

A Study on Credit Default Risk

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1. Introduction

Whether it be credit cards, home loans, or business loans, lending companies need to evaluate a customer's credit profile and income information to determine the willingness and ability to pay back the loans before making the decision of approving or declining the application. The challenges are usually that there may not be much data or relevant information available for the lender to make a good prediction if the customer will default. The fact that true default rate is generally less than 10% of the total portfolio also increases the difficulty for the true default accounts to be accurately predicted.

In this article we build a classification model to predict the probability of default on a new loan, based on customer's bureau information, income, previous loan status, credit card balance, install payment and so on. This model will provide lenders a predicted outcome of default or non-default to guide them making decisions to approve or decline the loan application.

The data of this project comes from Home Credit, which is a non-banking financial institution founded in 1997 in the Czech Republic. The company operates in 14 countries and focuses on lending primarily to people with little or no credit history, which will either fail to be approved for loans or became victims of untrustworthy lenders. The data comes from a variety of sources with more than 200 variables in total, and in some instances goes back to as far as 8 years of monthly balances, posing great challenges in data aggregation, wrangling, missing value imputation and feature engineering. In addition, due to the imbalanced nature of the target variable, we will use down sampling and compare the performances of 6 classification models evaluated on the training set, and finally apply the best selected model on an independently held out test set and report out the test AUC score, ROC curve and so on.

2. Data Wrangling

In this section, we will be implementing the basic data aggregation for each of the 5 data sources provided by Home Credit, by keeping only one or two of the summary statistics such as average, sum, max or min of each group having the same previous application ID. Categorical variables will be treated using one hot encoding. For variables with high cardinality of categories, some categories with low frequencies will be grouped before one hot encoding, and aggregation will be done after one hot encoding.

Current application data is the main table with static information for all current applications. No data cleaning is done at this point for this dataset. Merge this table with all of the 5 aggregated tables created above to get one combined lead file. Further data explorations and processing such as correlation analysis and missing value treatment will be performed on numerical variables, and one hot encoding will be applied to categorical variables after high cardinality categorical variables are treated.

3. Exploratory Data Analysis

The target variable is default vs. non default. As shown in Figure 3.1, overall default percentage is 8.07% in the entire dataset.

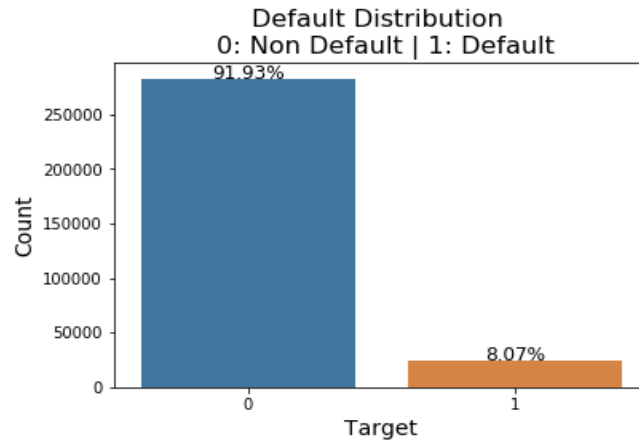


Figure 3.1

Next we explore distributions of some categorical variables.

Distribution of Contract type is shown in Figure 3.2. Revolving loans group appears to have a lower default rate than the Cash loans group. A hypothesis t-test can be done to test if the difference in default rate is statistically significant.

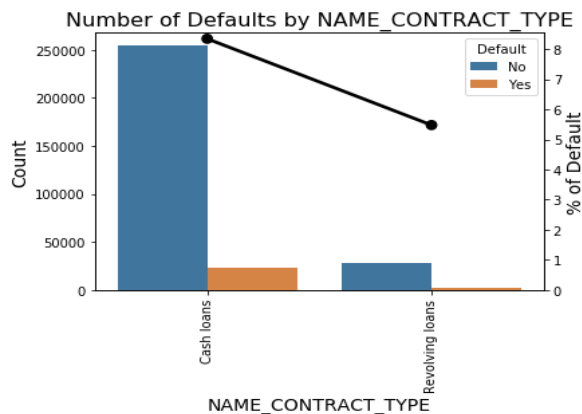


Figure 3.2

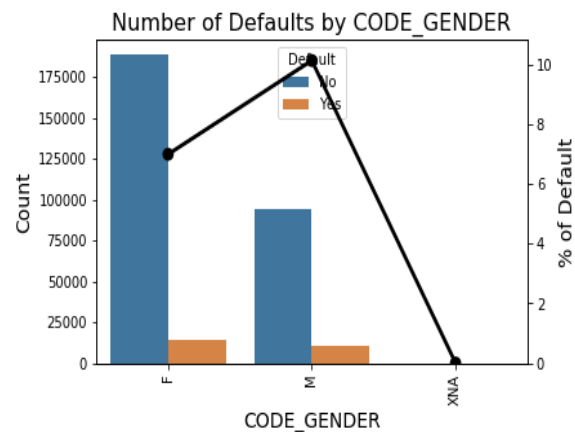


Figure 3.3

Notice from Figure 3.3 that there are 3 gender groups, we will remove the 4 records having gender = XNA. It can be seen from the graph that majority of the applicants are female, and the default rate within female applicants is lower than that in the male group.

