

P8106 - Final Project - NBA Players Salary Prediction

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Introduction

For teams in the National Basketball Association (NBA), a key strategy to win more games is to properly allocate their salary cap - an agreement that places a limit on the amount of money that a team can spend on players' salaries. How to evaluate the performance of each NBA player and give a suitable level of salary is a complicated problem. In this project, we intend to predict the salary of NBA players in the 2021-2022 season based on their game statistics. We collected game statistics that are commonly used to evaluate players from the NBA official website, built linear, generalized linear, tree-based, and neural network, and conducted model comparison to determine a final predictive model.

Data Preprocessing

The data used for exploratory analysis and model construction are based on two datasets: the NBA players' contracted salary dataset [1] and game performance statistics dataset [2] in 2021-2022. The data were preprocessed using the following pipeline:

- Two original datasets were inner joined by players and teams
- Kept only one record with most number of games played for each of players, given a player may transfer to other teams during the session and have multiple records.
- Removed 5 variables with missing values caused by division of other existing variables.
- Divided count variables (`field_goal`, `free_throw`, etc.) by variable `minute` to convert them to efficiency.

The final cleaned dataset contained 442 records and 24 variables, including 2 categorical variables, 21 numerical variables and 1 numeric response variable `salary` (Table 1).

Table 1: Table of Variables

Variable Name	Meaning	Variable Type
position	Position of the player	categorical (5 classes)
age	Player's age on February 1 of the season	numeric
team	Team that the player belong to	categorical (30 classes)
game	Number of games played	numeric
game_starting	Number of games played as a starter	numeric
minute	Minutes played per game	numeric
field_goal	Field goals per minute	numeric
fg_attempt	Field goal attempts per minute	numeric
x3p	3-point field goals per minute	numeric
x3p_attempt	3-point field goal attempts per minute	numeric

Variable Name	Meaning	Variable Type
x2p	2-point field goals per minute	numeric
x2p_attempt	2-point field goal attempts per minute	numeric
free_throw	Free throws per minute	numeric
ft_attempt	Free throw attempts per minute	numeric
offensive_rb	Offensive rebounds per minute	numeric
defenssive_rb	Defensive rebounds per minute	numeric
total_rb	Total rebounds per minute	numeric
assistance	Assists per minute	numeric
steal	Steals per minute	numeric
block	Blocks per minute	numeric
turnover	Turnovers per minute	numeric
personal_foul	Personal fouls per minute	numeric
point	Points per minute	numeric
salary	Salary of the player in million (Response)	numeric

Exploratory Analysis

Univariate Analysis

The distribution of each variable in the dataset was plotted and examined (Appendix A Figure 6&7). Categorical variables `team` and `position` were distributed quite evenly (Appendix A Figure 7). While 30 unique values in `team` might lead to too many dummy variables in the model, the variable was considered to be excluded or clustered into fewer classes for model fitting. For numeric variables, some of them (`game_starting`, `free_throw`, `offenssive_rb`, `block`), including response `salary` are skewed, with some players have extremely high salary.

Correlation Analysis

From the correlation heatmap (Figure 1A), some variables were found to be strongly correlated with others, leading to a potential problem of multicollinearity. Such problem could be handled by using penalized models (such as ridge/lasso regression and elastic-net) or ensembled models (such as random forest, boosting, and neural network). From the feature maps (Appendix A Figure 8), some predictive variables were found to have non-linear correlations with `salary`, such as `age`, `game`, `game_starting`, `free_throw`, `personal_foul` and `point` (Figure 1B). Generalized linear regression models and other non-linear models, including GAM, MARS, random forest and neural network model, could be used to capture such non-linearity.

Feature Engineering

To condense the 30-class categorical variable `team` into fewer dummy variables, we tried clustering `team` into fewer classes based on the median and standard deviation of player's salary in each team. The number of clusters $k = 3$ was chosen based on average silhouette width (Figure 2A). The resulting clusters of `team` were shown in Figure 2B and stored in a new variable `team_cluster`. Three clusters of teams are as below:

- Cluster 1: BRK, GSW, LAL, MIA, MIL, NOP, PHI, POR, UTA
- Cluster 2: ATL, CHI, CHO, CLE, DAL, DEN, DET, HOU, IND, MEM, MIN, NYK, OKC, ORL, PHO, SAC, SAS, TOR
- Cluster 3: BOS, LAC, WAS

In the tree-based models, the replacement of `team` with `team_cluster` led to a higher prediction accuracy. For other models, the variable `team` was still used for model construction.

