Implement SUPA Model and Develop Web-based Stochastic Superannuation Forecasting Tool

Soong Ying Quah

November 5, 2019

Acknowledgement

I am very grateful to be given the opportunity to join CSIRO for my internship project as part of the course requirement of Master of Financial Mathematics. During these three months, I have learnt a lot on stochastic modelling and how it is applied to real world in the form of superannuation and retirement outcomes. I have had so many rich experiences and opportunities that I personally believe will forever shape and influence my professional life while fostering personal growth and development. One of the very memorable experiences is that I was given the opportunity to travel to Sydney to join D61+ Live Exhibition. It was eye opening for me to see cutting-edge data science and technology that is shaping our industries, experiences and society.

Foremost, I would like to express my utmost gratitude to my supervisors, Dr. Zili Zhu, Dr. Monica Chen, Mr. Thomas Lo and other fellow team members in Risklab for the guidance and providing invaluable feedback on my project. You all have been tremendous mentors for me, providing encouragement and advices so that I could have a better idea for improving and understanding my project. At the same time, I would like to thank Prof Gregoire Loeper for being our academic coordinator so that we have a chance to go for internship. I also appreciate Mr. John Chan's dedication in supporting the Master of Financial Mathematics students in providing a pleasant internship experience.

Last but not least, I am thankful to have family and friends who would support and motivate me throughout the whole internship.

Abstract

This project focuses on establishing a live forecasting model on the web that can be used to estimate a person's superannuation balances and retirement benefits on retirement age 67 by choosing the asset investment strategies, contribution rates and superannuation withdrawal strategies. The underlying economic variables of the future are projected by a stochastic economic generator (ESG): SUPA (Simulation of Uncertainty for Pension Analysis) probabilistic model. The probabilistic approach allows us to estimate various outcomes regarding the retirement accumulation phase, such as worst-case percentiles accounting for the risks associated with investment returns and other economic variables. The web is constructed with HTML for page content, Cascading Style Sheets(CSS) for aesthetics, JavaScript for the interaction, Scalable Vector Graphics (SVG) for the vector graphics. The forecasts on these webpages can act as a benchmark model for individuals or even fund managers and financial advisors for their planning of future retirement outcomes.

Contents

1 Introduction **1**

2 Economic Scenario Generator : SUPA Model and Applications **2**

2.1 Model Parameters . . . 2

2.2 Applications . . . 3

2.2.1 Accumulation Phase . . . 3

2.2.2 Decumulation Phase . . . 4

2.2.3 Pension Multiplier . . . 6

3 Development **6**

3.1 System Description . . . 6

3.2 Implementation of Webpage . . . 8

4 Results and Analysis **9**

4.1 Stage 1 - SUPA Model . . . 9

4.2 Stage 2 - Accumulation . . . 11

4.3 Stage 3 - Decumulation . . . 12

4.4 Stage 4 - Pension Multiplier . . . 13

4.5 Challenges and Difficulties . . . 14

5 Conclusion and Future Research **15**

A Appendix **16**

References **19**

1 Introduction

With advances in medical science, public health policies and economic prosperity, Australians can expect to live longer. Amongst the Australian population, there is a considerable diversity of circumstances, expectations and behaviours related to the financial aspects of ageing. Survey by NAB[1] at Figure 14 have shown that most Australians think they won't have enough to retire on. However, a poll by Australian National University[2] (ANU) at Figure 15 have shown that majority of the retired people think they have sufficient money to live comfortably in retirement. This raises the question if awareness and financial planning are done correctly for Australians to prepare them for their retirement.

In Australia, consumption expenditure during retirement is funded from the three pillars retirement income structure: the full or part Age Pension, occupational superannuation arrangements and other forms of personal retirement savings (De Ravin et al. (2019)). For most working Australians, superannuation plays an important role in securing a stable financial future. Superannuation is the money saved during working life to help support the financial needs during retirement and it is a partly compulsory arrangement put in place by the government of Australia to encourage people to accumulate their funds to secure a stable retirement income. The government has set minimum standards for contributions (amount equal to 9.5% of the regular wage or salary as a minimum) by employees into the superannuation fund.

Retirement income requires careful planning as there are many risks that need to be managed along the way. These risks include longevity risk, inflation and sequential risks. This report will describe how the uncertainties of these risks are modelled by using a stochastic economic generator probabilistic model - SUPA (Simulation of Uncertainty for Pension Analysis) model to project uncertain future financial and economic outcomes. The stochastic economic scenario generator (ESG) have been becoming favourable tools to model risk aggregation and dependency of financial risk factors and economic variables via a cascading structure. The main objective of using ESG models is to simulate a large number of scenarios for possible future retirement income through pre-retirement contribution and post-retirement withdrawal to envisage possible likely future outcomes. The SUPA model modifies and further develops various extant investment and asset models in such a way that it can track the balance of funds following the decisions of individuals who want to secure appropriate retirement income. The validity of these simulated future scenarios requires that the model parameters are calibrated to historical data and reproduce historical economic scenarios statistically. The full spectrum of possible outcomes during the accumulation phase can help individuals to understand the adequacy of their superannuation savings, in particular the risks such as worst-case scenarios, and how long the superannuation balance can last before depletion. The model can thus be relied upon to find an optimal consumption level to meet the objectives of the retirees. (Chen et al. (2019))

In section 2 of this report, I provide a brief discussion on key components of the SUPA model which incorporates the interdependency between economic variables reflecting the economic environment in which the pension funds are handled. Other than that, I also describe the applications on using stochastic modelling to forecast superannuation outcome and retirement outcome which include the balance of Account Based Pension (ABP), Age Pension entitlement and total retirement income under different drawdown strategies, namely the minimum drawdown, and 1% above the minimum (1% plus) drawdown, Bengen's 4% golden rule, and the rule of thumb (RoT) in De Ravin et al. (2019), and different target e.g. ASFA modest and comfortable consumption rules (ASFA (2018)). The simulated pre-retirement contribution and post-retirement withdrawal outcomes are then shown on a live forecasting website for public usage. The intuition behind the development of a web-based superannuation forecasting tool is to promote higher awareness of employee's

[1] http://nabnews.efront-flare.com.au/wp-content/uploads/2017/08/MLCWealth-Sentiment-Survey-Q1-2017.pdf
[2] https://csrm.cass.anu.edu.au/sites/default/files/docs/ANUPoll-ageing-money-feb-2016_0.pdf

superannuation. In section 3, I describe the methods used to develop the web-based stochastic superannuation forecasting tool whereas in section 4, I will show the results and output as well as the challenges faced during development. Section 5 concludes the report and discusses about future research.

2 Economic Scenario Generator : SUPA Model and Applications

The SUPA model is a multi-factor stochastic investment model, which aims at projecting retirement income by simulation (Sneddon, Zhu, et al. (2016)). The SUPA model was developed by the CSIRO-Monash Superannuation Research Cluster (Sneddon, Reeson, et al. (2016) and Sneddon, Zhu, et al. (2016)) and comprises of fourteen economic factors as stochastic time series, such as price inflation $q(t)$; wage growth $w(t)$; long-term interest rates $l(t)$; short-term interest rates $s(t)$; cash returns $c(t)$; domestic (Australia) dividend yield $y(t)$; domestic equity returns $p(t)$; domestic dividend growth $d(t)$; domestic total returns $e(t)$; international equity total returns $n(t)$; domestic bond return $b(t)$; international bond return $o(t)$; house price $h(t)$ and unemployment rate $u(t)$.