Figure 3.4 shows some rank ordering in default rate by Education level. In general, applicants with low secondary education has the highest default rate. As we can imagine education level is

correlated with type of job the applicant can take and highly correlated with income, which is essential to repayment of a loan.

Occupation type variable shown in Figure 3.5 has over 15 categories, we will group the categories having ≤ 10000 counts into one group.

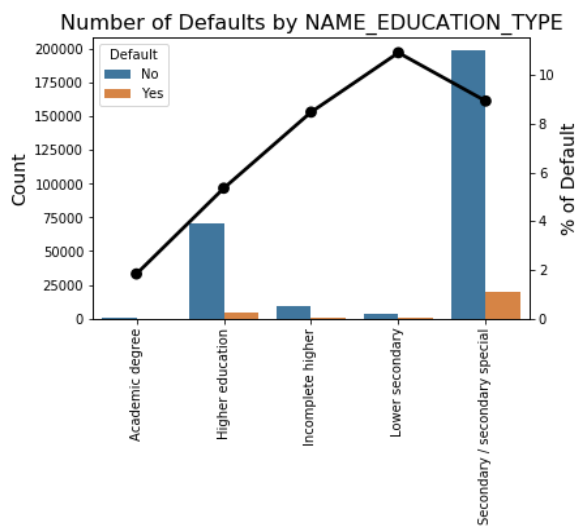


Figure 3.4

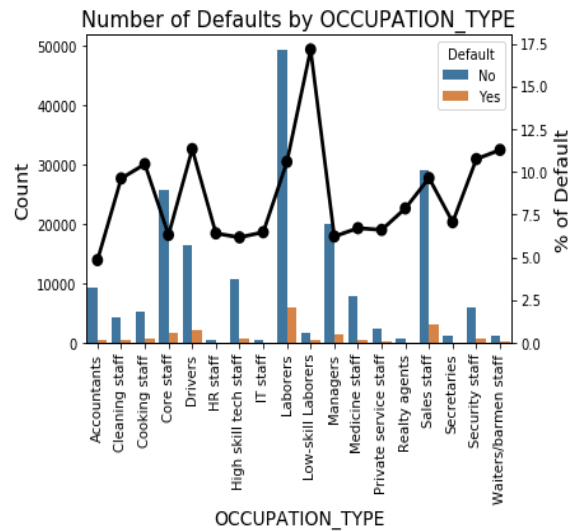


Figure 3.5

Next we explore some numeric variables by creating the correlation heatmap or KDE plots for each variable and split by default vs. non-default segments.

Figure 3.6 indicates there is a high positive linear correlation between observations of client's social surroundings with observable 30 days past due and 60 days past due. As a result, we remove one of them from the dataset.

The dataset contains many features related to the living area or conditions of the applicants. Their correlation heat map is shown in Figure 3.7. Some groups of variables are highly correlated, for example, 'APARTMENTS' variables and 'LIVINGAREA' variables.

