Using Monte Carlo Methods for Retirement Simulations

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Abstract. Retirement prediction helps individuals and institutions make informed financial, lifestyle, and workforce decisions based on estimated retirement portfolios. This paper attempts to predict retirement using Monte Carlo simulations, allowing one to probabilistically account for a range of possibilities. The authors propose a model to predict the values of the investment accounts IRA and 401(k) through the simulation of inflation rates, interest rates, and other pertinent factors. They provide a user case study to discuss the implications of the proposed model.

Keywords: Individual Retirement Arrangement (IRA), Monte Carlo, Retirement simulations, Machine Learning, Financial modeling, Retirement income, Probability analysis, Asset allocation

1 Introduction

Online retirement calculators are frequently used to calculate and project one's retirement savings [1]. Yet, as found by researchers at [2], many of these online retirement calculators compromise on the quality and accuracy of their predictions in a multitude of ways by using constant rates and assumptions in their predictions and calculations. Monte Carlo methods have been shown to resolve this shortcoming by probabilistically accounting for a range of possibilities [3].

Monte Carlo simulations have emerged as a valuable tool for retirement planning and simulations due to their ability to incorporate multiple uncertain variables and assess retirement strategies. Previous studies have highlighted the benefits of Monte Carlo simulations in modeling retirement scenarios and evaluating various factors such as investment returns, inflation rates, and life expectancies [4-5]. These simulations provide a probabilistic assessment of retirement outcomes, enabling individuals to gauge the likelihood of achieving their financial goals and identify potential risks [6]. Moreover, researchers have explored enhancements to traditional Monte Carlo methods, such as incorporating dynamic strategies and utilizing machine learning techniques [7], to optimize retirement portfolios and determine sustainable withdrawal rates [8-9]. The accuracy and reliability of Monte Carlo simulations heavily depend on the quality of input assumptions and data, emphasizing the need for robust modeling and careful calibration [10]. Overall, the existing literature shows support for the validity of Monte Carlo simulations as a powerful tool for retirement planning and decision-making.

In this paper, a framework is proposed based on Monte Carlo methods to accurately simulate retirement portfolios. Evidenced and proposed distributions for various factors, such as Inflation rates, ROI rates, and Tax rates, along with a multitude of other factors are used to simulate the values of 401K and IRA [11-12] accounts after a defined number of years. Monte Carlo simulations are used to come up with all-encompassing ranges for the aforementioned factors.

The proposed framework simulates potential retirement scenarios for a given user numerous times to create a range of predicted outcomes. It makes extensive use of random sampling to probabilistically determine the most likely outcomes [13].

The paper is structured as follows. Section II discusses the proposed model, and the tools utilized. Section III explains the assumptions used to create predictions for the factors fed into the model i.e Inflation rates, ROI rates, and Tax rates. Section IV analyzes a case study and simulations created by the model for potential retirees. Finally, the conclusion is presented in section V, with the implications of the proposed model.

2 Proposed Model

Python is utilized to create our model, taking advantage of modules that allow for random sampling in a given distribution.

Based on the model parameters discussed in section III, Monte Carlo methods are first used to simulate and generate the series of ROI rate, inflation rate, etc. for each distinct simulation for the specified number of years. With the series of distinct, generated rates for a particular simulation, the user specified starting values for variables specified in section III are taken, and used to conduct the simulation using these values. The values of the IRA and 401(k) accounts are simulated throughout a user-specified number of years.

In 2023, the IRA [15] the limits for annual contributions is $6,500, or $7,500 if you're age 50 or older. These limits increase over time due to inflation. More specifically, when $7000 will buy what $6500 buys in 2023, the IRA contribution limits would increase to $7000 [15].

The proposed model accounts for this increased contribution limit by utilizing the inflation values generated earlier to see whether the contribution limit must increase if the user is either above age 50 or if the contribution limits must be increased. For the purposes of this paper, it is assumed the user contributes the max allowable amount to their IRA.