The SUPA model is based on the well-known Wilkie investment model by Wilkie (1984) and Wilkie (1995) which is based originally on Box and Jenkins (1990) time series models. These time series are generated by autoregressive models. The main factor of the model which influences all asset prices is the consumer price index. The SUPA model incorporates the interdependency between economic variables via a cascading structure reflecting the economic environment in which funds are handled. The dynamics of each economic factor is influenced to some extent by other variables in the SUPA model.

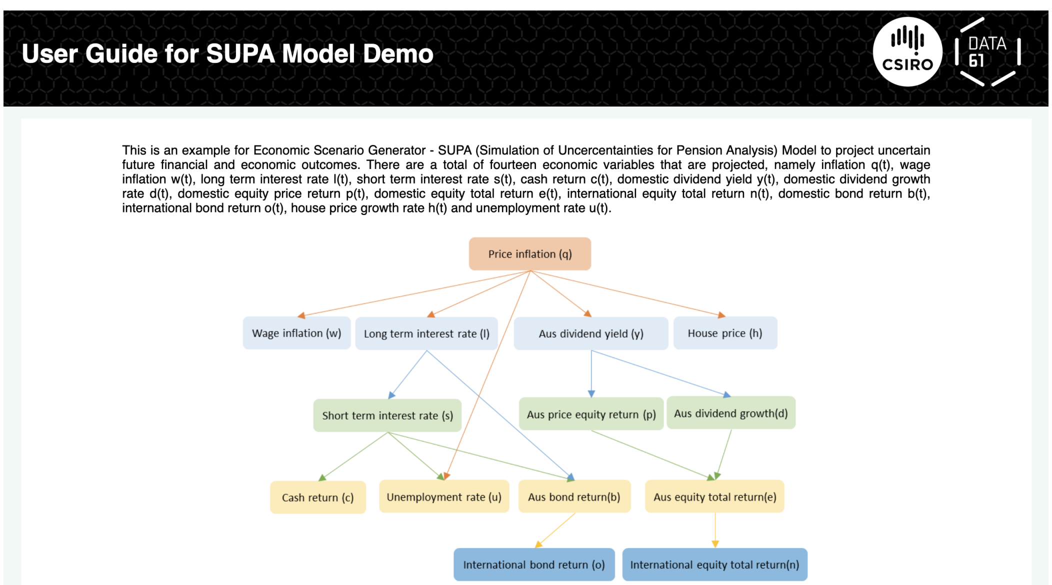


Figure 1: The cascading structure of the SUPA model of 14 variables from Screenshot of Stage 1 User Guide

2.1 Model Parameters

This section describes the dynamics of the variables of the SUPA model. The fourteen economic variables are simulated by using Monte Carlo numerical method and all parameters are calibrated using historical data from 1992-2018 with data from various sources such as Reserve Bank of Australia (RBA), Australian Bureau of Statistics (ABS) and Bloomberg

Terminal (Chen et al. (2019)). In this project, rather than spending my time most of my time calibrating the model parameters, I have used calibrations done by Chen et al. (2019) for calculations. Table A shows the calibrations and the autoregressive (AR) process of each constituent economic factor.

As each economic factor is specified as an AR process, they incorporate a disturbance term which captures a related stochastic component in its dynamics. Most variables follow an AR process, while the domestic dividend growth rate follows an ARMA(0,1) process. Whenever an economic variable's behaviour is related to the behaviour of other economic variables within the investment projection model, the time series data of past performance of these other variables were incorporated into the fitting process alongside that of the key economic variable being considered.

For example, inflation rate is computed as a log ratio of the change in Consumer Price Index(CPI) with the formula:

$$q(t) = ln(\frac{CPI(t)}{CPI(t-1)}).$$

The inflation rate $q(t)$ follows a discretised mean-reverting Ornstein-Uhlenbeck process, or an AR(1) process

$$q(t) = (1 - \phi_q)\mu_q + \phi_q q(t-1) + \epsilon_q(t),$$

where $t \in 1, 2, 3, ..., T, \mu_q$ is the long-term mean inflation rate, a positive ϕ_q is the AR coefficient, and $\epsilon_q(t)$ is the disturbance term.

Ordinary Least Square (OLS) method is applied to compute the parameters: the speed of mean reverting ϕ_q, the mean of inflation μ_q, and the noise $\epsilon_q \sim N(0, \sigma^2)$.

2.2 Applications

All simulated SUPA variables can be used to project the future possible superannuation balances of individuals throughout their working and post-retirement life. During the accumulation phase, individuals can understand the adequacy of their superannuation savings, in particular the risks of worst-case scenarios whereas during the decumulation phase, individuals can find an optimal consumption level and understand how long their superannuation balance can last before depletion. The simulated SUPA variables can also be used to calculate pension multiplier of an individual which represents the current or future income stream a retiree can expect in terms of a multiple of the government pension.

2.2.1 Accumulation Phase

The algorithm for superannuation accumulation is given as follows. Let B_0 be the initial superannuation balance at the starting age, B_t be the accumulated superannuation balance after t years of the employee's working life and B_T be the final superannuation balance at retirement. T varies between individuals. Let Tax_t be the tax rate for compulsory contribution at year t, which is equal to 15%. The superannuation balance is accumulated from time t to $t+1$ after the minimum contribution as follows:

$$B_{t+1} = B_t + B_t e^{R_t - 1}(1 - Tax_t) + SG_t W_t (1 - Tax_t) - Fee_t,$$

where SG_t is the superannuation guarantee rate at time t, R_t is the portfolio return at time t, $W_t = W_{t-1}.e^{w_{t-1}}$ is the wage at time t and w_t is the wage growth rate at time t simulated by the SUPA model.

The portfolio return is obtained as a weighted average of both risky and defensive asset returns: the portfolio weight in risky assets such as Australian equity is denoted by w_1, whereas the portfolio weight in defensive assets such as domestic bond is denoted by $w_2 = 1 - w_1$. The risky asset weights for each investment strategies are shown at Table 1.

The total annual superannuation fee usually consists of at least three components: 1) the annual administration fee which is fixed at \$50; 2) the account-based pension fee which is proportional to the balance with an indirect cost ratio depend on the fund level; 3) investment option fees which depend on the investment strategy in Table 1 and are also proportional to the superannuation balance. The rates and prices of the superannuation fund fees and costs are provided by the Money-Smart superannuation calculator of the Australian Securities & Investments Commission (ASIC)[3] and a linear de-risking strategy and dynamics optimal strategy (Forsyth et al. (2019), Zhang et al. (2019a), and Zhang et al. (2019b)).