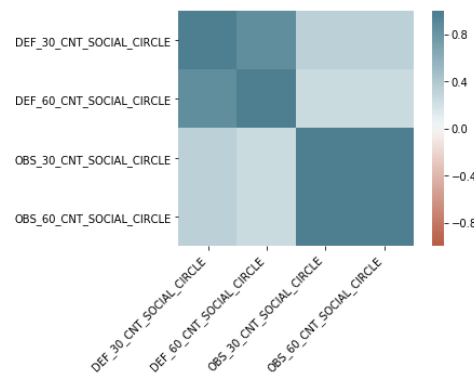


Figure 3.6

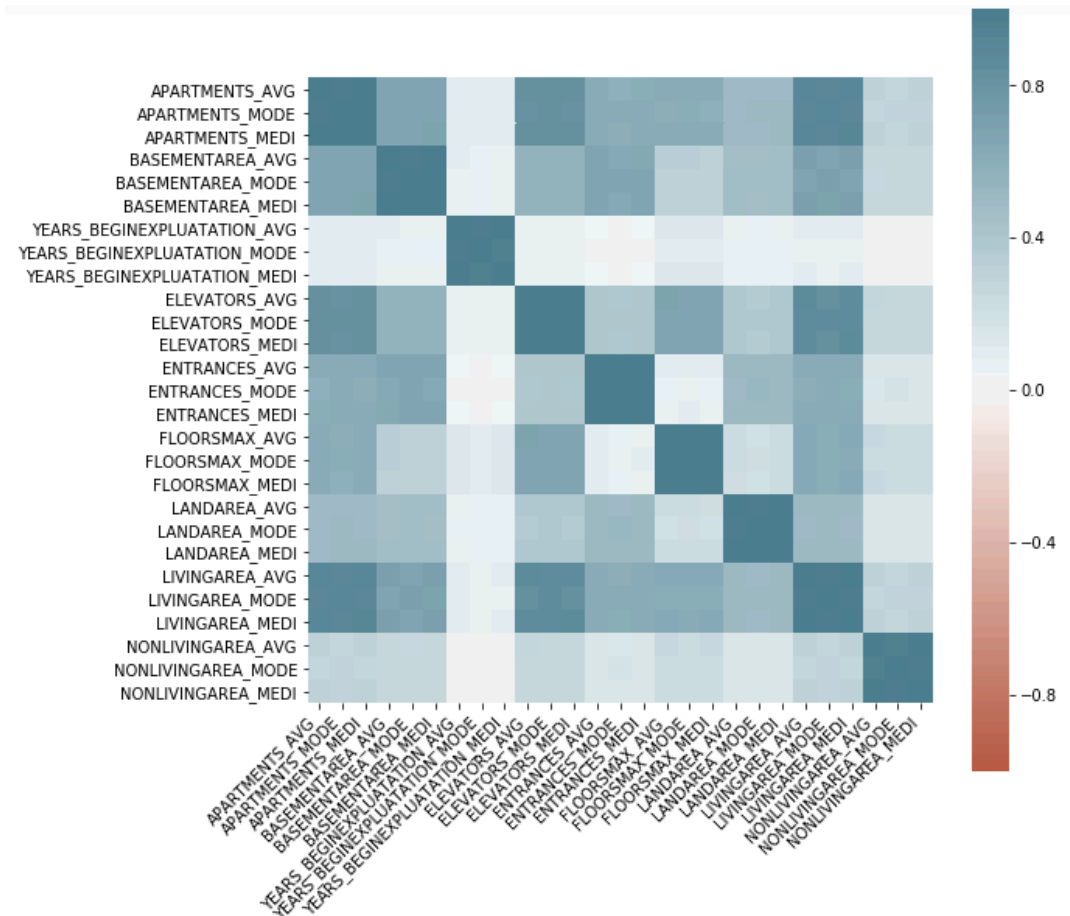
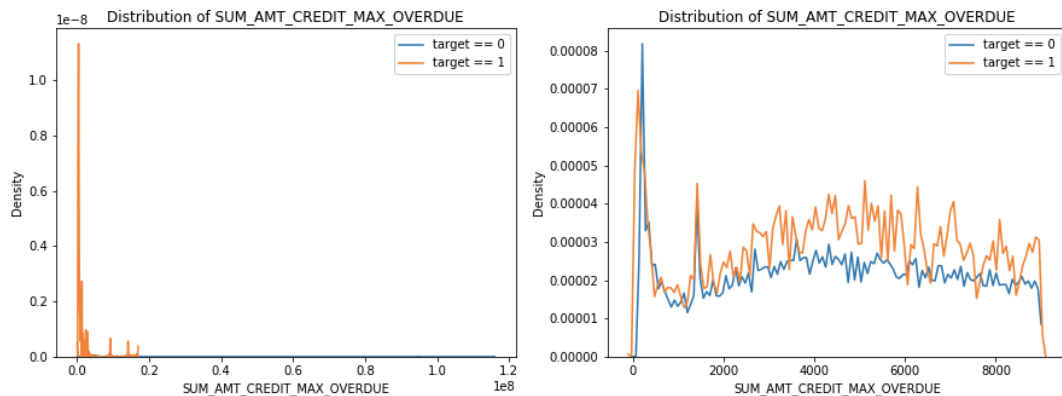


Figure 3.7

Figure 3.8 shows the KDE plots for some numeric variables related to the amount of credit or days of credit overdue. Left panel shows the original range of the variable. Since most of these variables are highly skewed to the right, we zoom in the head of the distribution and plot it on the right panel. A few variables show distinction between the default and non-default groups, while many others are quite similar in these 2 target groups.



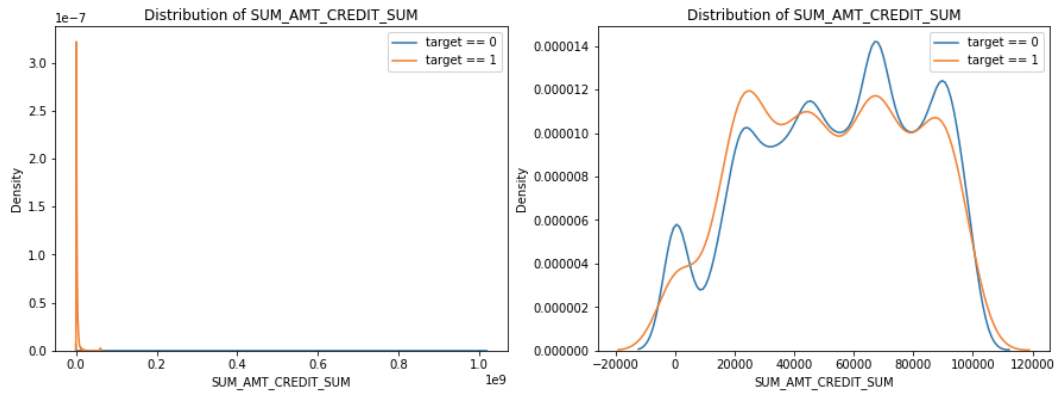


Figure 3.8

The following 3 variables are normalized scores from external data source. It turns out that several of the models we fit selected these variables to be the top important variables.

