more values** (in order to avoid staying "at the border" of the assumption, **10 folds** were selected).

5.1 Validation of the Assumptions

Both the test mentioned before were used since the Q-Q plot [Figure 4](#) of the scores showed that the distributions are **not normally distributed**.

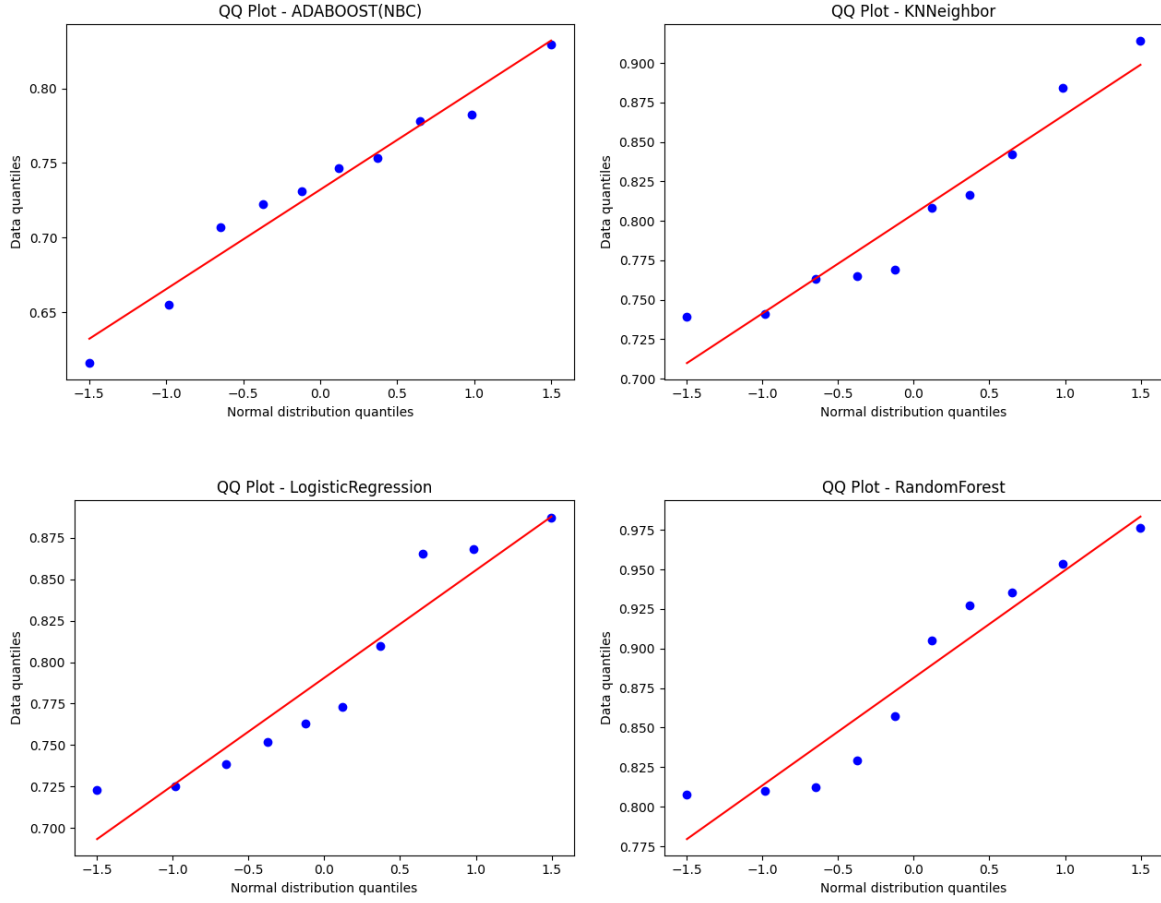
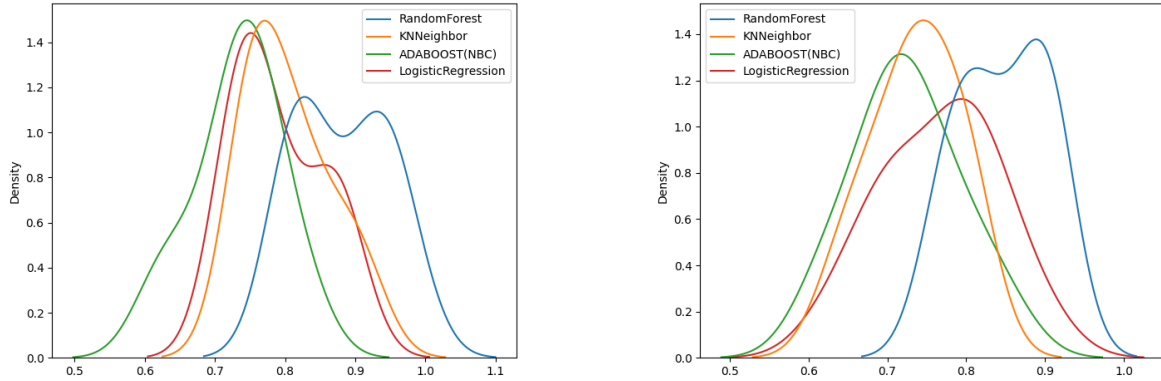


