Project

DSCI341101 - Fundamentals of Simulation (2023 Spring)

Simulation Analysis of Tic ac Toe: Evaluating Strategies for X and O Players

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Abstract:

This report presents a project focused on using simulation and the R programming language to compare different strategies in the game of Tic Tac Toe. The objective is to determine whether it is more advantageous to play as X (first move) or O (second move) by evaluating the performance of various strategies. The report provides a description of the game and formulates research questions to guide the analysis, explores four strategies including random choices, smart O player, smart X player, and a combined smart X and O strategy, and concludes with the findings and the best strategy based on the analysis.

1. Introduction

Tic Tac Toe is a classic paper-and-pencil game played on a 3x3 grid. The game involves two players who take turns marking X and O symbols in empty spaces on the grid. Tic Tac Toe is a simple yet strategic game that has been enjoyed by people of all ages for centuries. The objective is to create a horizontal, vertical, or diagonal line of three of their own symbols (X or O).

Examples of winning combinations are shown below:

```
     [,1] [,2] [,3]
[1,] " "  " "  " "
[2,] "X"  "X"  "X"
[3,] " "  " "  " "


     [,1] [,2] [,3]
[1,] " "  "X"  " "
[2,] " "  "X"  " "
```

[3,] " " "X" " "

[,1] [,2] [,3]

[1,] "X" " " " "

[2,] " " "X" " "

[3,] " " " " "X"

2.Research Questions

I. Is there an advantage to playing as X (first move) or O (second move) in Tic Tac Toe?

II. How do different strategies impact the outcome of the game?

III. Which strategy yields the highest winning percentage for each player?

3. Strategies in Tic Tac Toe Game

3.1 Random Choices by Player X and O

Each player selects an empty space randomly. The moves are made independently of the game's state or any strategy. Multiple games are simulated to determine the winning percentage for each player. First, we initialize N= 1000, which is the number of samples (simulation runs), and n= 1000, which is the size of the sample that contains multiple independent games simulated . In this sample, we write whether X has won, O has won, or a draw. Then after that, we get another 1000 samples (runs), and we compute the mean of all of the samples and place it on a bar plot, as shown in Figure 1.

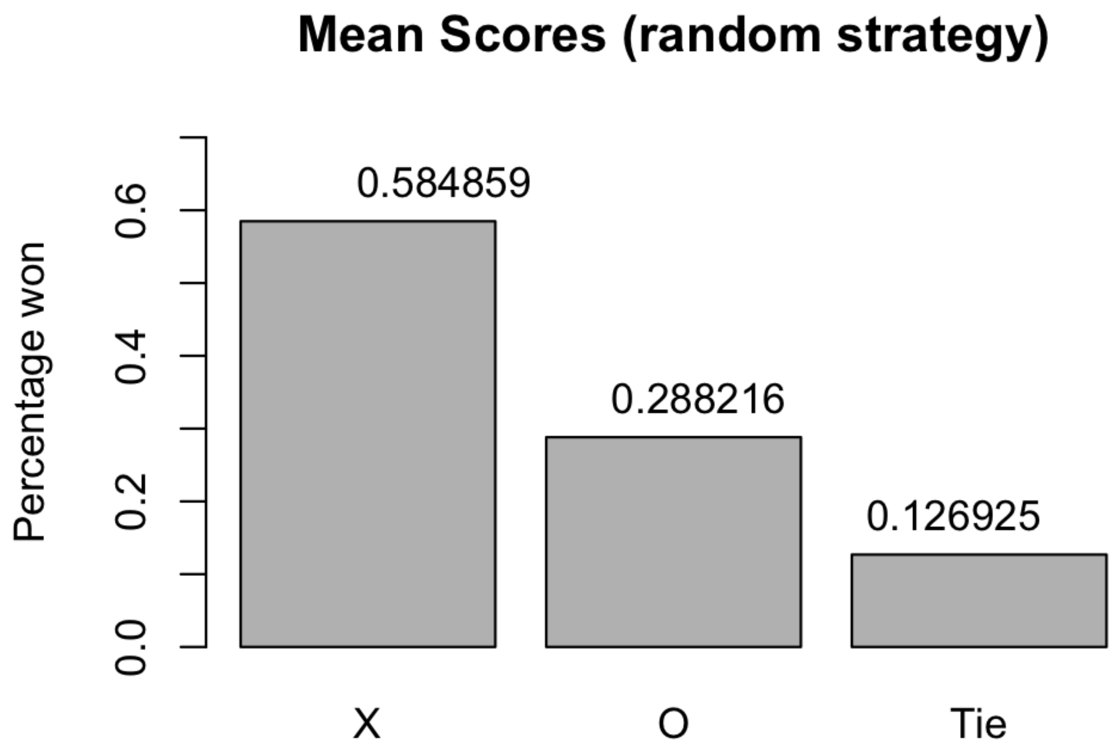


Figure 1: Mean Scores Percentage of Winning of 'X,' 'O', or 'Tie'

As shown in Figure 1, the mean score percentage of winning for player X is 58.4859%, for player O is 28.8216%, and for a tie would happen 12.6925%. Therefore, by analyzing the random choices by Player X and O, we can conclude that X has a great chance of winning.