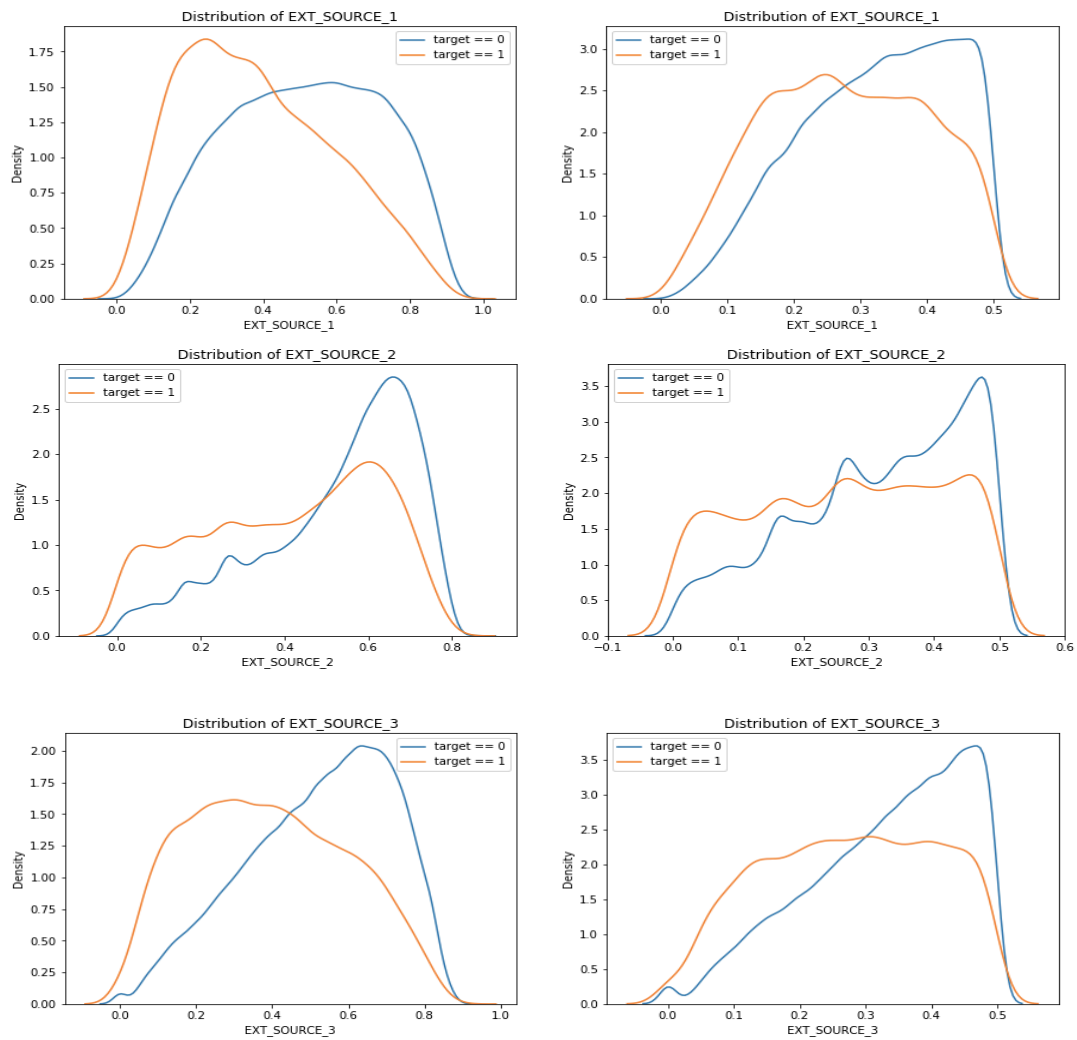


Figure 3.9

Variables in Figure 3.10 are originally presented in days in the dataset, convert them into years to better visualize the ranges. Here are some observations:

- “DAYS_EMPLOYED” has values over 1000 years, which are apparently errors.
- “MAX_DAYS_CREDIT_ENDDATE” is an aggregated field summarizing all previous applications within the same current application ID using the max aggregation function. It means over all the previous applications within the same current application ID, the maximum remaining duration of Bureau credit at the time of application. This variable should be a positive number, but we found negative values in the column. As a result, we floor the variable at 0. For missing values, impute using the median.