Second, a look is taken at the 401K account [4]. 401(k) plans, which are retirement savings programs with advantageous tax treatment for the saver, are offered by a large number of American businesses. Employees who sign up for 401(k) plans agree to have a portion of each paycheck automatically deposited into an investment account. The employer may match the entire contribution or just a portion of it. The employee has many investment options, most frequently mutual funds.

In 2023, 401k contributions are capped at $22,500 if you are under 50. Users over the age of 50 are allowed to contribute an extra $7500. The 401K is also indexed to inflation.[16]

Thus, the proposed model accounts for this increased contribution limit by utilizing the inflation values generated earlier to see whether the contribution limit must increase if the user is either above age 50 or if the contribution limits must be increased. For the purposes of this paper, it is assumed the user contributes the max allowable amount to their 401(k)[16].

Once the nature of these two types of retirement accounts in our model are defined, simulations based on the generated data and the user parameters defined in section III can be created.

For both the IRA and the 401K, the annual salary of the user is determined using the raise_rates generated. Once the salary of the user have been determined, the model uses the contribution limits described above and the specific nature of the retirement accounts to determine the contribution that the user will make to each account type, and account for the simulated ROI by appropriately changing the value of their simulated 401K and IRA values. The proposed model provides the user 2 different values for each simulation, one that gives the total value in each account, and the other gives the real value: discounted for inflation, by dividing the total cash values by the aggregate of the inflation rates [17].

This can be used to generate a more holistic and compete simulation of what the future retirement scenario will look for a user for both their 401(k) and their IRA accounts.

3 Model Parameters

For the model to accurately assign probabilities, create simulations, and create distributions representative of the true values of the various model parameters it uses, the authors first researched the mean values and standard deviations of the normal distributions of each parameter. It is assumed that all the distributions used in the model are normal with the proposed mean and standard deviation values. Distributions to represent the Inflation Rate, ROI Rate, and Raise Rate were then created. The results are shown in Table 1.

Table 1. Simulated Rates

Model Parameter	Definition	Mean Value	Standard Deviation Value
Inflation Rate	Simulated Rate of Annual Inflation [18]	2.58% [19]	2.29% [19]
ROI Rate	Simulated Return on Investment rate [20]	9.89% [19]	2.47% [19]
Raise Rate	Simulated annual increase in salary; can be changed by user as needed	5%	2.5%

In addition, a list of static parameters that the user must provide the model in order to get accurate calculations can be found in Table 2.

Table 2. Static Parameters of Model

Model Parameter	Definition
Year	Number of years simulation is being conducted for
Salary	Current annual remuneration of user
IRA_Start	Starting balance of IRA account
401k_Start	Starting balance of 401(k) account
IRA_contribution	Contribution by user to IRA account
401k_contribution	Contribution by user to 401(k) account
Age	Age of user. Used to see if contribution limits must increase.

Table 1 and Table 2 combined provide our model with all the needed parameters to conduct simulations for the 401(k) and IRA of users.

4 Case Studies

The proposed model is implemented for a user case study to demonstrate its applications. The user's static parameters (as defined in Table 2) are shown in Table 3.

Table 3. Static Parameters of User

Model Parameter	Value
Year	25 years
Salary	$100,000
IRA_Start	$0
401k_Start	$0
IRA_contribution	$5000
401k_contribution	5%
Age	30 years

The model starts by first conducting the simulation of the IRA account of this user. It simulates the value of the IRA account for 25 years, as specified, for one iteration, the results of which are shown in figure 1.

Fig. 1. One Iteration of Potential Growth of IRA over 25 years

To conduct a proper Monte Carlo simulation that probabilistically accounts for a range of possibilities, the authors conduct 1000 simulations of the IRA account for 25 years. The results of this can be seen in figure 2.