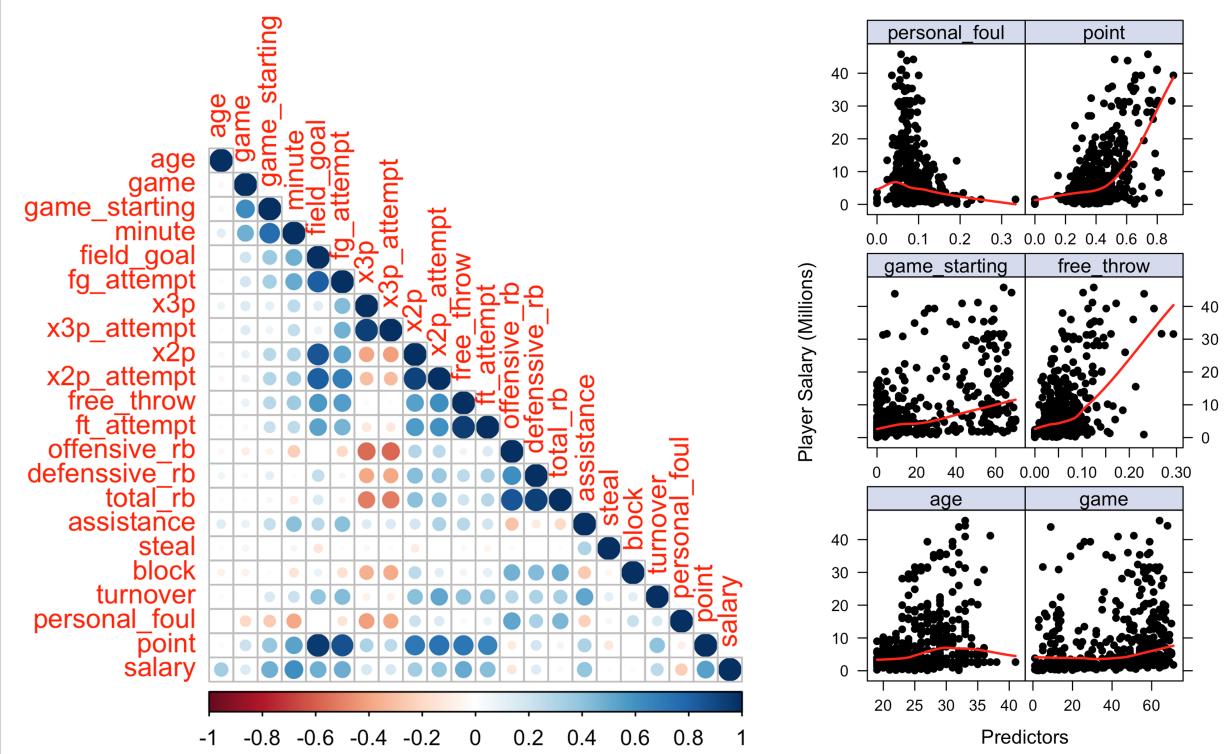


Figure 1: Correlation Heatmap and Feature Maps

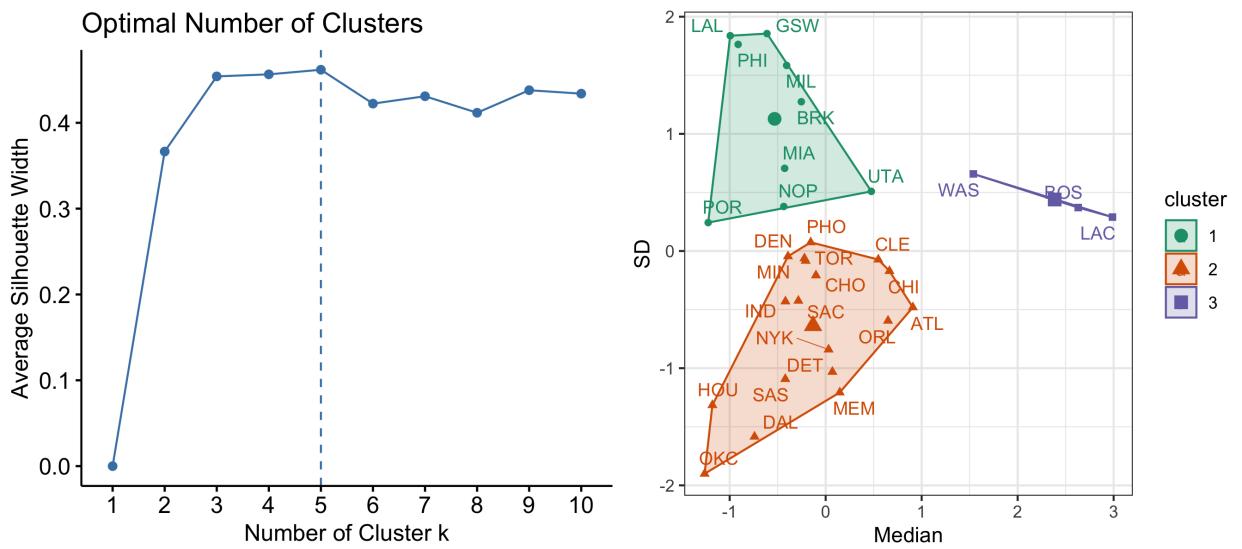


Figure 2: Clustering on variable team

Model Construction

After having an overview of the data, we splitted the dataset into training (80%) and test (20%) set, used 10-fold repeated cross validation to compare each model using training data, and evaluated the model performances based on test error. We built 8 types of models in four categories:

1. Linear Regression Models: Standard Linear Regression Model, Elastic Net Model, Principal Component Regression Model (PCR)
2. Generalized Linear Regression: Generalized Additive Model (GAM), Multivariate Adaptive Regression Splines Model (MARS)
3. Tree based Models Models: Random Forest (RF), Generalized Boosted Regression Modeling (GBM)
4. Neural Network

Part A - Linear Regression Models

(1) Standard Least-Squared Standard Least-Squared model is used for a reference of other models, as it may not perform well given the presence of multicollinearity and nonlinear trend in the data. There is no tuning parameter for standard least-squared model.

(2) Elastic Net The elastic-net model has two parameters, which are α (compromise between LASSO and ridge) and λ (the penalty term limits the number or magnitude of predictor coefficients). The elastic-net model reached its best tune at $\alpha = 0.6$ and $\lambda = 0.44$ (see Appendix B Figure 9A).

(3) Principle Component Regression The tuning parameter of PCR is the number of principal components (PCs) included in the final model. There are 12 PCs included in the model with minimum RMSE (see Appendix B Figure 9B).

Part B - Generalized Linear Regression Models

(4) GAM There is no tuning parameter for GAM. The GAM model can capture the non-linear trend in the model, but it may have a high variance. `age`, `game_starting`, `assistance`, `personal_foul`, and `point` are statistically significant predictors at 0.0001 significant level.