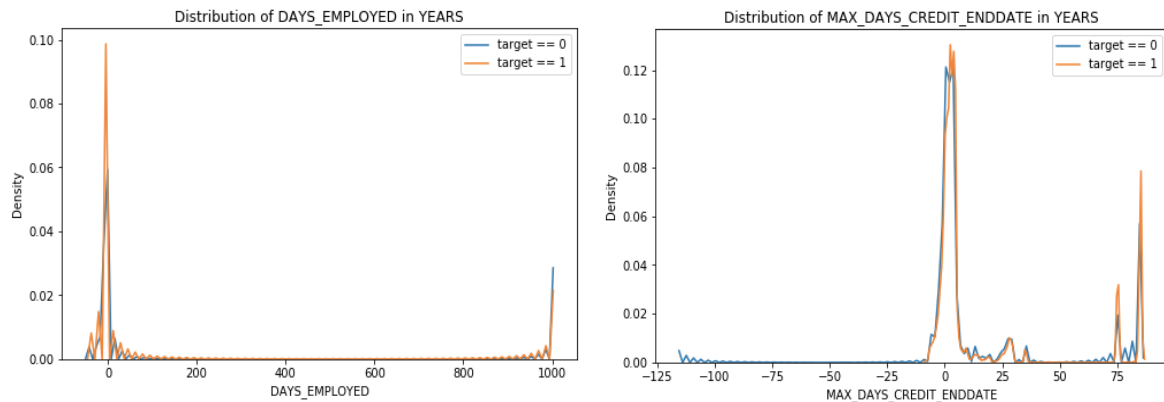


Figure 3.10

In addition, we also examined the following age-related variables in years (Figure 3.11).

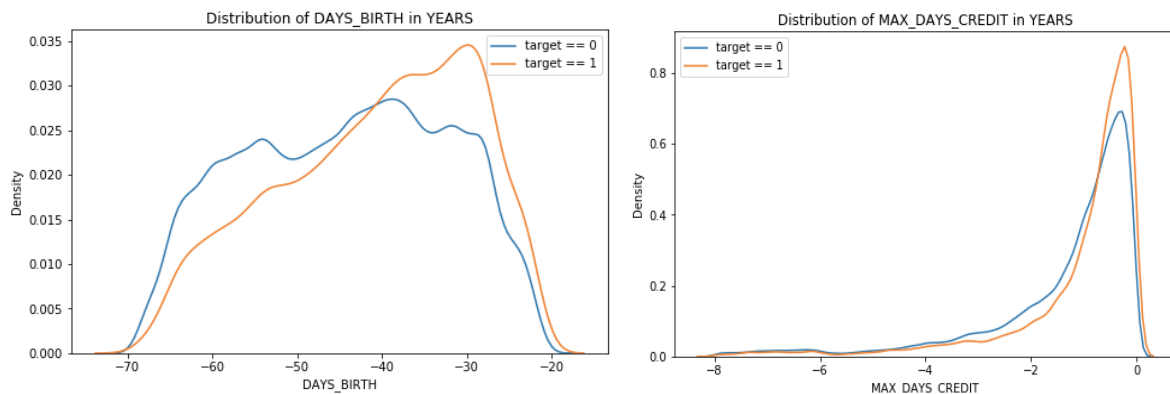


Figure 3.11

Distributions of variables such as “AMT_ANNUITY”, “AMT_CREDIT” and “AMT_GOODS_PRICE” are skewed to the right, we recommend to take the log transformation to normalize the data. To save space, we only show the distribution of “AMT_ANNUITY” in Figure 3.12.