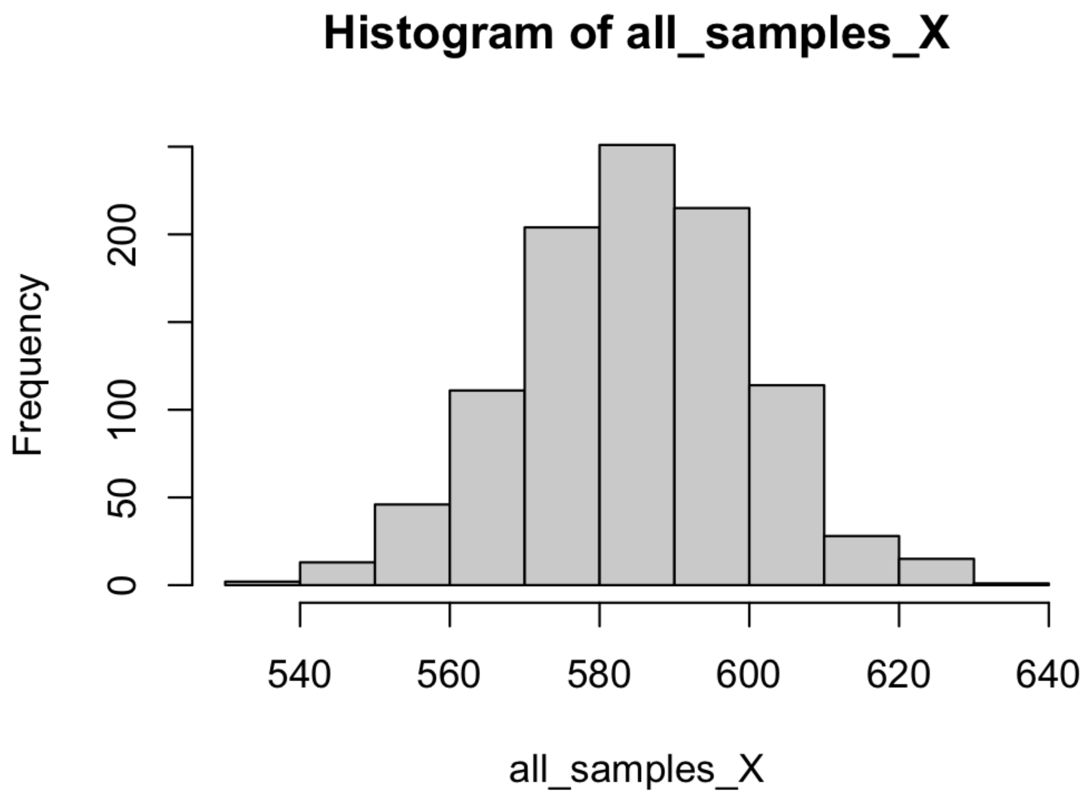


Figure 2: Histogram of all_samples_X

In Figure 2, it shows that all_samples_X follow a normal distribution, with all the samples of the number of times X won from the 1000 games played, the mean is 585.215 and variance is 240.5253.

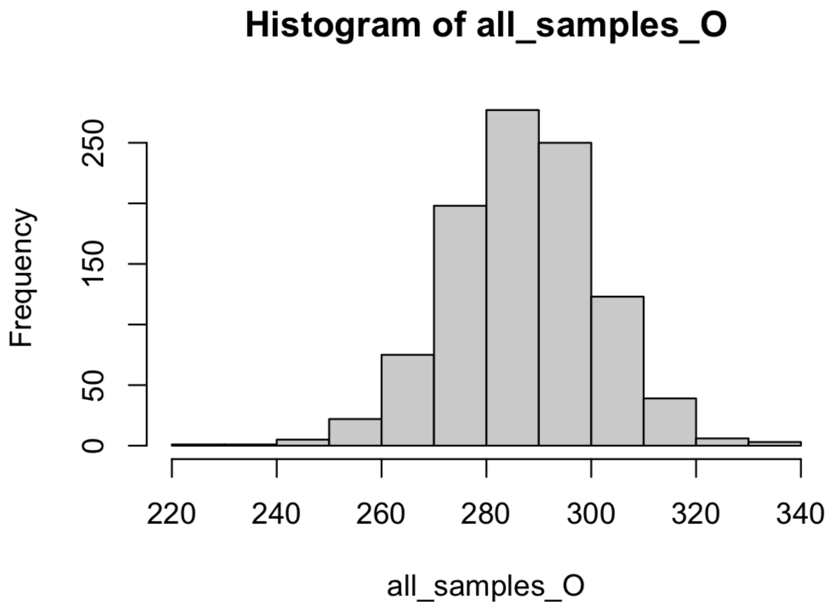


Figure 2: Histogram of all_samples_O

As shown in Figure 2, for O winnings, it appears also to follow a normal distribution, and the mean is 287.526, and the variance is 197.0884.

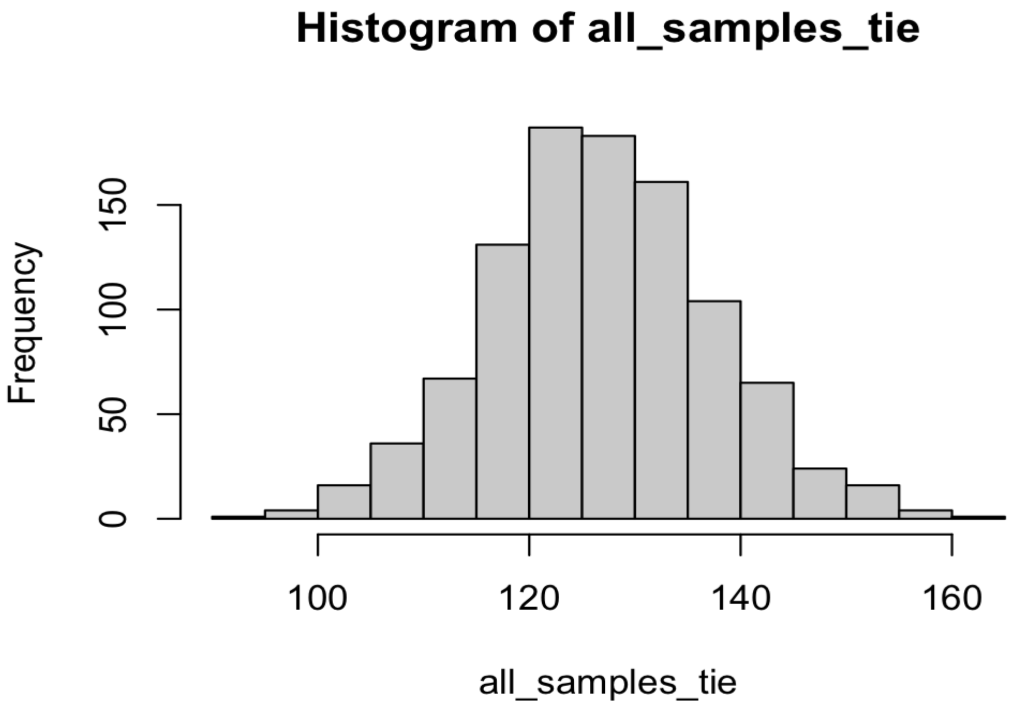


Figure 3: Histogram of all_samples_tie

In Figure 3, it shows that all_samples_tie follow a normal distribution and the mean is 127.259, and the variance is 114.1641.