(5) MARS The tuning parameters for MARS are `nprune` and `degree`. When attempting to fit the MARS model, we noticed that the RMSE increased drastically when degree was over 3 and nprune was over 8. Therefore, we chose the range of degrees as 1:4 and range of nprunes as 2:8. When `nprune = 6` and `degree = 3`, MARS model reached its best tune and RMSE was the lowest. 6 of 54 predictors were included in the model, and the top 3 important predictors were: `age`, `minute`, `game`. MARS model is highly adaptive comparing with previous models and has a higher prediction accuracy (see Appendix B Figure 9C).

Part C: Tree-Based Models

(6) Random Forest Tuning parameter for random forest regression in package `ranger` are `mtry` (number of variables to split at in each node) and `min.node.size` (minimal size of each node). Through 10-fold repeated CV (see Appendix C Figure 12), the optimal random forest model had parameters `mtry = 26` and `min.node.size = 1`. Random forest preserves the advantage of single decision trees that can handle correlation between variables and non-linearity. However, since here `mtry = 26` equals our total number of variables, thus the random forest estimator may not well decorrelate single trees, and thus may overfit the dataset.

(7) Generalized Boosted Regression Modeling (GBM) Tuning parameters for Generalized boosted regression modeling (GBM) are `n.trees` (total number of trees to fit), `interaction.depth` (maximum depth of each tree), `shrinkage` (learning rate), and `n.minobsinnode` (minimum number of observations in the terminal nodes). Through 10-fold repeated CV (see Appendix C Figure 13), the optimal random forest model had parameters `n.trees = 6000`, `interaction.depth = 5`, `shrinkage = 0.0008`, and `n.minobsinnode = 1`.

Part D: Neural Network

Several 2-hidden layer neural networks were built to fit the data. The optimal model fitted after parameter tuning is a 2-hidden layer neural network with $n_1 = 10$ and $n_2 = 5$ nodes in the first and second layers (Figure 3A), applying dropout regularization. Figure 3B shows the resulting MSE in the training and validation sets after 250 epochs.

As shown in Figure 3C, as the number of nodes in the first and second hidden layers increases, neural networks can provide very accurate fittings of the training data, with much lower MSEs compared to other methods. However, the predictions are not satisfying when the models are applying to the test data.

Despite trying different number of nodes and applying regularization techniques (L2 and dropout), the resulting models still have a noticeable overfitting problem. Given the size of the dataset is very small ($n = 442$), the performance of neural network is not as good as some traditional statistical models. It is more useful when the size of dataset is much larger with more variables.

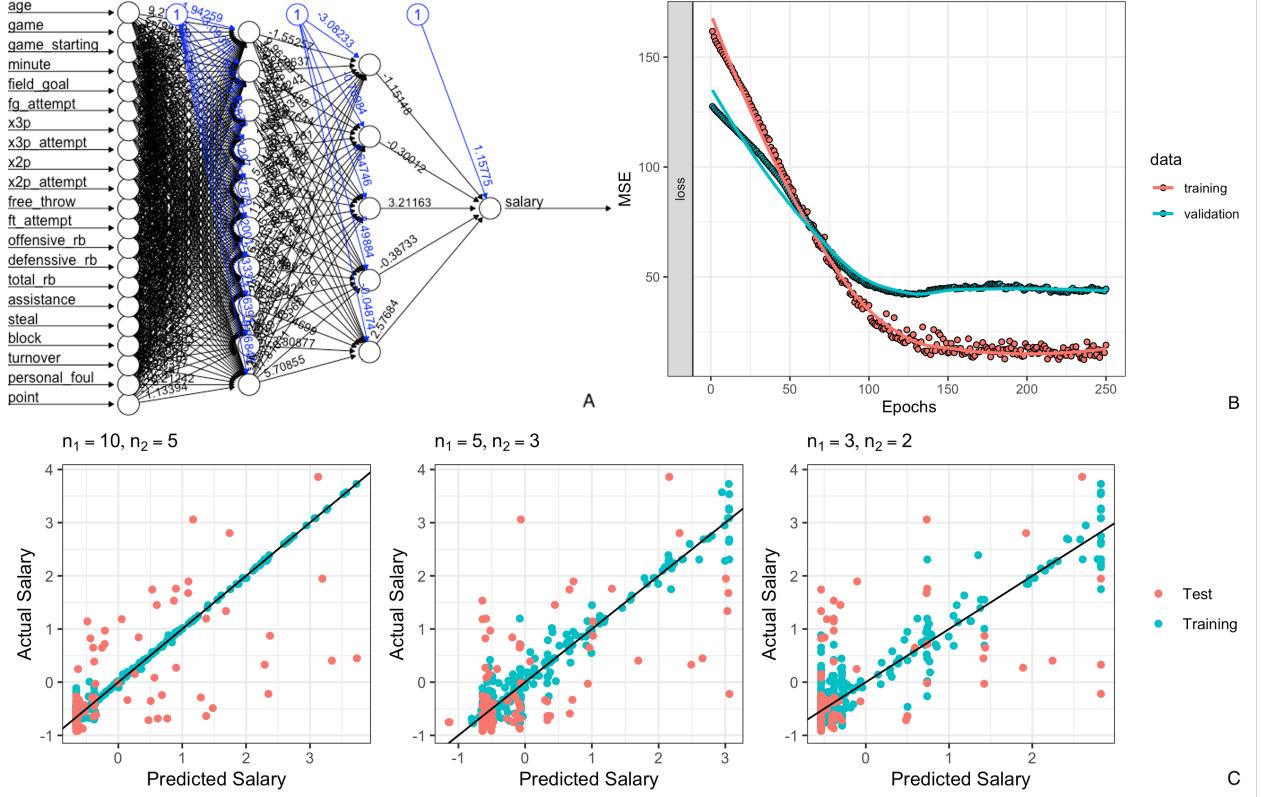


Figure 3: Structure and MSE of the resulting 2-hidden layer neural network

Model Comparasion and Final Model Interpretation

Model Comparison

The 10-fold CV RMSE (validation set RMSE for neural network) and test set RMSE for all candidate models are shown in Table 2. The GBM has the best performance in terms of CV RMSE.