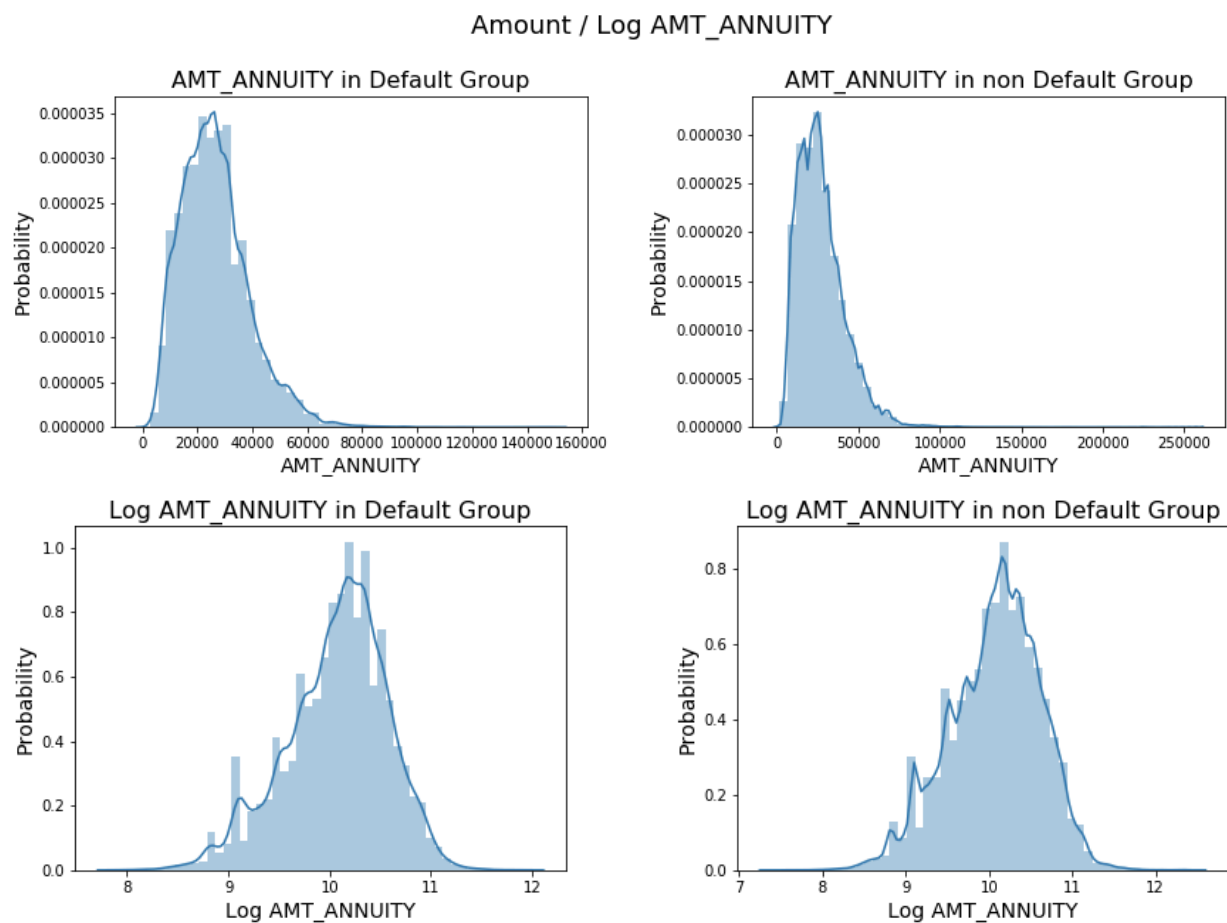
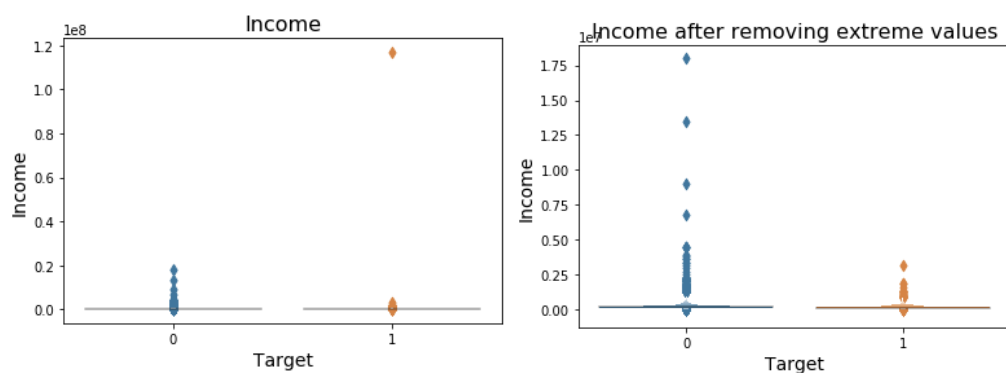


Figure 3.12

There is one extremely large income value in the default group (\$120 million), and 4 very large values ($> \$7.5$ million) in the non-default group. Recommend to remove the outliers and use log transformation to normalize the income data (Figure 3.13).