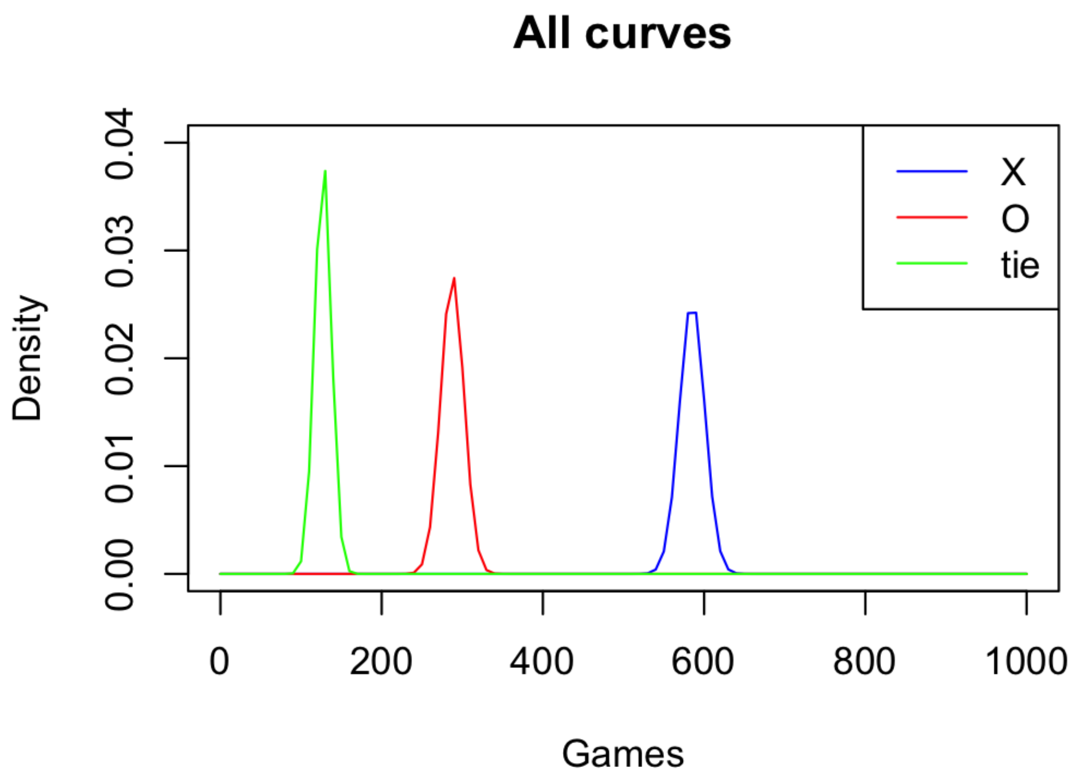


Figure 4: Density plot of 'X,' 'O', and 'Tie'

As we can see here, we have concluded X, O, and Tie follow a normal distribution we can approximate the graphs by plotting continuous normal distribution. To conclude, it appears for the random strategy that playing first (X) has an advantage for winning more games however, in real life, most people play with different strategies, and these games are not very reflective of real life.

3.2 Smart O Player

The O player follows a predetermined strategy that focuses on blocking the X player's winning moves and finding winning moves. If there are no immediate threats, the O player makes a random move. Multiple games are simulated to determine the winning percentage for each player. Since most of the time, X wins if both players are random, what would happen if O followed a strategy while X played randomly? And vice versa. We will first start with O. The strategy for O is the same as before (random), except now there are the following two conditions:

1- If O has a winning move (two O symbols and one empty space), O's next move would be to place the symbol in the empty space

2- If X has a winning move (two X symbols and one empty space) O's next move will prioritize blocking the move by placing an O on the empty space.

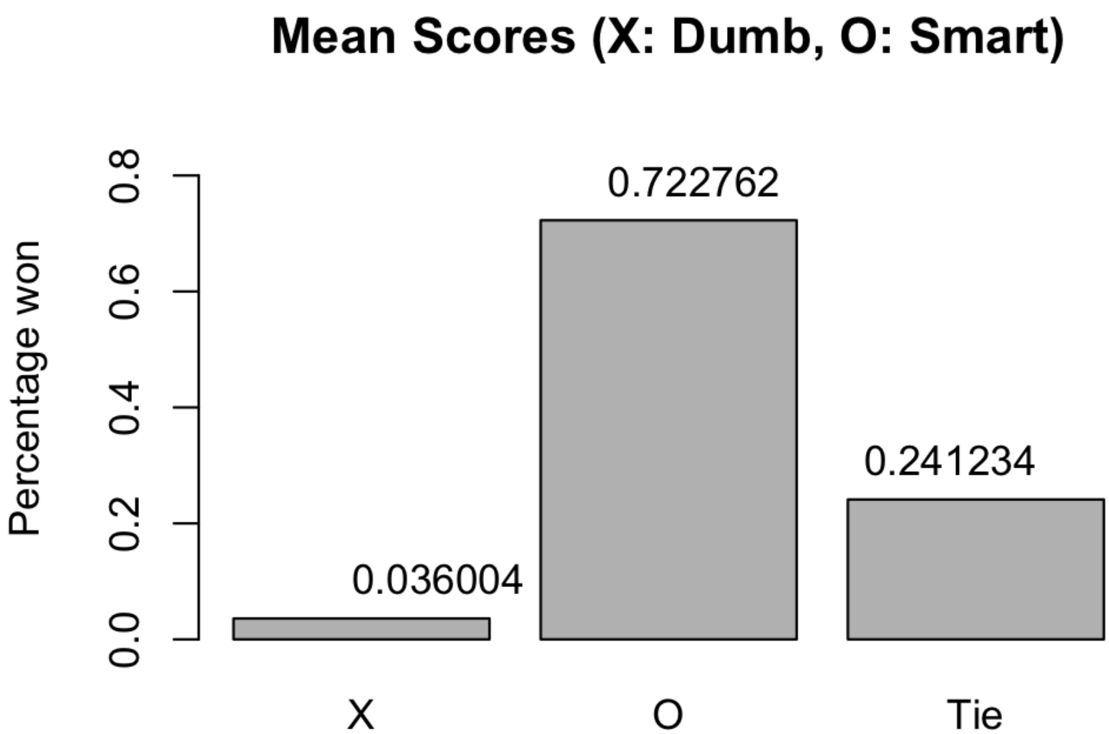
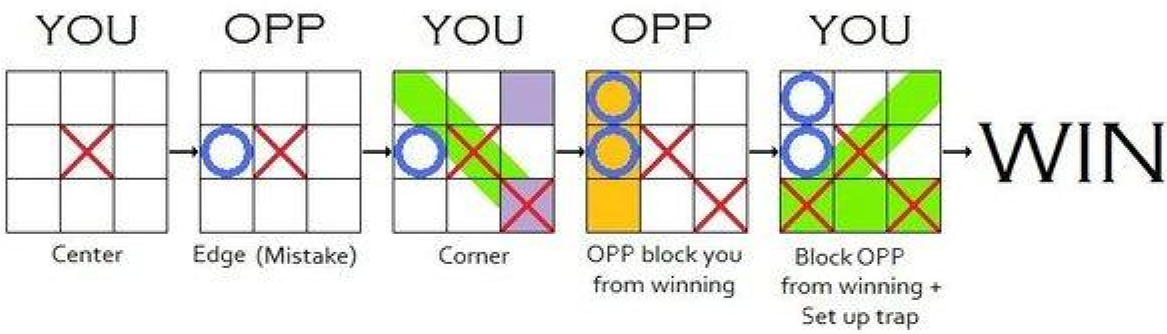