Table 2: Summary of Model Performance

	Linear	ElasticNet	PCR	GAM	MARS	RandomForest	GBM	NeuralNetwork
CV RMSE	6.79	6.45	7.16	6.84	6.06	5.42	5.41	6.40
Test RMSE	6.66	6.04	5.39	6.84	5.16	4.83	4.75	6.64

Final Model Interpretation

Based on the CV RMSE and validation set RMSE, our best model is the GBM with tuning parameters:

- `n.trees = 6000`
- `interaction.depth = 5`
- `shrinkage = 0.0008`:
- `n.minobsinnode = 1`

10 most important variables (computed from permuting OOB data) are `minute`, `age`, `point`, `free_throw`, `fg_attempt`, `game_starting`, `assistance`, `ft_attempt`, `team_cluster`, and `defenssive_rb` (Figure 4).

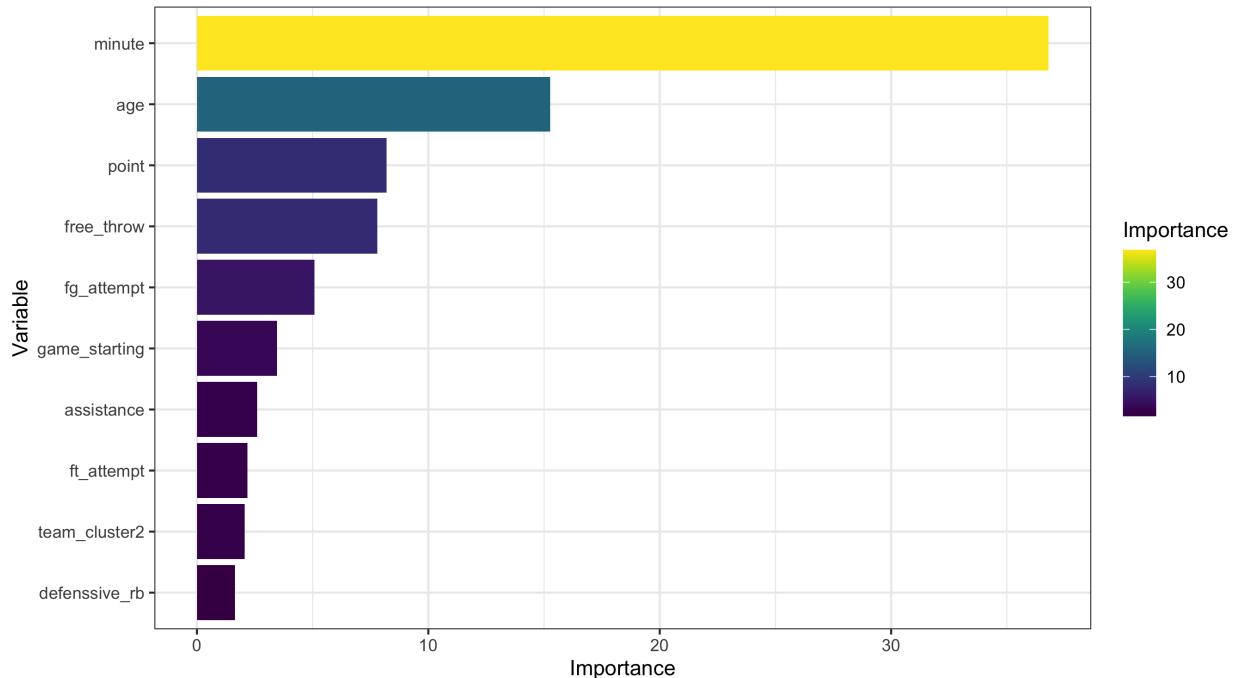


Figure 4: Variable Importance of GBM model

With our fitted GBM model, we can make predictions on new observations. The RMSE on our test data is 4.745948, which is the best among all the 8 models.

Given that GBM is a black-box model, we refer to the `lime` package to explain the predictions of the model on new observations, by fitting a simpler model to the permuted data with the above 10 most important features. Table 3 displays 6 randomly selected observations from the test data. The players' name, true salary (in millions), and predicted salary from GBM are shown.

Table 3: Prediction on Randomly Selected New Observations

player	salary (true)	salary (predicted by GBM)
Cade Cunningham	10.050120	8.590867
Cam Reddish	4.670160	3.627087
Christian Wood	13.666667	14.730414
Corey Kispert	3.383640	3.248053
D'Angelo Russell	30.013500	14.735256
Danuel House Jr.	2.045094	4.792719

The explanation of the GBM model from `lime` are shown in Figure 5. Inside the plot, the x-axis shows the relative strength of each variable, and positive values (blue) show that the the variable increases the value of the prediction, while the negative values (red) decrease the prediction value.