Figure 4: Q-Q plots for non SMOTENC pipeline.

After seeing this, the assumptions for the test are few: independence of the data and similar shapes. This can be seen by [Figure 5](#):



(a) Distribution of non SMOTENC scores.

(b) Distribution of SMOTENC scores.

Figure 5: Distributions of the scores in the different pipelines.

6 Final Results

The result of the pipelines showed that overall the RandomForest approach **performed better in every situation**.

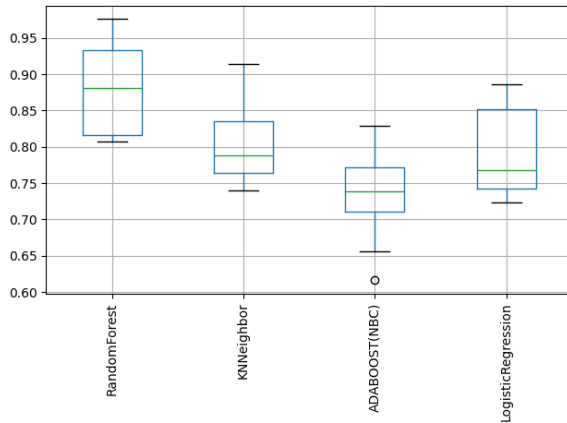
The following are the best parameters for both the pipeline:

- Non SMOTENC pipeline:

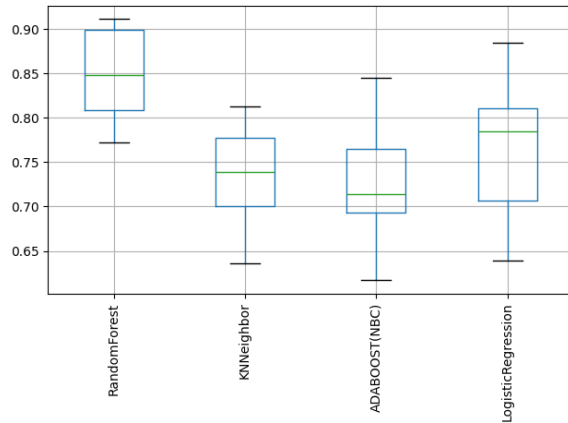
```
{
'sampler__k_neighbors_cleaning': 3,
'sampler__k_neighbors_borders': 7,
'preprocessor__num__imputer__n_neighbors': 11,
'feature_selector__k': 14,
'classifier__max_depth': 7,
'classifier__criterion': 'entropy'
}
```

- SMOTENC pipeline:

```
{
'sampler2__k_neighbors_cleaning': 3,
'sampler1__k_neighbors': 8,
'preprocessor__num__imputer__n_neighbors': 15,
'feature_selector__k_num': 11,
'feature_selector__k_cat': 2,
'classifier__max_depth': 5,
'classifier__criterion': 'gini'
}
```



(a) Result with non SMOTENC pipeline.