Figure 5: Mean Scores Percentage of Winning of X: Dumb, O: Smart, or tie

As illustrated in Figure 3, the mean score percentage of winning for player X: Dumb is 3.6004%, for player O: Smart is 72.2762%, and for a tie would happen 24.123%. Therefore, following this strategy, we could see that the number of Games X won drops down to 3.6004%. But why is it, not 0%? Well, that's because there is a slight chance X might make a winning combination by accident due to randomness where O can not block both attacks from X.



[1]

Figure 6: A showcases the strategy of X winning

An Example of X winning randomly because of the nature of randomness, it is possible that a game like this has happened in the sample and no matter what O does, eventually X will win. X first starts by placing its symbol in the middle of the grid. Due to O not seeing a winning combination or blocking X from winning, O will place its symbol randomly on the grid also. X might randomly put its symbol on one of the corners, and the code will instruct O to block X's attack. X might randomly block O's attack, so X has two lines to complete to win the game, which are the diagonal or the other line. O will prioritize placing its symbol in a way to block X from winning, but X has two winning combinations, not only one. Therefore, O cannot block both in the same turn. X can randomly complete the winning combination and win the game. As shown below, a scenario of a game similar to the one mentioned above in one of the samples.

[1] Source: https://www.quora.com/What-are-the-best-strategies-to-win-a-4*4-Tic-Tac-Toe

Scenario example:

sample_games[17]

[[1]]

[,1] [,2] [,3]

[1,] "O" " " "X"

[2,] "O" "X" "O"

[3,] "X" "O" "X"

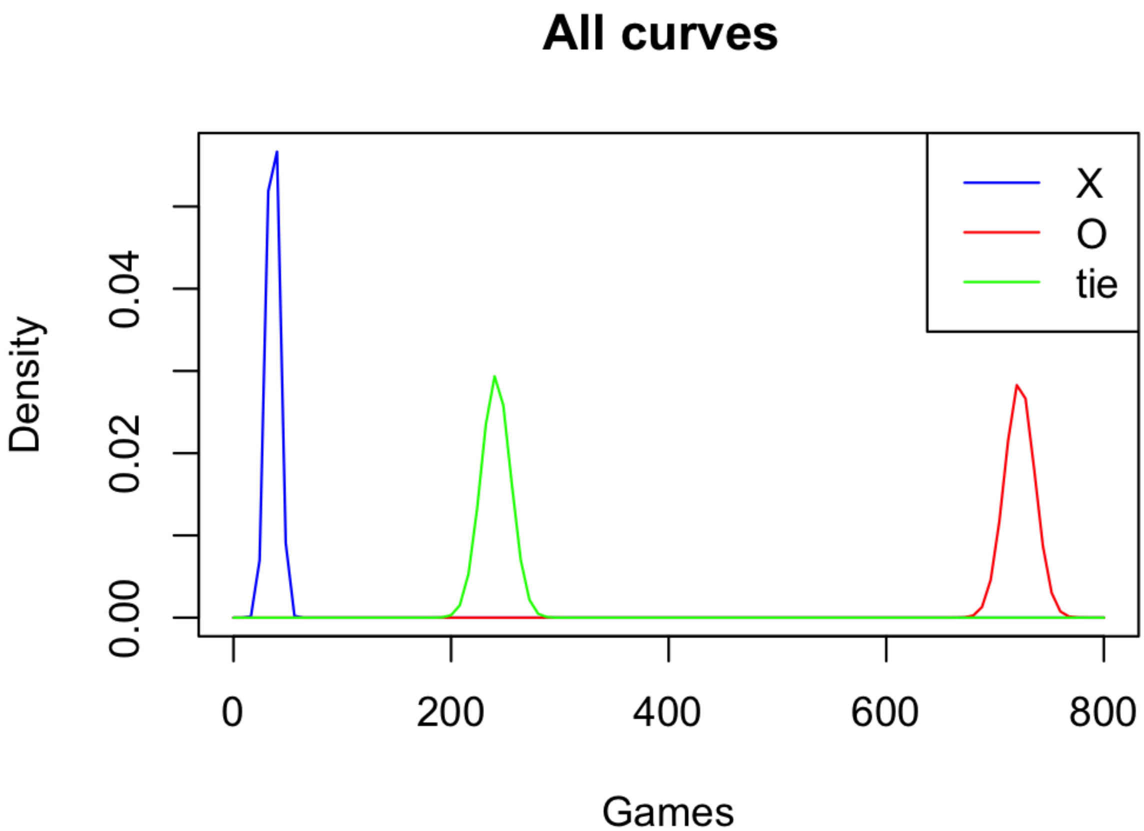


Figure 7: Density plot of 'X,' 'O', and 'Tie'

Since the histograms follow a normal distribution, we can just use curves to represent it, as we can see here, O wins almost all of the games, while X barely wins any. For O, we concluded that if O plays smart and X plays random, O will win 72.2762% of the games most of the time, now we will see what happens if X plays smart and O plays random.