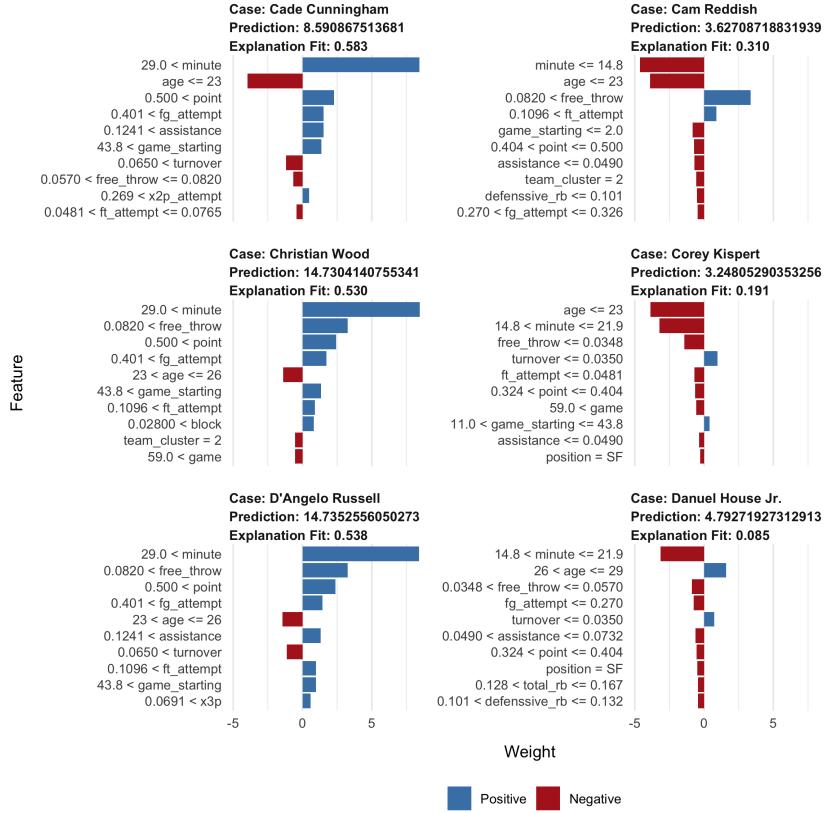


Figure 5: Explanation of final GBM model from lime package

Take the first case of player Cade Cunningham as an example. Cade's true salary is 10.050120 millions. His predicted salary from GBM is 8.590868 millions, which are quite similar to each other. Among the 10 most

important variables, factors `mintue > 90`, `point > 0.5`, `game_starting > 43.8`, `assistance > 0.1241`, `fg_attempt > 0.401` and `x2p_attempt > 0.269` increase Cade's salary, while factors `age <= 23`, `turnover > 0.065`, `0.057 < free_throw <= 0.082` and `team_cluster = 2` decrease his salary.

Conclusion

In this project, we explored different ways of building statistical models to predict the salary of NBA players based on their game statistics. We preprocessed the original raw data by removing missing values, joining datasets, and deriving more meaningful variables based on the existing ones. We then conducted an exploratory analysis to detect useful patterns in variable distribution and their correlations. To deal with the problems emerging from the preliminary analysis, such as co-linearity, non-linearity, and a large number of dummy variables, we did feature engineering to collapse categories, conducted variable selection to reduce model dimensions, applied various regularization techniques to prevent model overfitting, and introduced more sophisticated statistical methods to capture non-linear relationships. Among the 8 models fitted, we selected the GBM as the final predictive model after evaluating their performances on cross validation RMSE. Applying the final model on the test set, it also achieved a small RMSE value, indicating an excellent prediction accuracy and a low level of over-fitting. Other models did not achieve the same level of prediction accuracy as the GBM, either underfitting the data with higher CV RMSE or fitting the training data too well (particularly, in the case of the neural network model).

From the GBM model, we also gained insights into important variables that influence the player's salary, among which the top 10 variables are `minute`, `age`, `point`, `free_throw`, `fg_attempt`, `game_starting`, `assistance`, `ft_attempt`, `team_cluster`, and `defensive_rb`. These findings are consistent with our understanding of factors that commonly affect the income of NBA players.

The study has several limitations. Interaction analysis can be conducted in the family of linear regression models. In building the neural network, we only trained the multilayer perceptron model with the ReLU activation functions. Several other model structures and activation functions are worth trying in the future. The model accuracy can be further improved by introducing new variables. For example, the current salary level of a player should be more related to his performance in the year before making a new contract. Therefore, apart from the statistics for the 2021-2022 season, player data from previous seasons can also be included in the analysis. Furthermore, some players having a high salary may suffer injuries in recent games; injury data can also be taken into account.

References

- [1]<https://www.basketball-reference.com/contracts/players.html>
- [2]https://www.basketball-reference.com/leagues/NBA_2022_per_game.html
- [3]<https://www.geeksforgeeks.org/how-neural-networks-are-used-for-regression-in-r-programming/>