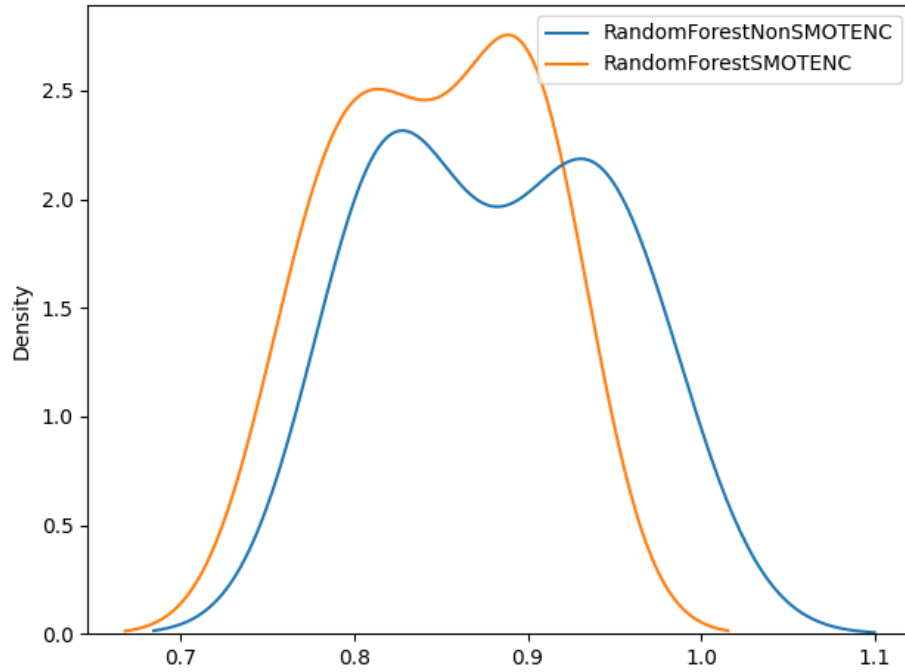


(b) Result with SMOTENC pipeline.

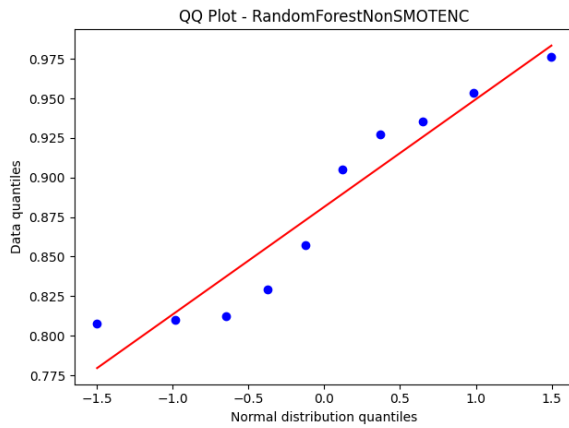
As a final step we can compare just the RandomForest pipelines and see if there are further considerations that can be done.

Since we are comparing two **bimodal** distribution we need to search for more powerful test in order to say if there are statistically relevant difference between the two models.

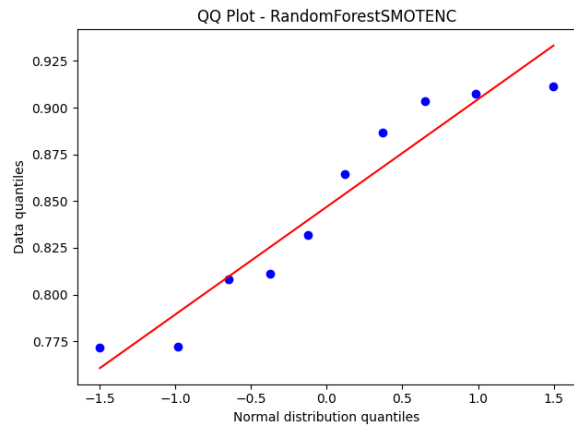
For this task, the selected test will be the **Kolmogorov-Smirnov**, since the Wilcoxon test uses the information about the **median** to perform the test, and in a bimodal distribution this information can be **misleading**.



The *S*-shape showed by the Q-Q plot is **typical of a bimodal distribution**.



(a) Q-Q Plot with non SMOTENC pipeline.



(b) Q-Q Plot with SMOTENC pipeline.

The test showed no statistically relevant difference between the pipelines.

Differently from before, just observing the boxplot it's not sufficient to estimate if one model is better than the other.