3.3 Smart X Player

The X player follows a predetermined strategy that prioritizes winning moves. If there are no immediate winning moves, X player makes a random move. Multiple games are simulated to determine the winning percentage for each player.

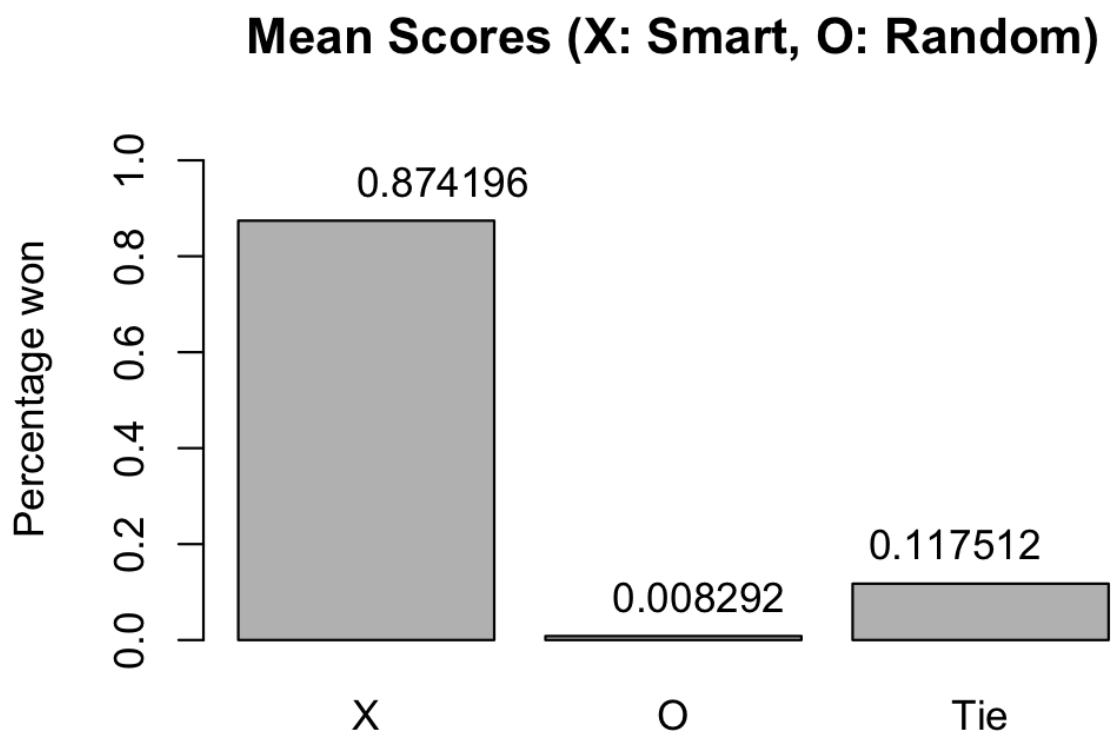


Figure 8: Mean Scores Percentage of Winning of X: Smart, O: Random, or tie

As shown in Figure 8, the mean score percentage of winning for player X: Smart is 87.4196%, for player O: Random is 0.8292%, and for a tie would happen 11.7512%. By analyzing the scores, we can say X now wins most of the games approximately 87.4196% of the time, which is actually higher than the number of times when O plays smart 72.2762%.