Appendices

Appendix A - Numeric Variable Distribution

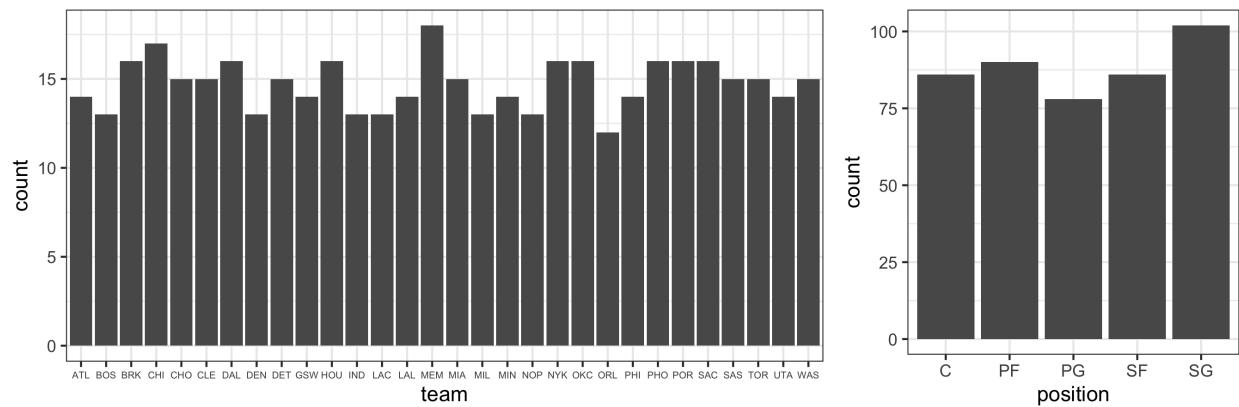


Figure 6: Histograms of Predictive Variables

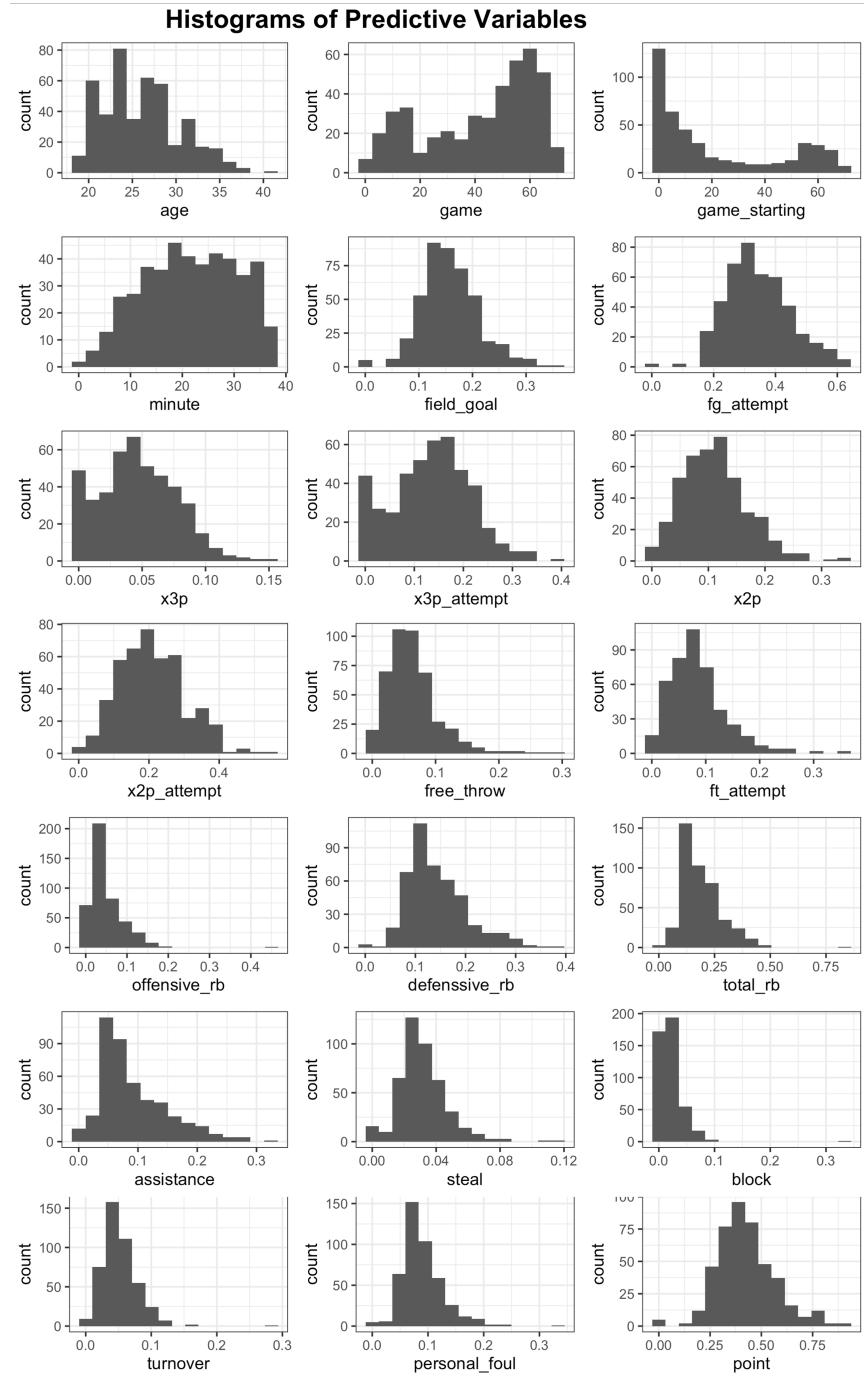


Figure 7: Histograms of Predictive Variables