Investment	Cash	Conservative	Linear Decrease	Moderate	Balanced	Growth	High Growth
risky asset weight w_1 (%)	0	30	max[1-{age}%,0]	50	70	85	100
fees (% p.a)	0.05	0.3	0.35	0.4	0.5	0.6	0.7

Table 1: Investment strategies risky asset weights and fees

The Australian Superannuation Guarantee (SG) is introduced in 1992, mandates that employers make compulsory contributions to an employee's Defined Contribution superannuation fund. The current SG rate is 9.5% but is set to gradually increase to 12% of salary by 2025 as reported in Table 2.

years t	1992	1994	1995	1996	1998	2000	2002	2013	2014	2021	2022	2023	2024	2025
SG rate (%)	3	4	5	6	7	8	9	9.25	9.5	10	10.5	11	11.5	12

Table 2: Super guarantee (%) SG_t from 1992 to 2025

2.2.2 Decumulation Phase

The decumulation phase mainly focuses on how different superannuation withdrawal strategies will affect the retirement outcomes of an individual. Retirement income is composed of the annual superannuation withdrawal, mean-tested Age Pension and other post-retirement incomes such as private savings. The dynamics of the retirement income is as follows:

$$RI_t = W_t + P_t + A_t,$$

where RI_t is the retirement income per annum, W_t is superannuation withdrawal per annum, P_t is the entitled Age Pension, A_t is annuity payment where $t = 0, 1, ..., T, T$ is the number of years after retirement.

The withdrawal strategies are explained as below:

1. Minimum: minimum drawdown rate required by superannuation regulation rule: Depending on the age, there is a minimum amount you must withdraw from an ABP each financial year below.

Age	65	65-74	75-79	80-84	85-89	90-94	over 95
Minimum drawdown (%)	4	5	6	7	9	11	14

2. Minimum + 1%: Minimum rate + 1% drawdown rule

3. 4% Rule: 4% of the initial balance, regardless of the market performance and age.

[3] https://www.moneysmart.gov.au/tools-and-resources/calculators-and-apps/account-based-pension-calculator

4. Rule of Thumb: The rule of thumb defines a baseline drawdown rate % of the first digit of the age, adding 2% to the rate if the account balance is between \$250, 000 and \$500, 000, also subject to the minimum drawdown rule (De Ravin et al. (2019)).

Age	under 65	65-69	70-74	75-79	80-84	85-89	90-94	over 95
$250k \leq$ Balance $< 500k$	8	8	9	9	10	10	11	14
Balance $\geq 500k$ or $< 200k$	6	6	7	7	8	9	11	14

5. Modest Target: ASFA modest lifestyle of drawdown of \$27,368 per annum.

6. Comfortable Target: ASFA comfortable lifestyle of drawdown of \$42,764 per annum

7. Luxury Target: Luxury lifestyle of drawdown of \$60,000 per annum

Mean-Tested Age Pension

The amount of Age Pension is mean-tested depending on the current asset value (total testable asset), future income and homeownership status. At time t, the Age Pension P_t one can receive is the minimum of the values under the asset test P_t^A and income test P_t^I. $P_t = min(P_t^A, P_t^I)$

- Asset test can be calculated as follow:

$$P_t^A = max(\hat{P}_t - \tau^A max(b_t - \tilde{b_t}), 0),$$

where P_t^A is the Age Pension entitlement under the asset test at time t, $\hat{P}_t$ is the maximum Age Pension at time t; it is indexed with CPI. For single homeowner, it is \$926.2 per fortnight including the pension and energy supplements. τ^A is the taper rate for asset test; it is a fixed value (0.3%) according to current policy. $\tilde{b_t}$ is the asset test threshold for full pension (for single homeowner, it is \$258,500); it is indexed with CPI. b_t is the total assessable asset which is the sum of superannuation, annuity and non-superannuation asset (financial and other testable asset such as investment property or gifting etc). The value of the residential home is excluded.

- Income test can be calculated as follow:

$$P_t^I = max(\hat{P}_t - \tau^I max(I_t - \tilde{I}_t), 0),$$

where P_t^I is the Age Pension entitlement under the income test at time t, τ^I is the taper rate for income test; it is a fixed value (50%) according to current policy. $\tilde{I}_t$ is the income test limit, indexed with CPI, it is \$172 per week. I_t is the total income which is the sum of deemed income from financial asset, annuity income etc. and other income.

Asset Allocation Strategy

The dynamics of superannuation balance is

$$B_{t+1} = (B_t - W_t - Fee_t)e^{R_t},$$

where R_t is the return of the portfolio in the table below.

Growth assets		Defensive assets	
Australian Equity	50%	Australian FI	50%
International Equity	30%	Cash	30%
Property	20%	International FI	20%
$R_{growth} = 50\% AuEq + 30\% IntEq + 20\% Pro$		$R_{defensive} = 50\% AuFI + 30\% Cash + 20\% IntFI$	

Table 3: A diversified asset allocation strategy of 50% growth asset and 50% defensive asset

2.2.3 Pension Multiplier

The Pension Multiplier (PM) is a value with a base level of 1, which represents the current or future income stream a retiree can expect in terms of a multiple of the government pension. It can be computed as below where we assume that the retirement age is 67 and the terminal age is 104.

$$PM = \frac{\sum_{t=67}^{T=104} C_t . p_{67,t}}{\sum_{t=67}^{T=104} A_t^{full} . p_{67,t}},$$

where $C_t = A_t + W_t$ is the discounted retirement income or consumption which is the total of Age Pension entitlement and account-based pension withdrawal at time t, A_t is the full Age Pension. $p_{67,t}$ is the conditional survival rate for people over 67 years old. The denominator is the expected total Age Pension received by a single person without any asset or income who is entitled full Age Pension during the entire retirement period and the numerator is the expected total consumption for a single person.

3 Development

The motivation behind the development of webpages is to showcase the applications of using stochastic modelling to project financial uncertainties such as superannuation balance and retirement income as well as to promote SUPA model. The webpages are available to the public as they contain practical examples that are relevant to everyone's life. As mentioned in Section 1 and also in Figure 15, a lot of non-retired people are not confident with having enough money during retirement. The forecasts on these webpages can act as a benchmark model for individuals or even fund managers and financial advisors for their planning of future retirement outcomes. This section describes how the system of the webpages and forecast model comes together and how it is implemented as a webpage.

3.1 System Description

In Figure 2, the system is designed to present the forecasted superannuation balances to a web-based user interface with calculations done at the backend with Python. The whole system is being generated by two Python modules: Tornado[4] as a Web Server Gateway Interface (WSGI) server and Flask[5] for the URL routing and templates. WSGI comes into picture because the Web Server needs to communicate with the Web Application. WSGI specifies the rules which needs to be implemented by the Web Application side and the Web Server side so that they can interact with each other. The

[4] https://www.tornadoweb.org/en/stable/
[5] https://palletsprojects.com/p/flask/

two modules are the chosen method as Flask's web framework is easier to use, however, Flask requires a WSGI server for production, which is how Tornado is chosen as the WSGI server. Flask request is used to send data from the HTML form to Python for the processing of data.