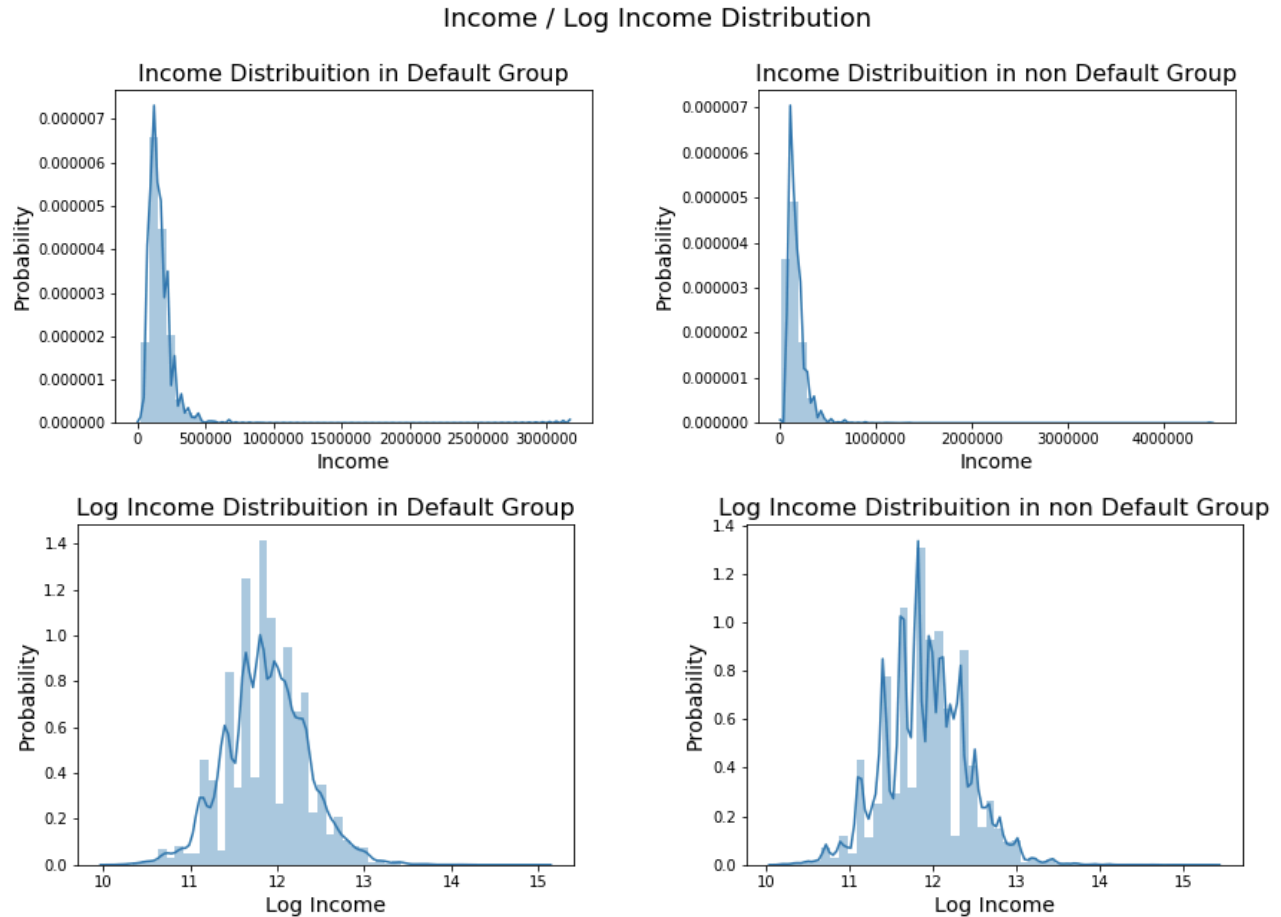


Figure 3.13

4. Modeling

In this section, we explore 6 commonly used classification models including tree-based methods such as Random Forest, XGboost and LightGBM, as well as classical models such as Logistic regression with regularization, K-nearest neighbors (KNN) and support vector machine / classifier (SVM). Due to the imbalanced nature of the data, we down sampled the non-default counts to be approximately the same as the default counts in the training data, while the test data is still a randomly held out 20% imbalanced dataset. Note that we also tried using the original imbalanced data to build a Random Forest model, and as expected, every data point was classified as non-default loan, which is not useful.

4.1 Model Selection

For each classification model, a 5-fold CV with RandomizedSearchCV in Scikit-learn is run on the down-sampled balanced training set to select the best combination of hyper-parameters. The parameter that yields the highest average AUC on the 5 validation sets is chosen, and the standard deviation is also reported to show the variability of the AUC scores among the 5 validation sets.

- Random Forest: A well-known bagging algorithm which builds hundreds or even thousands of trees on bootstrap samples of data and a random subset of features. The model uses majority votes to determine the final classification labels.
- XGboost: A scalable and accurate implementation of gradient boosting machines and it has proven to push the limits of computing power for boosted trees algorithms as it was built and developed for the sole purpose of model performance and computational speed. Gradient boosting is an ensemble method where trees are built sequentially based on residuals from the previous tree and the misclassified samples are given higher weights such that the mistakes can be corrected in the following iteration.
- LightGBM: Uses XGboost as a baseline and outperforms it in training speed and dataset sizes it can handle. Some advantages of LightGBM include: faster training speed and higher efficiency, lower memory usage, better accuracy, support of parallel and GPU learning and capable of handling large-scale data.
- Logistic Regression with Regularizations: A widely applied linear classifier that predicts the probability of an event (default). Regularization terms are introduced to control model complexity or reduce overfitting.
- K-Nearest Neighbors (KNN): For any new data point, KNN classifies it based on the majority class from its K nearest neighbors. Usually Euclidean distance is used as a measure of similarity of data points. K is the only hyper-parameter needs to be tuned.
- Support Vector Machine (SVM): A separating hyperplane that yields the largest distance to the nearest training data point of any class. The decision boundary can be non-linear with the help of a kernel function which maps the data to a higher dimension where a separating hyperplane is constructed and then projected onto the original lower dimension feature space. SVM usually has pretty good accuracy in classification tasks but takes very long to train when dataset is large.

Table 4.1 shows the highest average AUC scores among the validation sets along with its standard deviation, for each of the models we trained. XGboost beats LightGBM slightly with the highest AUC among all models.