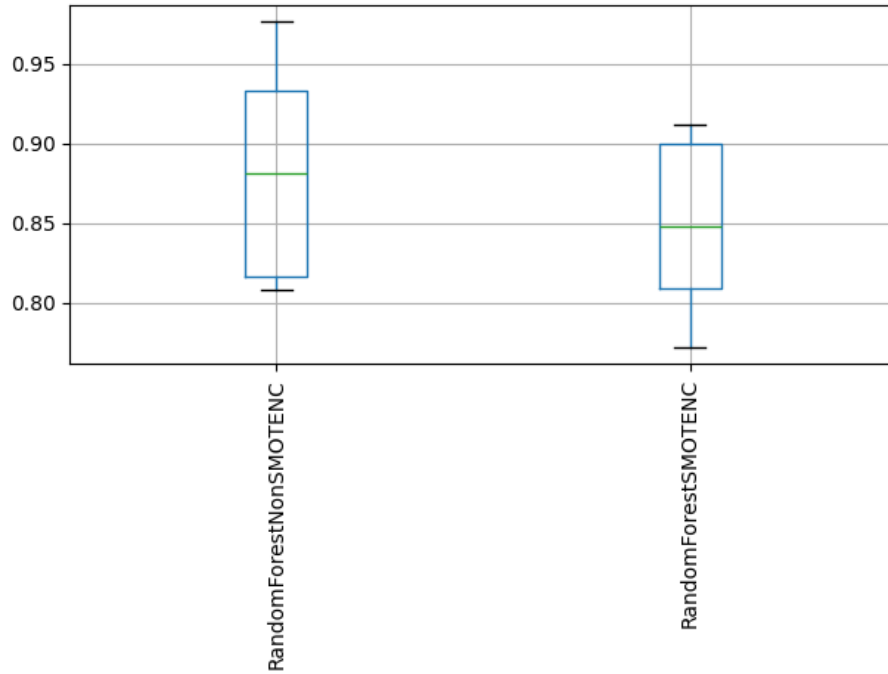


Figure 8: Boxplot of RF scores.

Here are provided the results of both the Kolmogorov-Smirnov test and the Wilcoxon test for comparison:

- Kolmogorov-Smirnov:

KS statistic: 0.4
p value: 0.41752365281777043
There is no statistically relevant difference.

- Wilcoxon:

Wilcoxon statistic: 7.0
p value: 0.037109375
There is a statistically relevant difference.

As expected, the Wilcoxon test suggest that one model is better than the other, while the Kolmogorov-Smirnov test says otherwise.

7 Appendix

7.1 Evaluation with non SMOTENC pipeline

```
Kruskal-Wallis statistic: 16.280917534477908
p value: 0.000993087171942368
There is a statistically relevant difference between at least two groups.
Comparing RandomForest and KNNNeighbor
Wilcoxon statistic: 0.0
p value: 0.001953125
There is a statistically relevant difference between RandomForest and KNNNeighbor
----
Comparing RandomForest and ADABOOST(NBC)
Wilcoxon statistic: 0.0
p value: 0.001953125
There is a statistically relevant difference between RandomForest and ADABOOST(NBC)
----
Comparing RandomForest and LogisticRegression
Wilcoxon statistic: 0.0
p value: 0.001953125
There is a statistically relevant difference between RandomForest and LogisticRegression
----
Comparing KNNNeighbor and ADABOOST(NBC)
Wilcoxon statistic: 5.0
p value: 0.01953125
There is a statistically relevant difference between KNNNeighbor and ADABOOST(NBC)
----
Comparing KNNNeighbor and LogisticRegression
Wilcoxon statistic: 16.0
p value: 0.44126813332892967
There is no statistically relevant difference between KNNNeighbor and LogisticRegression
----
Comparing ADABOOST(NBC) and LogisticRegression
Wilcoxon statistic: 0.0
p value: 0.001953125
There is a statistically relevant difference between ADABOOST(NBC) and LogisticRegression
----
```

7.2 Evaluation with SMOTENC pipeline

```
Kruskal-Wallis statistic: 14.746829268292714
p value: 0.002046294277869287
There is a statistically relevant difference between at least two groups.
Comparing RandomForest and KNNNeighbor
Wilcoxon statistic: 1.0
p value: 0.00390625
There is a statistically relevant difference between RandomForest and KNNNeighbor
----
Comparing RandomForest and ADABOOST(NBC)
Wilcoxon statistic: 0.0
p value: 0.001953125
There is a statistically relevant difference between RandomForest and ADABOOST(NBC)
----
Comparing RandomForest and LogisticRegression
Wilcoxon statistic: 0.0
p value: 0.001953125
There is a statistically relevant difference between RandomForest and LogisticRegression
```

Comparing KNNNeighbor and ADABOOST(NBC)

Wilcoxon statistic: 22.0

p value: 0.625

There is no statistically relevant difference between KNNNeighbor and ADABOOST(NBC)

Comparing KNNNeighbor and LogisticRegression

Wilcoxon statistic: 14.0

p value: 0.193359375

There is no statistically relevant difference between KNNNeighbor and LogisticRegression

Comparing ADABOOST(NBC) and LogisticRegression

Wilcoxon statistic: 8.0

p value: 0.048828125

There is a statistically relevant difference between ADABOOST(NBC) and LogisticRegression

8 References

1. Medical News Today, "Cirrhosis of the liver: Life expectancy,"
<https://www.medicalnewstoday.com/articles/cirrhosis-of-the-liver-life-expectancy>
2. Cirrhosis Prediction Dataset
<https://www.kaggle.com/datasets/fedesoriano/cirrhosis-prediction-dataset>