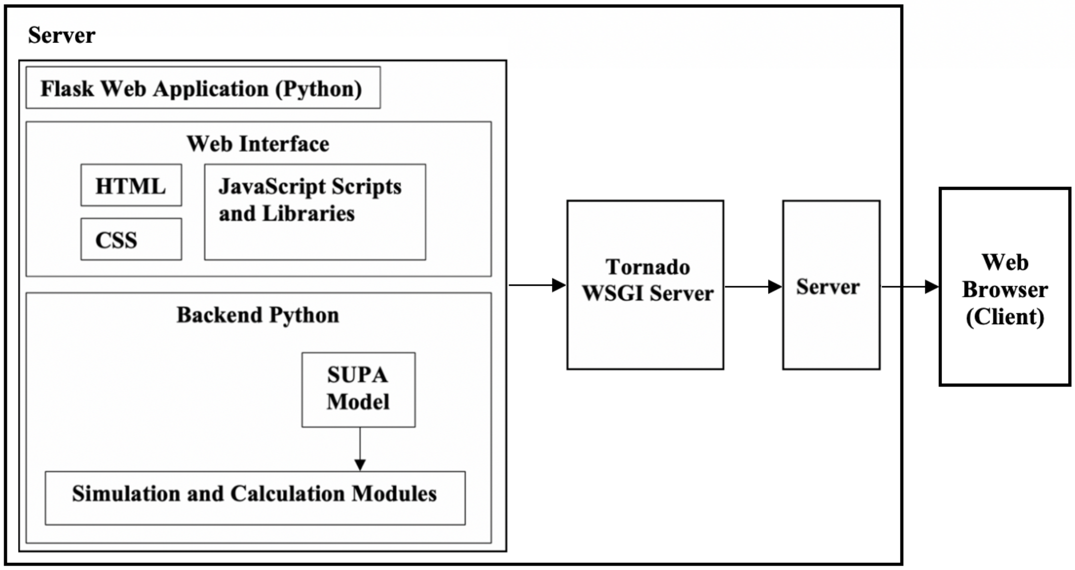


Figure 2: System Architecture

The WSGI server can be setup with the following code:

```python
from tornado.wsgi import WSGIContainer
from tornado.httpserver import HTTPServer
from tornado.ioloop import IOLoop
from flask_service import app

http_server = HTTPServer(WSGIContainer(app))
http_server.listen(5000)
IOLoop.instance().start()
```

Figure 3: Code snippet to setup WSGI server; flask_service.py is the flask app file that arranges all the URL routings and directories to templates.

There are slightly different steps in running the server with different operation systems (OS). In this report, I will only document the cases in Windows OS and Mac OS. To setup the server in localhost (own computer), the following steps can be followed:

For Windows user:

1. Firstly, open Command Prompt (cmd) or Anaconda Prompt.
2. Get your computer's ip address by typing "ipconfig".
3. Change the ip address of the "run.bat" file and "ip.js" file.
4. Find and copy the file path of the run.bat file.
5. Change directory of the cmd to the file path of the run.bat file by typing "cd *file_path*".

6. Type “run” to run the server. If an error exists on no module, install the module with either pip-install or conda install -c conda-forge flask-script.

7. Try to run the server again and open the webpage with URL localhost:5000/supa(calculator/drawdown) in browser.

For Mac user:

1. Firstly, open Terminal.

2. Get your computer’s ip address by typing “ipconfig”.

3. Change the ip address of the “run.sh” file and “ip.js” file.

4. Find and copy the file path of the run.sh file.

5. Change directory of the Terminal to the file path of the run.sh file by typing “cd *file_path*”.

6. Type “./run.sh” to run the server. If an error exists on no module, install the module with either pip-install or conda install -c conda-forge flask-script.

7. Try to run the server again and open the webpage with URL localhost:5000/supa(calculator/drawdown) in browser.

If a python file or html file has been updated, there is a need to rerun the server to show the latest update on the webpage. The run.bat/run.sh is basically a python command. In the figure below, the series of numbers after --host is the ip address of the computer. To run on your local computer, you just have to change that to your computer’s ip address.

```
python ./tornado_server.py runserver --host 127.0.0.1 --port 5000
```

Figure 4: Code snippet of run file

3.2 Implementation of Webpage

When building visualizations, designers often employ multiple tools simultaneously. On the web part of the development, I have used HTML for page content, Cascading Style Sheets(CSS) for aesthetics, JavaScript for the interaction, Scalable Vector Graphics (SVG) for the vector graphics. The JavaScript library that is mainly used is D3.js which is for producing dynamic, interactive data visualizations in web browsers. It makes use of the widely implemented SVG, HTML5, and CSS standards. The designs of all web pages follow the corporate identity of CSIRO. All information from Python is passed to the web interface through a file format called JavaScript Object Notation (JSON). The JSON file is then read by JavaScript functions and then converted to an array of objects that can be used as inputs for D3’s visualisations.

Figure 5 shows an implementation of D3 for drawing the line of the distribution plot in Stage 3. D3 supports method chaining for brevity when applying multiple operators: the operator return value is the selection. The append and insert operators add a new element for each element in the current selection, returning the added nodes, thus allowing the convenient creation of nested structures. The append operator adds a new element for each element in the current selection, returning the added nodes, thus allowing the convenient creation of nested structures (Bostock et al. (2011))

```
// append and draw the line to the graph
this.vis.select("#linegraph".concat("RI" + id + k))
  .selectAll('null')
  .data(self.lines)
  .enter()
  .append('path')
  .attr('d', function(d, i) {
    return self.lineFunction(d.points);
  })
  .style("stroke", function(d, i) {
    return (i == 0 ? "#004B87" : i > 2 ? "#DF1995" : "#FFB81C");
  })
  .style("stroke-dasharray", function(d, i) {
    return (i == 0 ? "" : i > 2 ? "10,10" : "3,3");
  })
  .style("stroke-width", function(d, i) {
    return (i == 0 ? 2 : 1.5);
  })
  .attr("opacity", function(d, i) {
    return (i == 0 ? 1 : 0.8);
  })
  .style("fill", "none");
```

Figure 5: Code snippet of drawing the line of distribution plot of Stage 3

4 Results and Analysis

Throughout this internship, I have worked on four stages of SUPA Model implementations: Stage 1 showcases the variables of SUPA Model where user can choose to display the number of simulated years and paths; Stage 2 is a superannuation balance accumulator that allows the user to enter age, income, preferred investment strategy to forecast the accumulation of superannuation balance until retirement; Stage 3 is a calculator for retirement income where user can input individual asset details, investment and withdrawal preferences to forecast his retirement outcomes; Stage 4 is a pension multiplier calculator which calculates a multiplier of government Age Pension that a retiree can expect to receive. In this section, I will show the screenshots of the webpages for all four stages and demonstrate a scenario on how the forecast model will turn out for different investment and withdrawal strategies.

4.1 Stage 1 - SUPA Model

In Stage 1, there are two pages, the main webpage displays the simulation paths of all fourteen economic variables starting from 1994 to 2049 with a maximum of 50 Monte Carlo paths out of 100,000 paths. The user can choose to display the number of simulation years and number of paths and click on the recalculate new paths button to display new paths. The bold line in the graphs represent the median of all shown paths with dotted points to show the value at the following year. There is also a checked list to enable display of percentiles. Due to the limitation of drawing large number of simulation paths as it would slow down the loading time of the page, the percentiles are pre-defined from the 100,000 Monte Carlo paths therefore it remains fixed for each of the graph even after recalculation. I have also added a tab view to the webpage so that the user can view each economic variable graph alone in a bigger and clearer display.