Model	Average AUC	STD AUC
Random Forest	0.7500	0.0076
XGboost	0.7722	0.0074
LightGBM	0.7704	0.0065
Logistic Regression	0.7652	0.0040
KNN	0.5860	0.0053
Kernel SVM	0.7565	0.0013

Table 4.1

4.2 Model Evaluation

We evaluated XGboost model on the independent test set, which is a random 20% of the original imbalanced dataset. The AUC on the test set is 0.7738. Classification report and ROC curve are shown in the following Figures.

	precision	recall	f1-score	support
0	0.96	0.71	0.82	56533
1	0.18	0.69	0.28	4968
micro avg	0.71	0.71	0.71	61501
macro avg	0.57	0.70	0.55	61501
weighted avg	0.90	0.71	0.78	61501

Figure 4.2.2

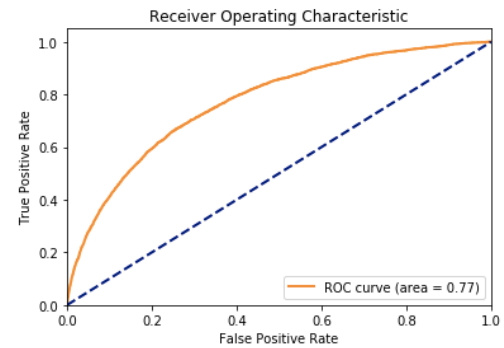


Figure 4.2.3

5. Conclusions and Future work

5.1 Conclusions

In this project we predicted the probability of default for each current loan for Home Credit, based on aggregated information from previous loan histories that belong to the same current loan ID, Bureau credit information, demographics and social network attributes of applicants, income and education level, living area conditions and so on.

Our model reports are based on 0.5 decision threshold when predicting if a future loan will go default or not. However, analysts in Home Credit can leverage the model predicted probabilities and adjust the threshold in their decisions to achieve better tradeoff between precision and recall rate, to fit in their risk appetite and eventually making an appropriate decision to decline or approve a new loan.

To achieve all of these, we started by aggregating each of the 5 data sources provided by Home Credit, and conducted exploratory data analysis on both categorical and numeric variables to visualize correlations between the target and features. Some features show better separation of default vs. non-default and others not so much. We compared the performances of 6 classification models and below are our findings:

1. The model with the highest AUC on the validation data is XGboost. LightGBM comes second and Logistic regression ranks the 3rd place, followed by SVM, random forest and KNN.
2. In terms of computation times, tree-based methods are generally faster than other methods. Logistic regression and KNN take slightly longer than tree-based methods. Kernel SVM is the slowest to train and predict.

5.2 Future work

We realized that the precision for all of the models are not ideal, somewhere around 0.17. Low precision indicates a high number of false positives, which means we are predicting a non-default customer as default. This will hurt the revenue of Home Credit as we are excluding many

profitable good loans. On the other hand, our recall rate is about 70%, indicating we are correctly identifying 70% of the default loans within the truly default ones. There may be room to improve both the precision and recall rates. Specifically, below are some thoughts for future work:

1. Feature engineering can be further explored by looking into combinations of various columns, quadratic terms or using different aggregation methods at sub-ID levels.
2. In the final dataset used in modeling, Bureau balance dataset was not included in the features due to limited time and computation power. In future work, it can be aggregated and incorporated into the training data.
3. More missing value imputation techniques can be used to better impute the missing values based on overall shape of the distribution, rather than using the median for every numeric variable.
4. More sampling techniques such as up sampling of the minority class, or SMOTE can be used to compare with the performances with down sampling.
5. PCA or other dimension reduction methods can be leveraged to reduce the dimension of the feature space, however, model interpretability may be lost.
6. In this project we only tried to use scaled features in Kernel SVM model, to speed up the convergence of the algorithm. For all other 5 models we used the original scale of the variables, as tree-based methods can deal pretty well with different scales of variables. In future work we can try using scaled / normalized features in Logistic Regression and tree models as well, to see if there is any performance gain.
7. In all of the models we trained, we throw in all of the over 300 features without picking any subset of features. In Logistic regression, L1 penalty was selected, so we automatically got some feature selection benefits. Tree-based models naturally produce the rankings of features, so we can try to use the top 100 or so to train the model again to see if there are any performance improvements. In future work, more variable selection techniques can be considered to fit a more parsimonious model rather than using the full set of features.
8. In the SVM model cross validation step to select the optimal hyperparameters, due to the prohibitive training time of SVM algorithms, we only tried random search 2-fold cross validation with 2 random parameter combinations. More combinations can be tested to achieve possibly higher AUC provided with GPU or a high computation power CPU. Similar with tree-based models, more combinations can be tried when searching for best hyperparameters.
9. Other classification models can be tested such as neural networks, linear and quadratic discriminant analysis, other tree-based methods such as Adaptive Boosting, or other bagging and ensemble methods.

Reference

[1] <https://www.kaggle.com/c/home-credit-default-risk/data>

[2] https://github.com/lisalb168/Credit_Risk_Default_Prediction