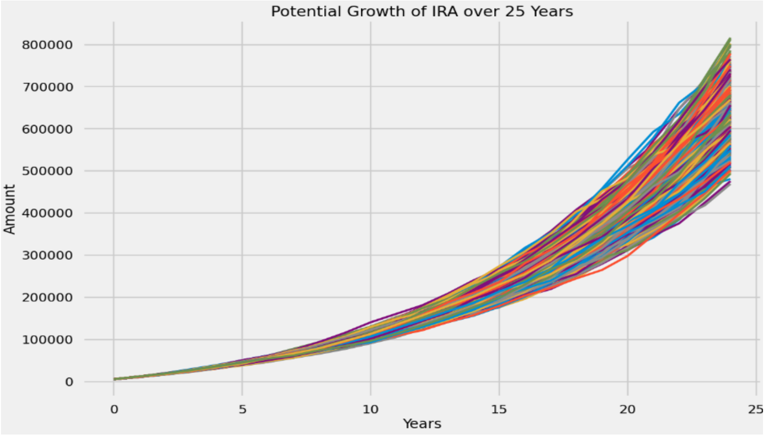

Fig. 2. Potential Growth of IRA over 25 years

As the framework also simulated the inflation rates, the model allows for the discounting of inflation in the simulation to see what the real buying power of the IRA would be in the simulated time frame. The results of this are shown in figure 3.

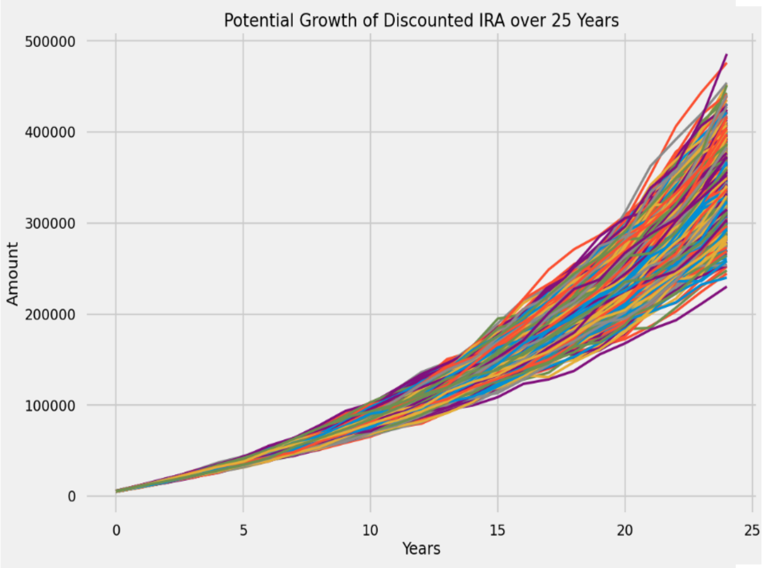

Fig. 3. Potential Growth of Discounted IRA over 25 years

The model next conducts the simulation of the 401(k) account of this user. It simulates the value of the 401k account for 25 years, as specified, for one iteration, the results of which are shown in figure 4.

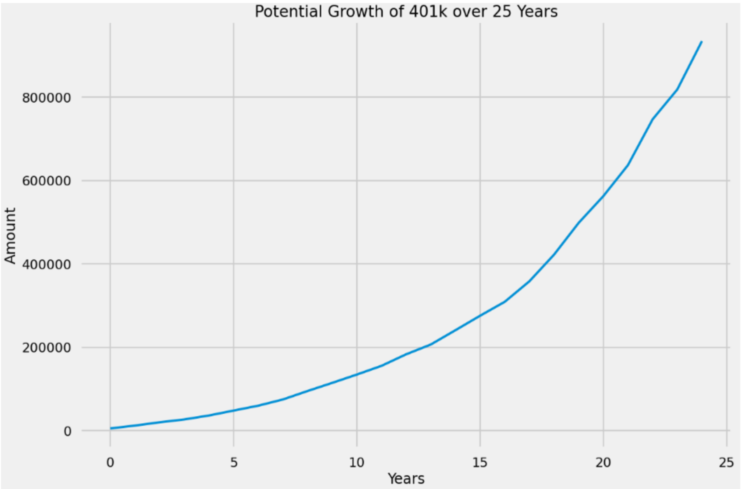

Fig. 4. One Iteration of Potential Growth of 401k over 25 years

To conduct a proper Monte Carlo simulation that probabilistically accounts for a range of possibilities, the model conducts 1000 simulations of the 401(k) account for 25 years. The results of this can be seen in figure 5.