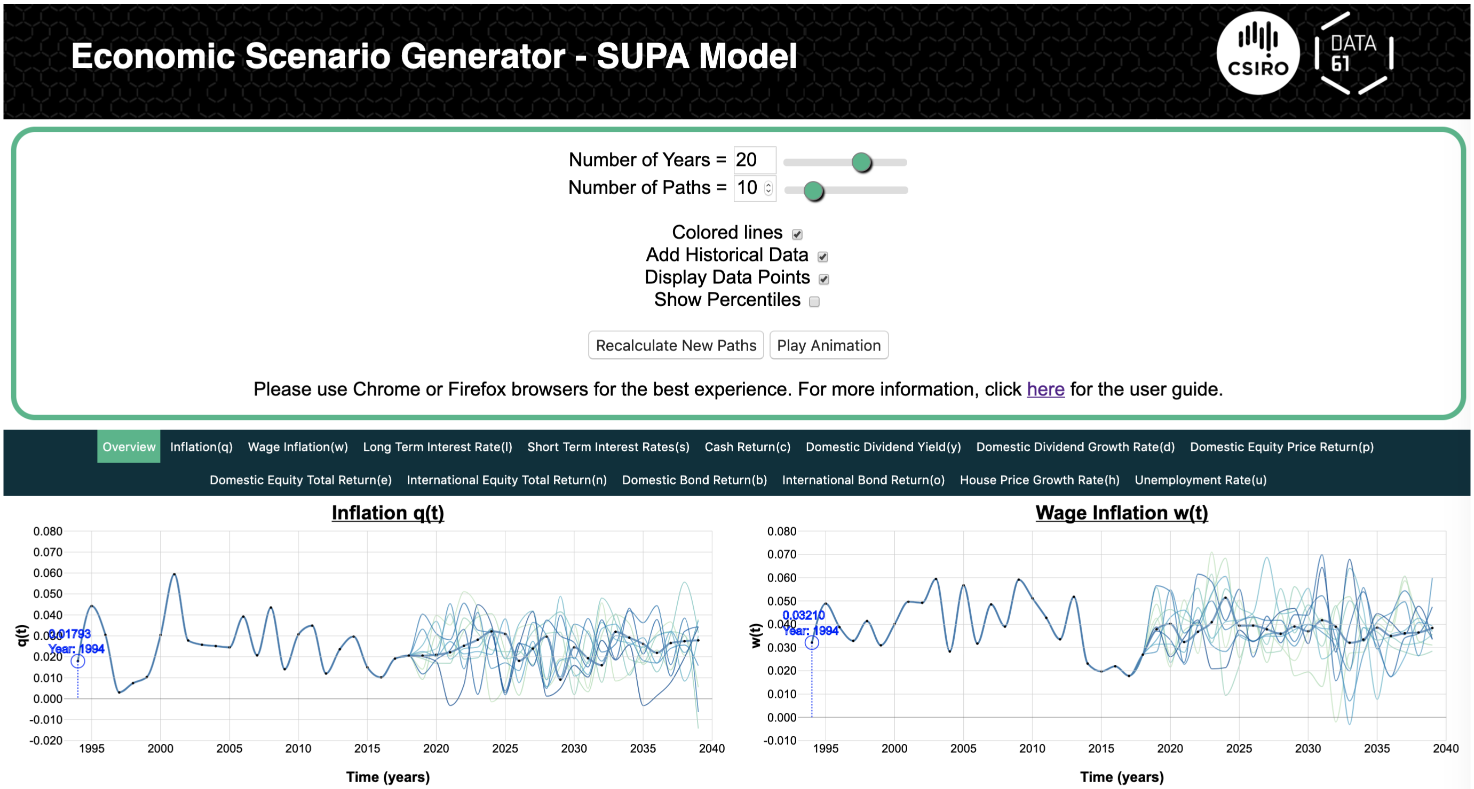


Figure 6: Screenshot of stage 1 overview

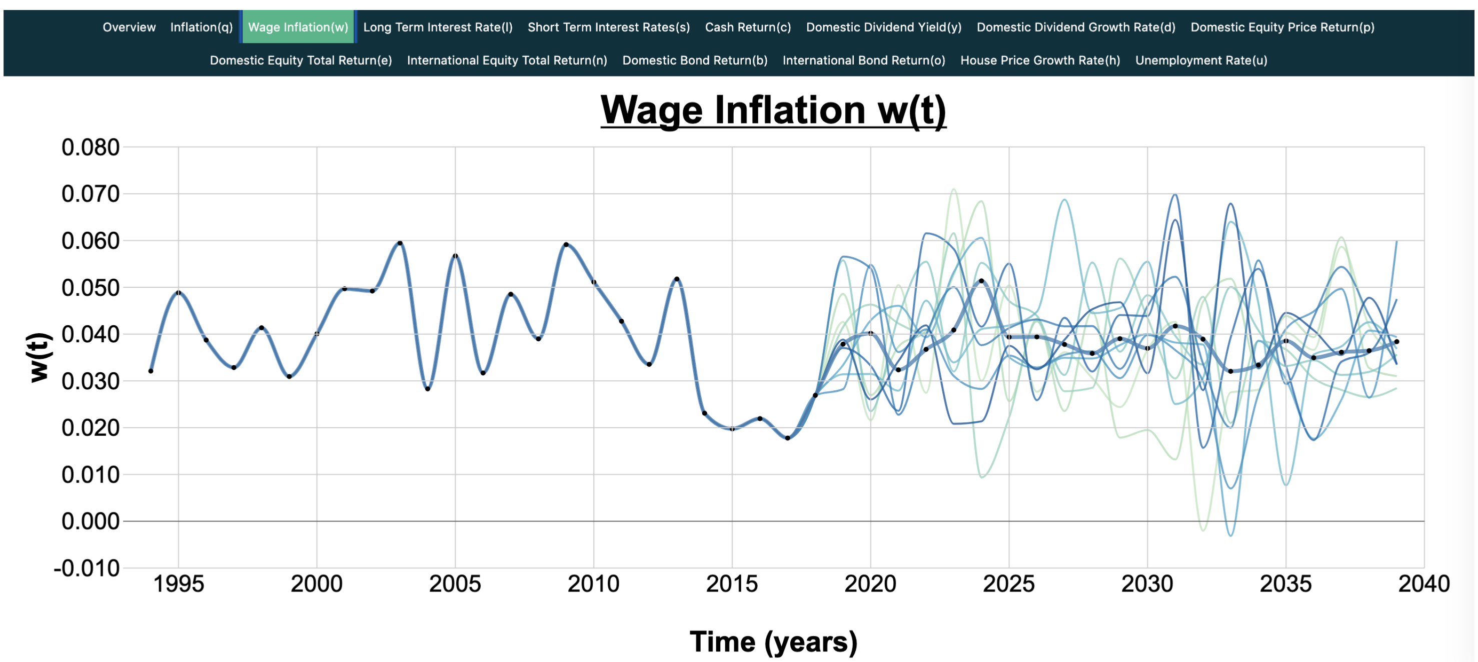


Figure 7: Screenshot of stage 1 tabbed view

The second page is a user guide that describes the fourteen economic variables, explains all functions and features available and shows an overview of all the variables.