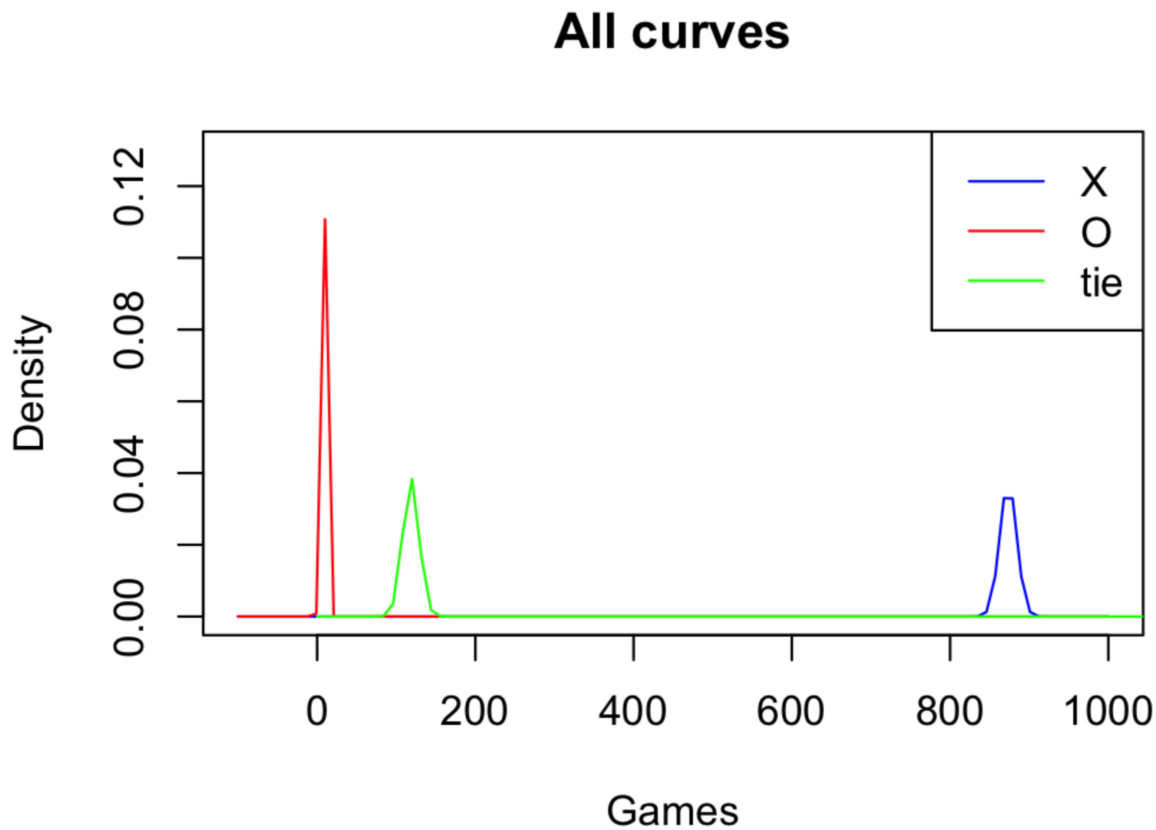


Figure 8: Density plot of X: Smart, O: Random, or tie

As shown in the histograms, all X: Smart, O: Random, and tie follow a normal distribution, and X wins almost all of the games, while O barely wins any.

3.4 Smart X and O

The X player follows the smart X strategy, while the O player follows the smart O strategy. Both players aim to maximize their chances of winning. If Both players are smart, X is still more likely to win since when they start first, they might accidentally do one of the winning combinations strategies before O does one. Multiple games are simulated to determine the winning percentage for each player.

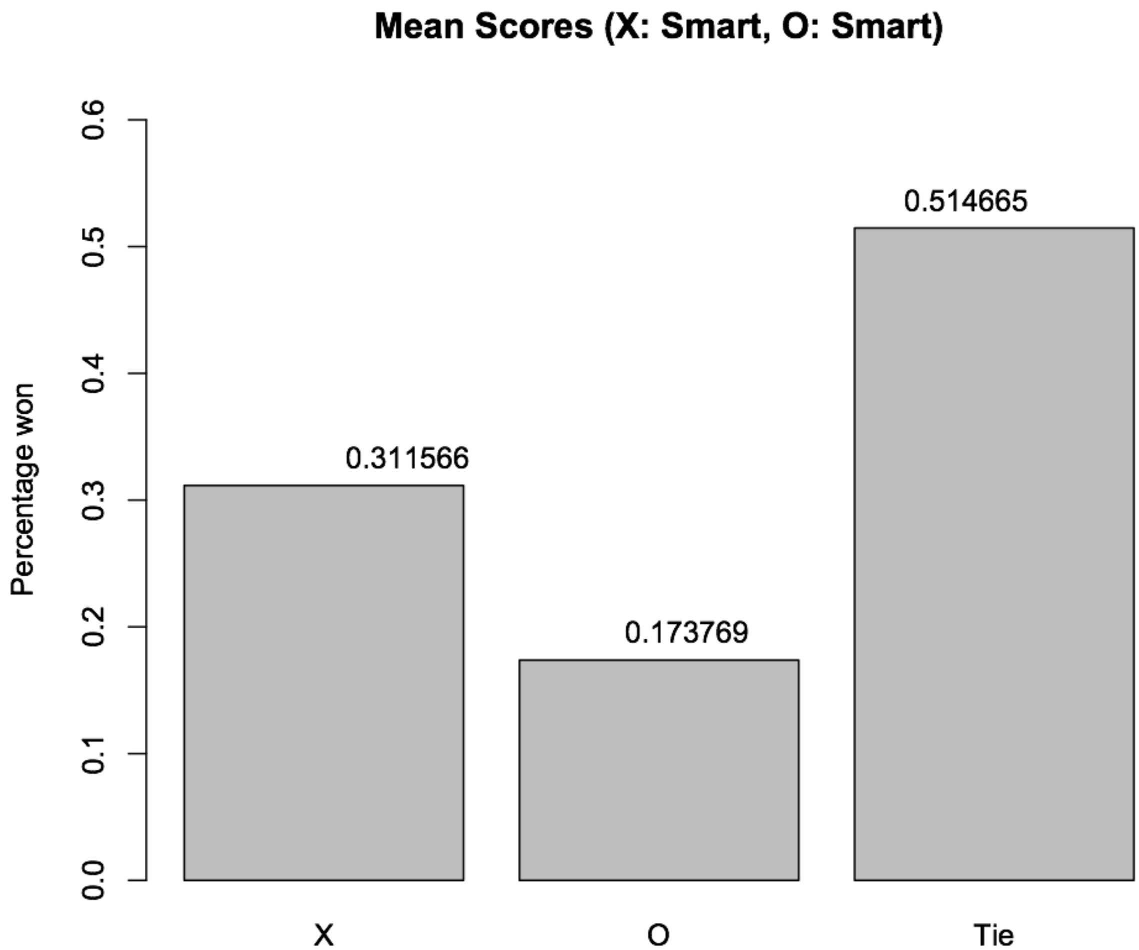


Figure 9: Mean Scores Percentage of Winning of 'X,' 'O', or 'Tie'

As shown in Figure 9, the mean score percentage of winning for player X is 31.2112%, for player O is 17.3184%, and for a tie would happen 5.14704%. Overall, most of the games ended in a tie because X and O would just keep blocking each other from winning when they played randomly, they did not do that, so they would let the other user win accidentally.