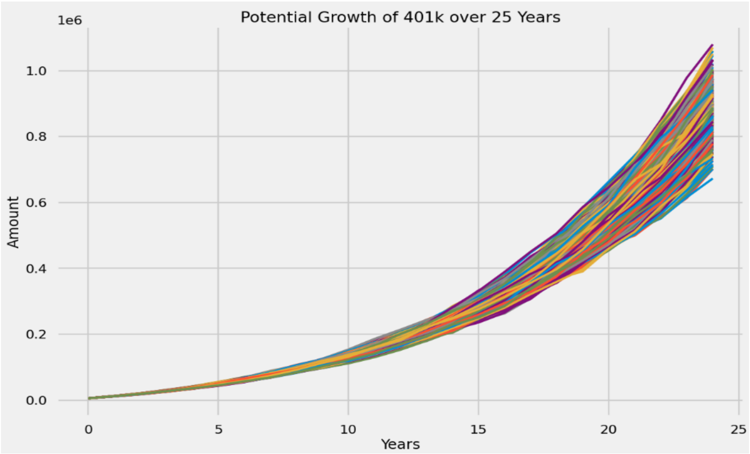

Fig. 5. Potential Growth of 401k over 25 years

As the framework also simulated the inflation rates, the model allows for the discounting of inflation in the simulation to see what the real buying power of the 401k would be in the simulated time frame. The results of this are shown in figure 6.

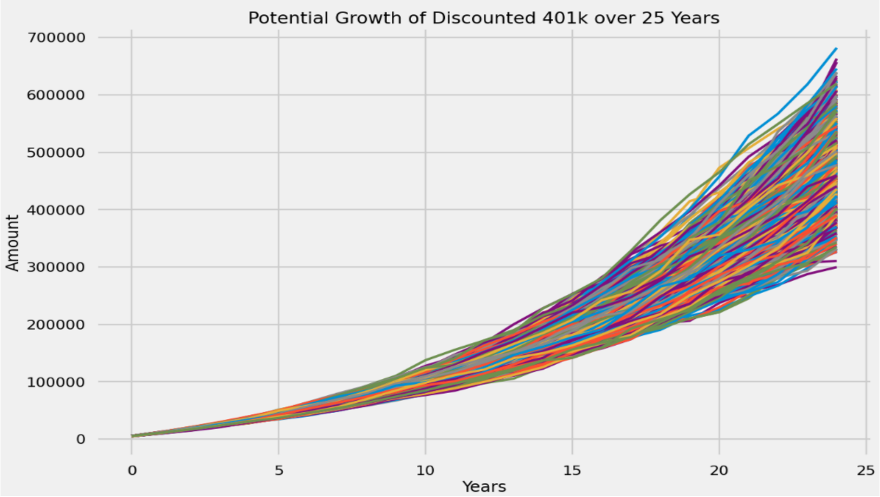

Fig. 6. Potential Growth of Discounted 401k over 25 years

Simulating both the IRA and 401(k) for the case study user provides the user with a more complete picture of what the retirement scenario may look like for them. More graphs for this simulation are shown in Appendix I.

5 Conclusion

Using Monte Carlo methods to probabilistically simulate retirement allows to incorporate uncertainty into predictions. Through the creation of the proposed interface, user can reliably simulate the value of the 401K and IRA accounts of an individual based on custom parameters as shown in section III. The proposed model does this by conducting simulations of important rates like the ROI, inflation, etc.

The proposed model may serve as a baseline for further research in the field. The topics of research include (i) how assets and equity (i.e homes) may be factored into such simulations (ii) how risk may better be considered in such simulations to provide more accurate probabilistic ranges. Machine Learning methods have been extensively applied to other finance domains i.e the stock market [22], however their uses in retirement scenarios have scope for further applications.