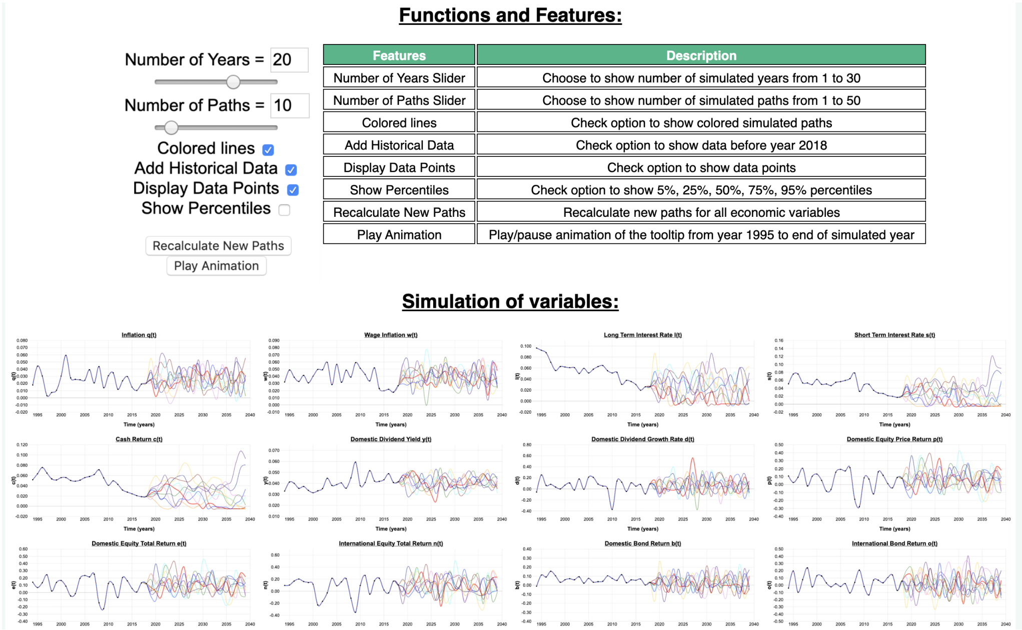


Figure 8: Screenshot of stage 1 user guide

4.2 Stage 2 - Accumulation

Stage 2 is a calculator that demonstrates the superannuation accumulation for a single person until retirement age 67. For example, David, who is 30 years old and has an income of $80,000 per annum prefers to have a "Balanced" strategy with "Medium" fund fees level for his superannuation accumulation. For detailed information on the portfolio weights of each strategies and fund fees level, please refer back to Figure 1 in Section 2.2.1. His current superannuation balance is 0. As on in Figure 9, the yellow dotted lines are the median of 200 simulated paths. Due to the constraints of the webpage, drawing too many paths would cause the page to be slow and unresponsive, hence I have limited the display of the accumulation graph to 200 simulated paths. So, at age 67, David would have a median of $608,241.04. The superannuation balance is discounted by inflation.

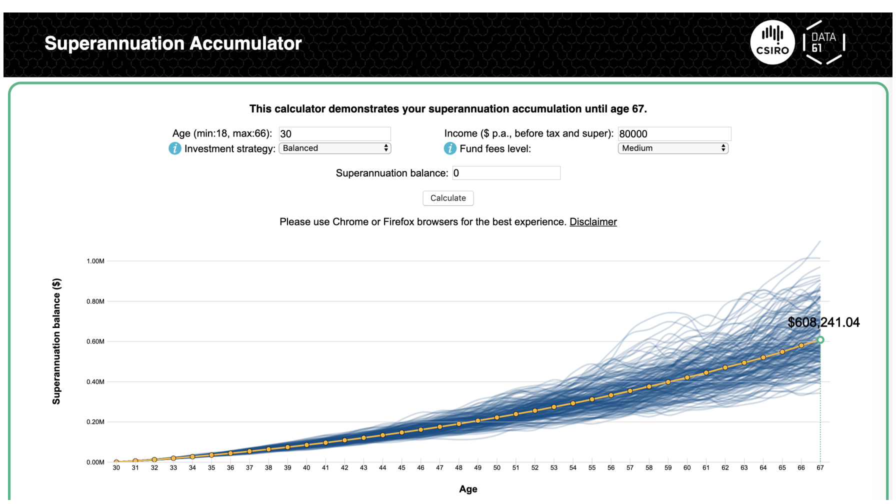
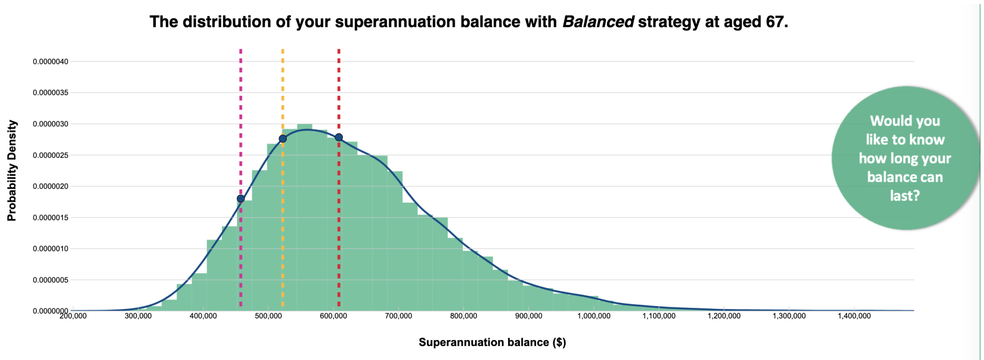


Figure 9: Screenshot of stage 2 superannuation accumulation plot

At the same time, I have also drawn the distribution of the superannuation balance at age 67 with a tabulation and analysis of percentiles of the balance. From here, David will have a rough idea on how much superannuation balance he will get at aged 67 even with the worst- and best-case scenario of the market. If he wants to know how long it can last after retirement, he may click on the green circle on the right side which will link him to Stage 3 - Retirement Income Calculator.



Percentiles	5th	25th	50th	75th	95th
Superannuation balances	$421,135.25	$522,024.06	$608,241.04	$708,681.40	$892,636.82

**The percentile rank of a score is the percentage of scores in its frequency distribution that are equal to or lower than it. For example, your superannuation balance has a 95% chance to get an accumulation of less than $892,636.82 when you retire at age 67.*

Figure 10: Screenshot of stage 2 distribution plot

4.3 Stage 3 - Decumulation

Stage 3 shows how much retirement income, Account Based Pension, Age Pension a person is entitled under different investment and consumption strategies after age 67. This webpage allows a comparison of two different strategies. Back to our scenario from Stage 2, let's say at age 67, David already owns a home and has financial assets of $50,000 and his superannuation balance is $400,000.