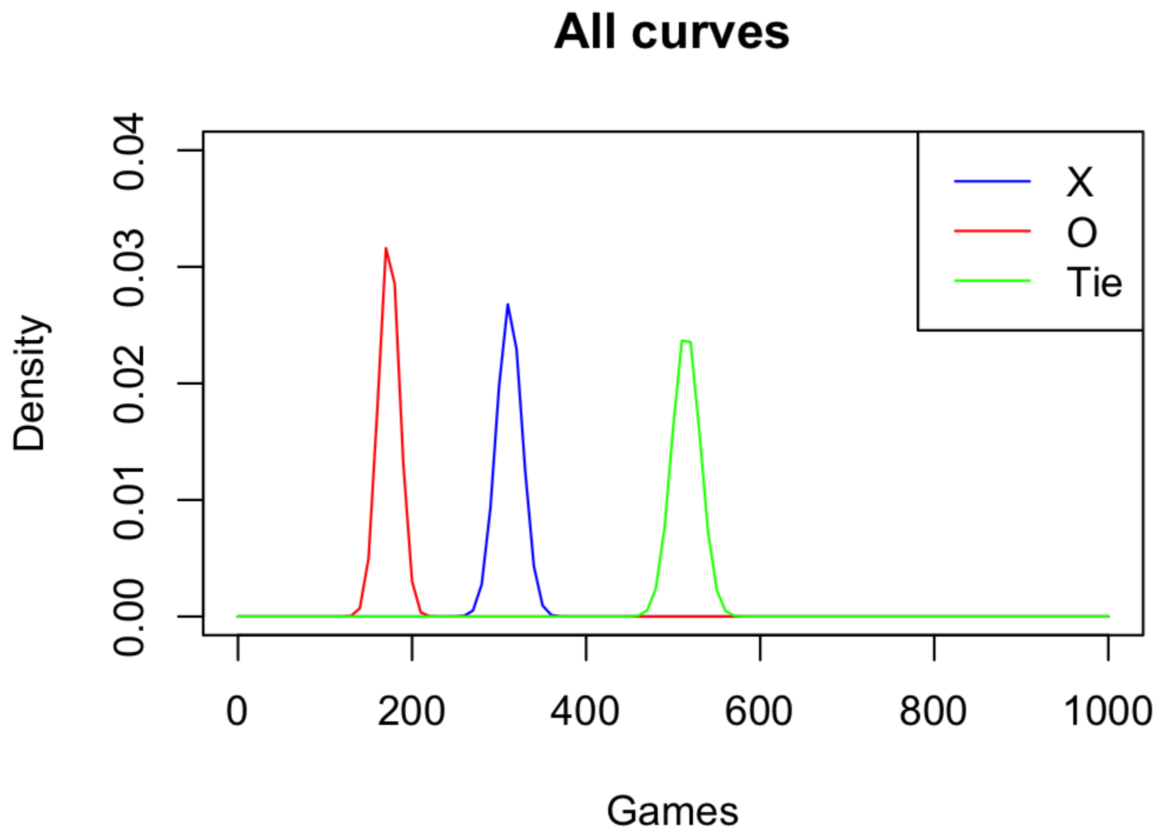


Figure 8: Density plot of X, O, and Tie

As shown in the histograms, all X: Smart, O: Smart, and Tie follow a normal distribution. Although most of the time it's a tie, if we disregard the tie, X wins almost all of the games, while O barely wins any.

4. Conclusion

Based on the simulation analysis, the findings indicate the following:

Random Choices: X player has a higher winning percentage compared to O player.

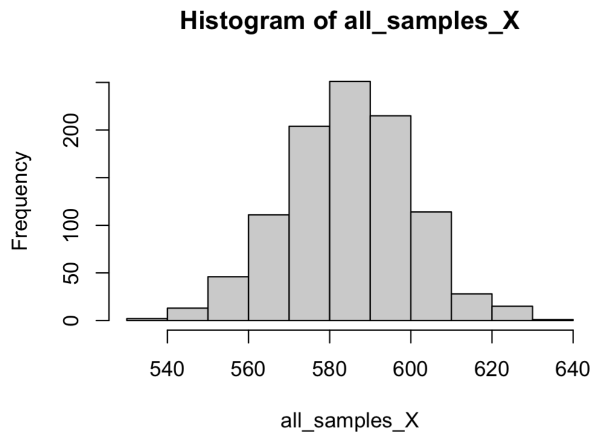
Smart O Player: O player has a higher winning percentage compared to X player.

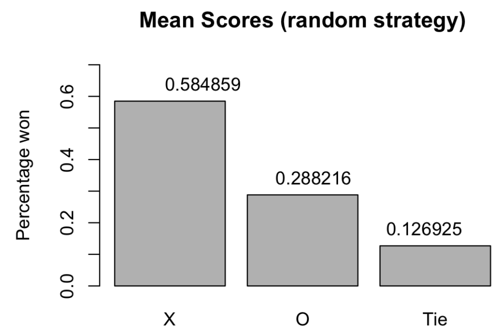
Smart X Player: X player has a higher winning percentage compared to O player.

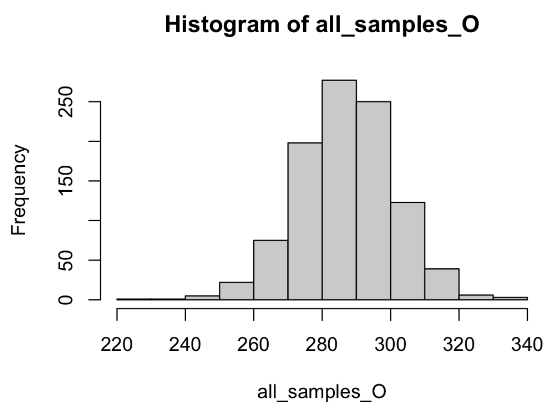
Smart X and O: if we disregard the tie, X player has a higher winning percentage compared to O player.

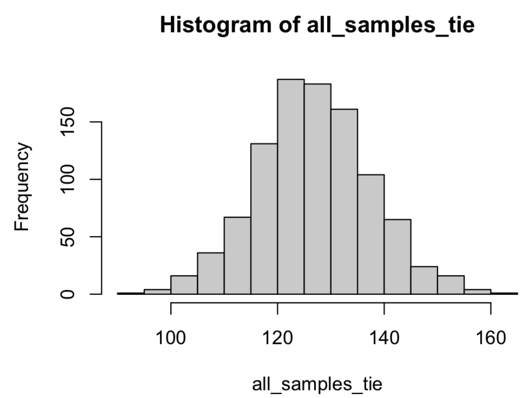
In conclusion, the simulation analysis suggests that playing as X (first move) provides an advantage in the Tic Tac Toe game. The smart X strategy yields the highest winning percentage for the X player, while the smart O strategy yields the highest winning percentage for the O player. These findings provide valuable insights for players seeking to improve their performance in the game of Tic Tac Toe. With all the data we collected, it is clear that playing first as X will, most of the time, guarantee a win or a tie at best if both players play accordingly.