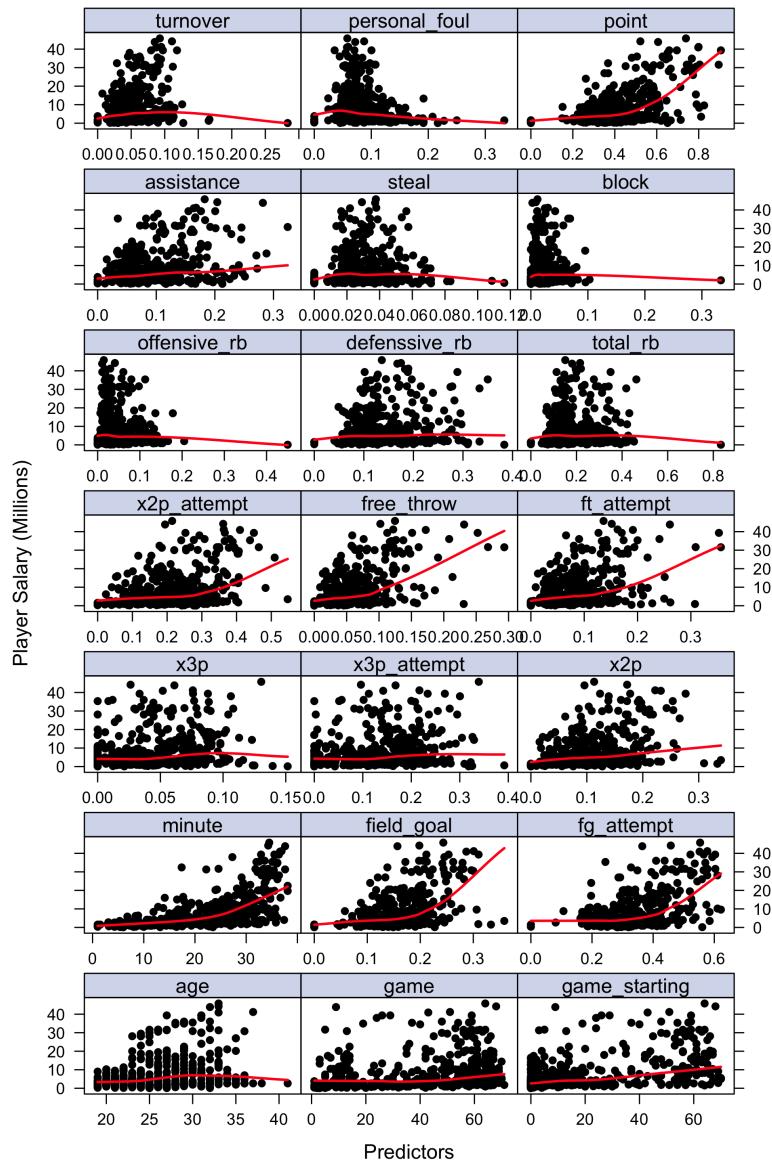


Figure 8: Featureplot of Numeric Variables

Appendix B - Linear Regerssion

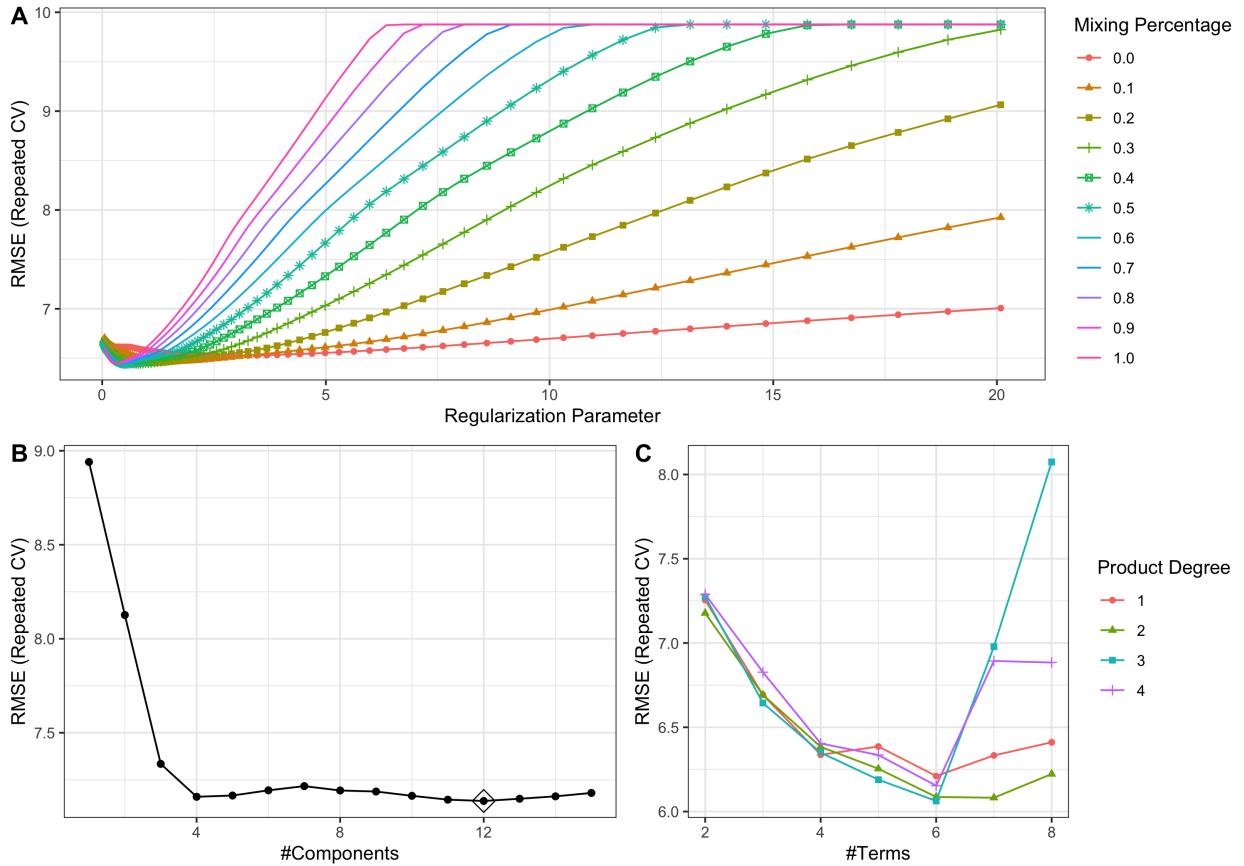


Figure 9: Parameter Tuning Plot of (A) Elastic-net Model; (B) PCR; (C) MARS