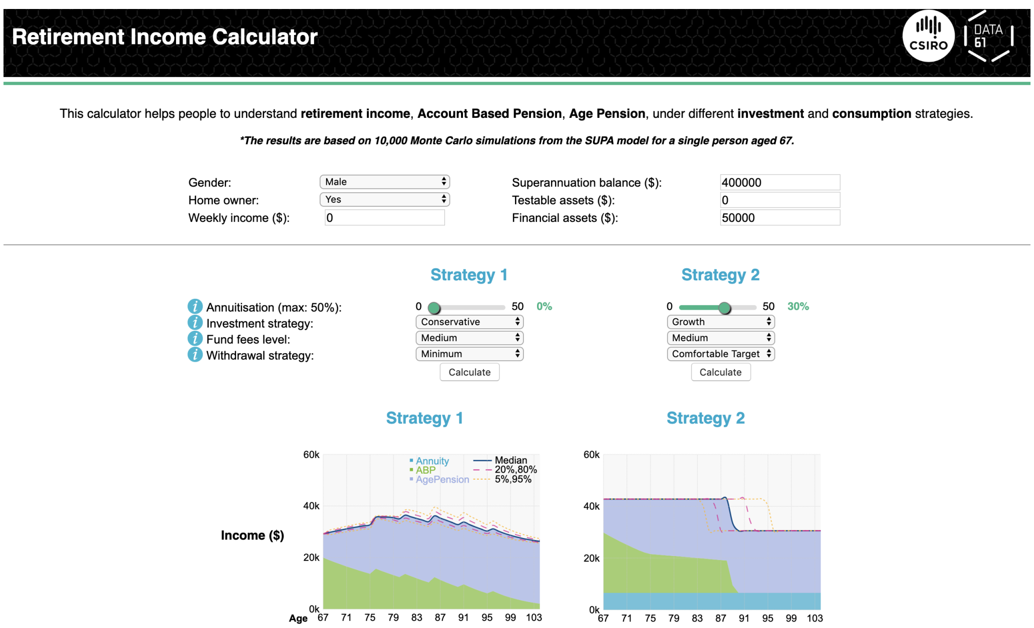


Figure 11: Screenshot of stage 3 user interface

As an output, it displays graphs of Retirement Income eligible by the user at age 67. We can see the differences between both strategies from the graphs in Figure 11 and 12. With comfortable lifestyle of drawdown of $42,764 per annum, the superannuation is exhausted at median age 90 and David will be living solely on Age Pension after age 87 (20% worst case scenario) or age 93 (20% best case scenario). Other than that, with the annuitisation of superannuation, it creates a smooth retirement income that lasts whole life and allows David to be eligible for Age Pension at an earlier age. The retirement outcome is discounted by inflation.

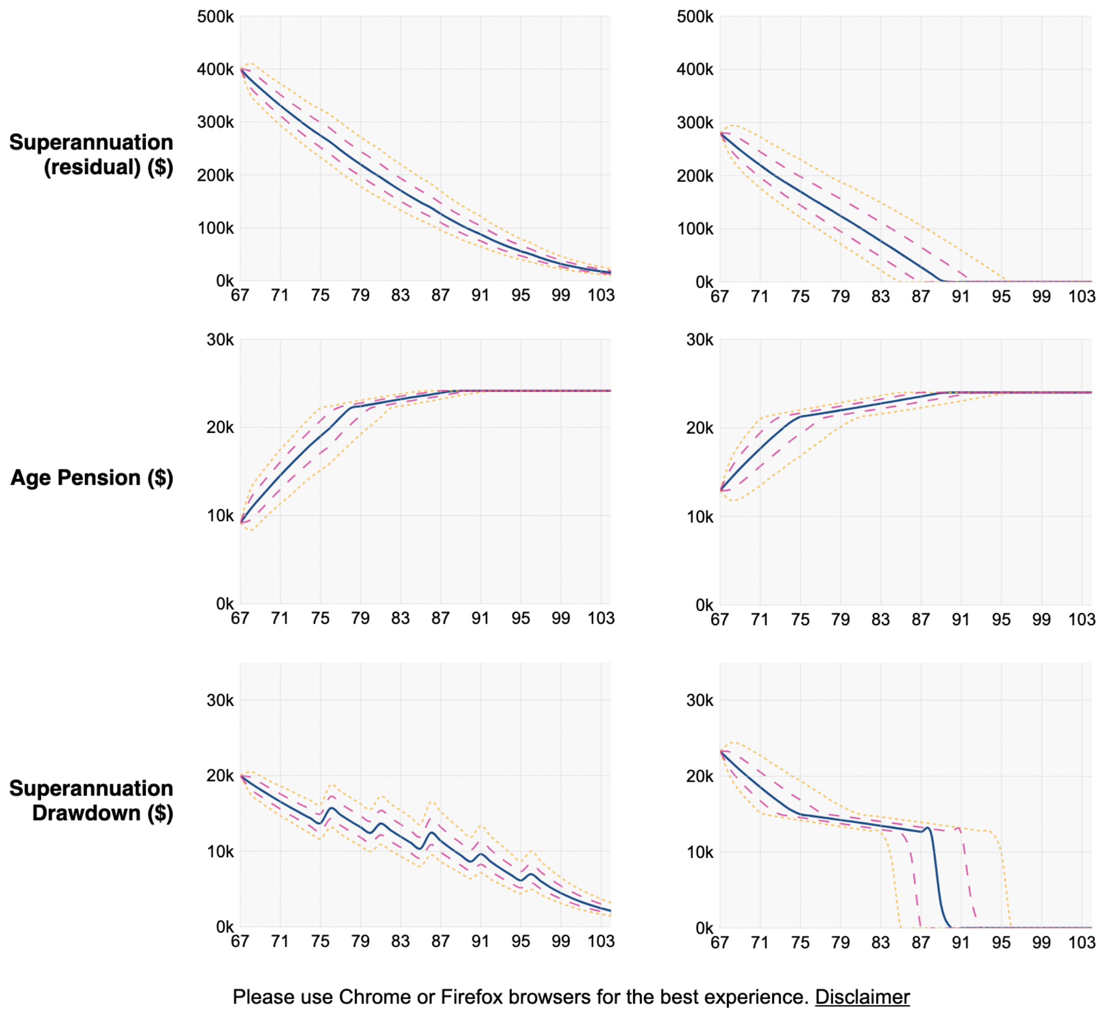


Figure 12: Screenshot of stage 3 graphs

4.4 Stage 4 - Pension Multiplier

Stage 4 is a calculator that helps to demonstrate the pension multiplier of an individual. Following the scenario from Stage 3, David's pension multiplier is 1.39 with $400,000 superannuation balance at age 67. It can be seen from Figure 13 that David's choice of minimum withdrawal of superannuation is not an optimal strategy. If he currently possesses $500,000 superannuation balance, he would lose out on the benefits of Age Pension compared to people with $400,000 superannuation balance. In fact, all strategies are not optimal except for rule of thumb, people with more superannuation balance may not be sharing the same benefit as people with lesser superannuation balance. As for investment strategies, riskier strategies give a higher pension multiplier and vice versa.