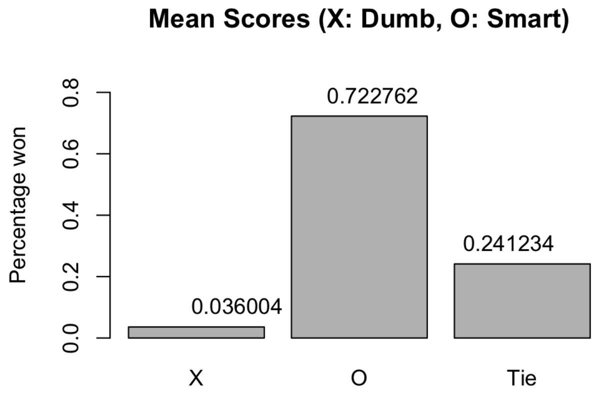
5. Appendix

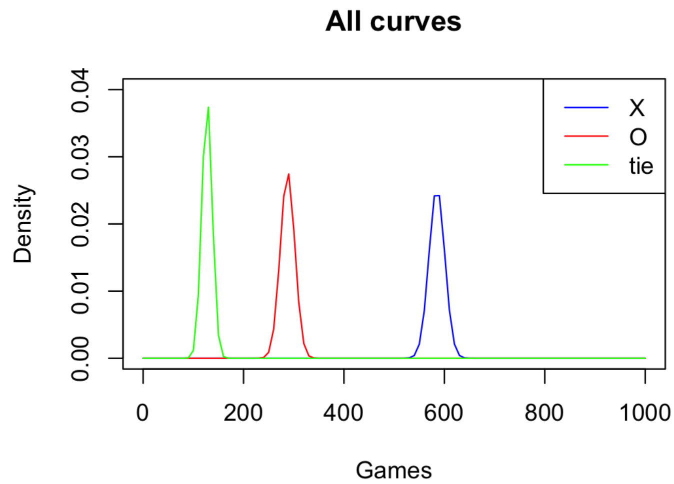

Histogram of all_samples_X
Frequency
0
50
100
200
540
560
580
600
620
640
all_samples_X

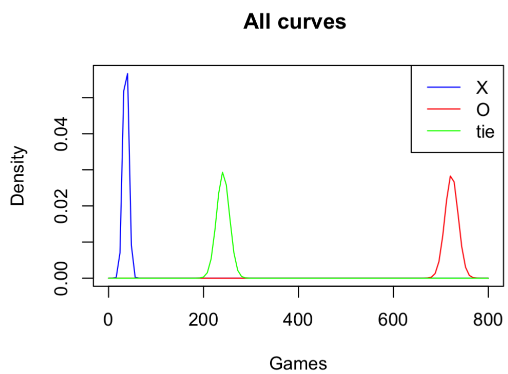

Mean Scores (random strategy)
Percentage won
0.0
0.2
0.4
0.6
0.584859
0.288216
0.126925
X
O
Tie

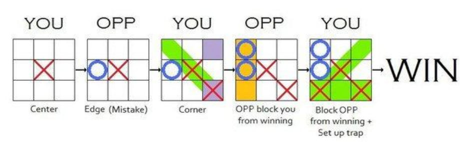

Histogram of all_samples_O
Frequency
0
50
150
250
220
240
260
280
300
320
340
all_samples_O


Histogram of all_samples_tie
Frequency
0
50
100
150
100
120
140
160
all_samples_tie

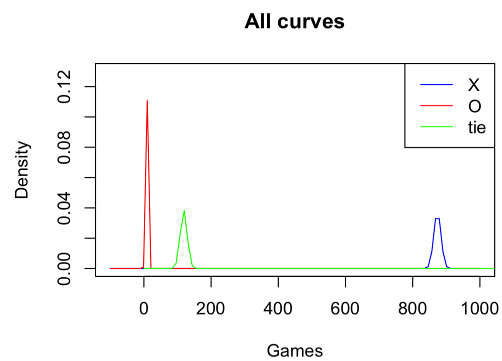

Mean Scores (X: Dumb, O: Smart)
Percentage won
0.0
0.2
0.4
0.6
0.8
0.036004
0.722762
0.241234
X
O
Tie

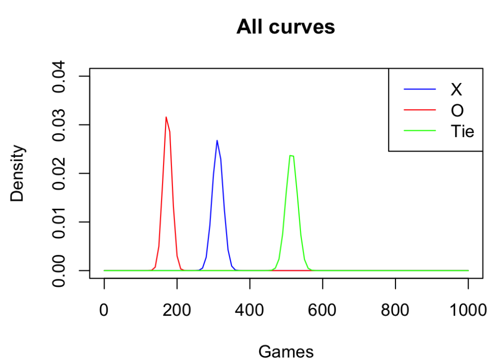

All curves
Density
0.00
0.01
0.02
0.03
0.04
X
O
tie
0
200
400
600
800
1000
Games

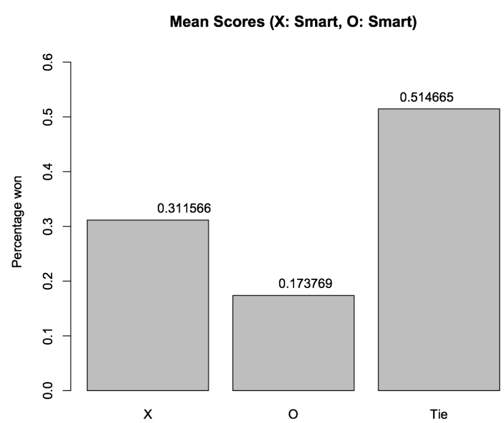

All curves
Density
0.00
0.02
0.04
X
O
tie
0
200
400
600
800
Games


YOU
OPP
YOU
OPP
YOU
Center
Edge (Mistake)
Corner
OPP block you from winning
Block OPP from winning + Set up trap
WIN


Mean Scores (X: Smart, O: Random)
Percentage won
0.874196
0.008292
0.117512
X
O
Tie


All curves
Density
Games
X
O
tie


All curves
Density
Games
X
O
Tie


Mean Scores (X: Smart, O: Smart)
Percentage won
0.311566
0.173769
0.514665
X
O
Tie