Appendix C - Tree-based Models

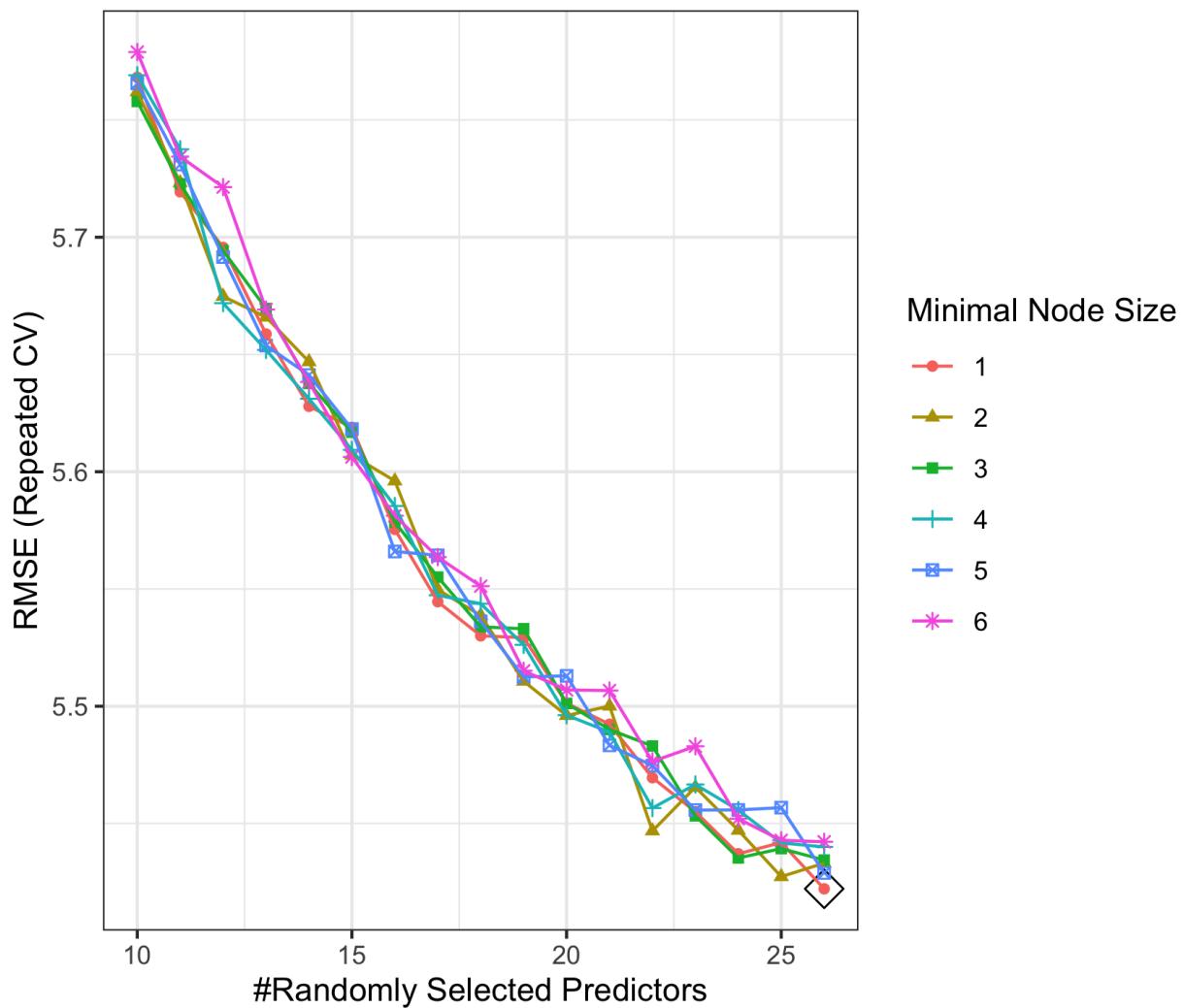


Figure 10: Parameter Tuning of Random Forest

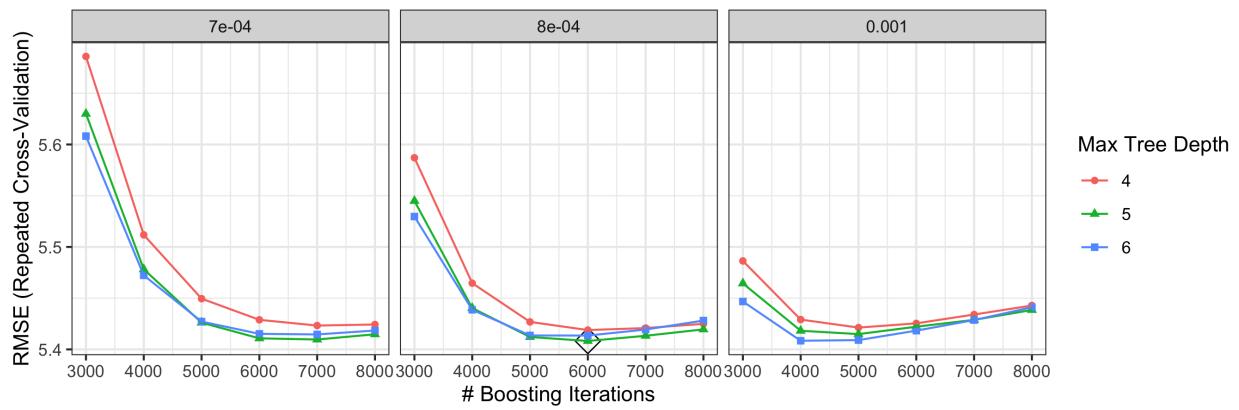


Figure 11: Parameter Tuning of GBM