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Appendix

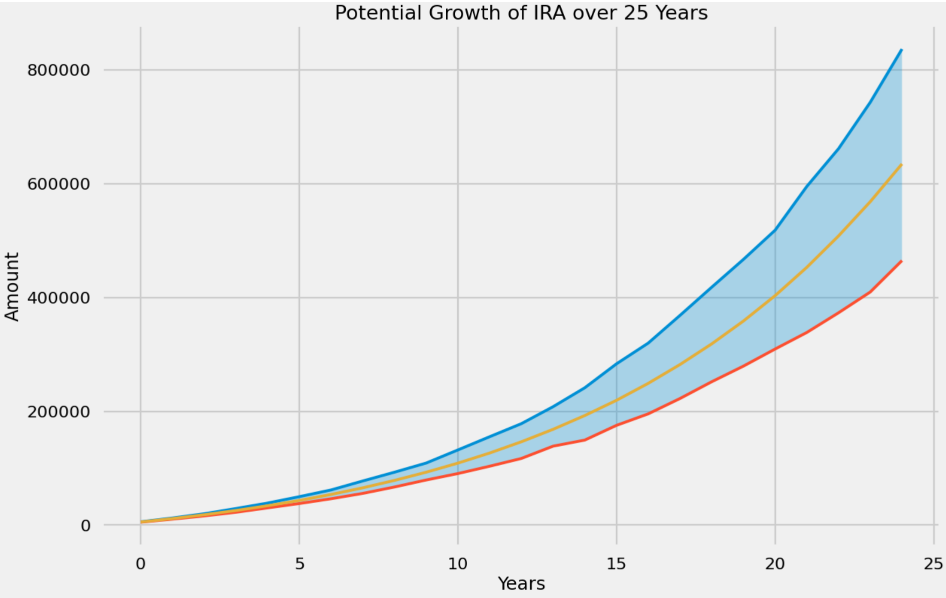

Fig. 7. Potential Growth of IRA over 25 years

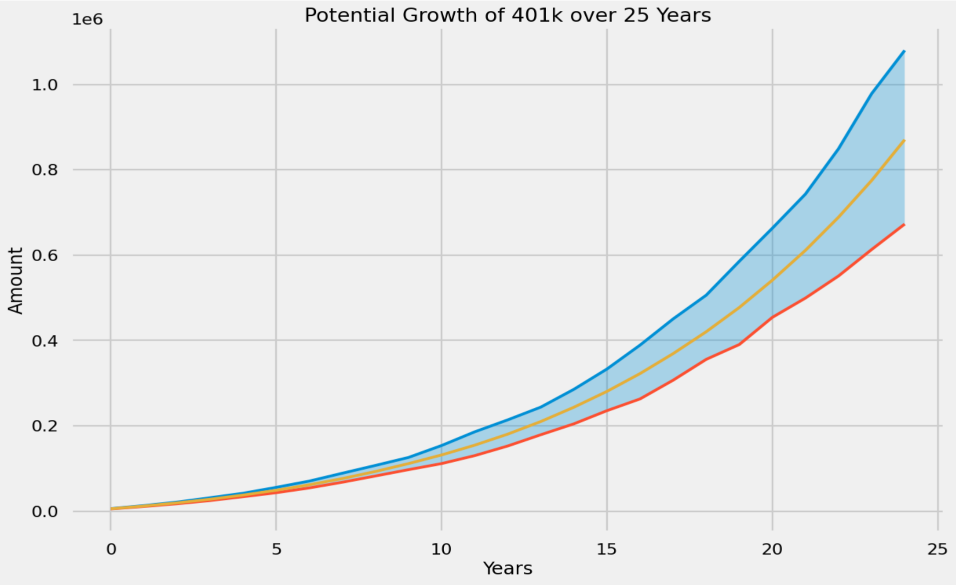

Fig. 8. Potential Growth of 401k over 25 years