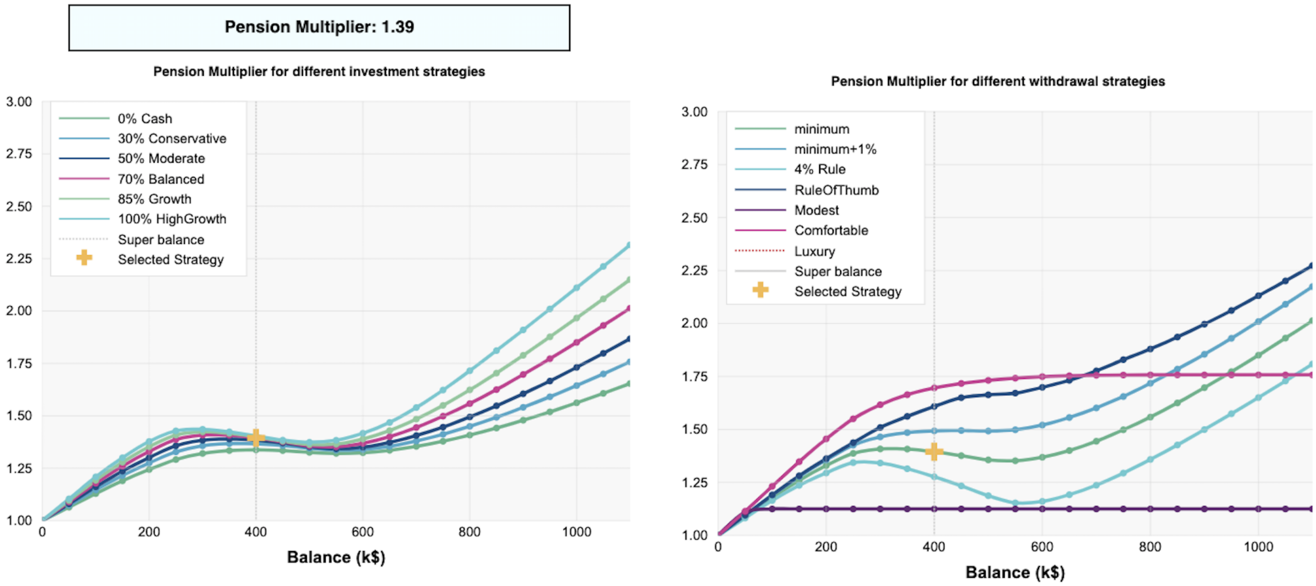


Figure 13: Screenshot of stage 4

4.5 Challenges and Difficulties

Besides the challenges of understanding the theoretical knowledge of economic scenario generator: SUPA Model, superannuation and retirement system of Australia, I have also faced challenges in the development area of the webpages. Previously, I had some experience with HTML, CSS and Javascript, however, this project requires more programming knowledges that were yet to be explored by me. Some examples are: Javascript library - d3.js which is mainly used for data visualisations and the Python web frameworks - Tornado and Flask. Some other challenges throughout the project:

- D3 is not supported by older browsers. Hence, I have only tested the webpages on Firefox and Google Chrome browsers.
- D3 is very complicated to learn due to its sheer amount of libraries.
- Debugging of the codes is strenuous and time-consuming. When a page could not load, it could mean that errors have occurred in either the front-end application or at back-end calculation, therefore, debugging has to be done for both ends.
- Limitation of Monte Carlo simulation paths to shorten processing time. Large number of simulation paths require longer processing time in Python and when shown in webpage, the whole page will be slow as too much data increases the loading time.
- The parameters of the SUPA model need to be recalibrated every year and is time consuming.
- Currently, all strategies are pre-determined. Some users may have their own preference of risky asset weights or have their own withdrawal strategy. For example, an individual would finish his superannuation balance in 10 years' time after retirement and to live entirely on Age Pension. The current choice of strategies is not dynamic and may not be of user's preference.

- Superannuation and Age Pension rates and thresholds change periodically – sometimes annually, and sometimes several times in the year. During these changes, the parameters of the calculations will have to be updated again.

5 Conclusion and Future Research

This whole project is based on using a probabilistic approach as the framework to analyse and to understand the uncertain future outcomes of superannuation assets in both accumulation and decumulation phases. The probability distribution of uncertain outcomes of superannuation saving and spending pattern enables us to not only estimate the mean/median income but also to quantify the risks as expressed in percentiles which represent underperforming market conditions. With the projections of inflation, wage growth and asset return from SUPA model, the projection of superannuation balances can be obtained. In conclusion, this project focuses on demonstrating the effectiveness and usefulness of using a stochastic modelling approach to model superannuation through live forecasting models on the web. Everyone in the public can use it to work out how much superannuation they can get when they retire. Other than promoting awareness of financial planning for future retirement income, we hope to promote the probabilistic approach of using economic scenario generators such as SUPA model to model future retirement income and expenditure.

As there is always room for improvements no matter what, for future development work, we can consider using different Javascript modules for data visualisations such as Recharts which incorporates React.js and Node.js. With more time for development, we can make the pages look fancier with AngularJS which is a JavaScript framework designed to build dynamic web apps. The webpages' view can also be optimized for different devices in the future. In this project, all the investment and withdrawal strategies are pre-determined, in the future, maybe we can develop a dynamic setting for portfolio strategies so users can create their own strategies. Since the current trend in technology revolves around mobile application, in the future, we can also develop the superannuation calculator as a mobile application. As mentioned in Section 4.2, the parameters of the SUPA model need to be recalibrated every year, that means the historical data will have to be mined again from sources such as Bloomberg terminal. To make things convenient, we can develop an application to obtain live feed straight from the terminal.

A Appendix

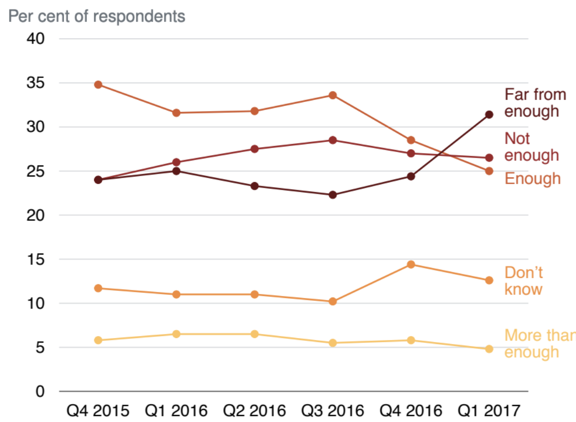


Figure 14: MLC Australian Retirement Sufficiency Pulse check

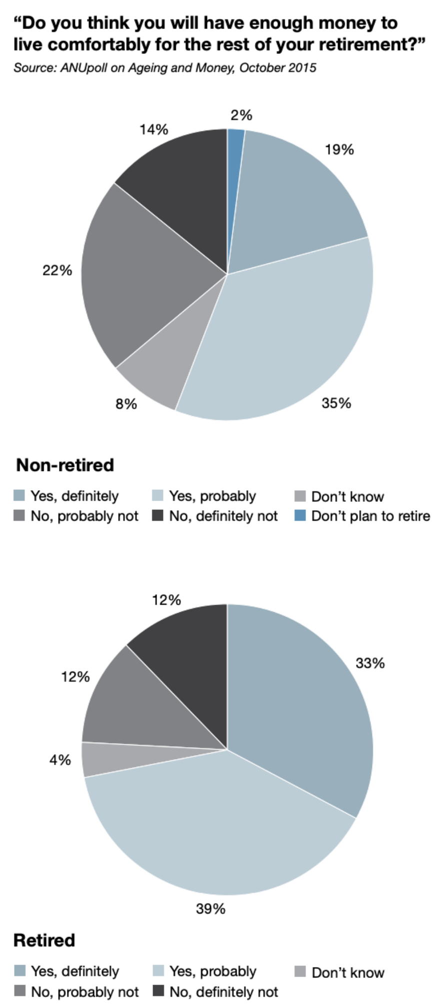


Figure 15: ANU poll on Ageing and Money, October 2015

Stage 1: https://risklab1.it.csiro.au:5000/supa

Stage 2: https://risklab1.it.csiro.au:5000/supacalculator

Stage 3: https://risklab1.it.csiro.au:5000/supadrawdown

Figure 16: QR codes for webpage access

Variables	Notations	Parameters	Values (std)
Price inflation $q(t) = (1-\phi_q)\mu_q + \phi_q q(t-1) + \epsilon_q(t)$	$q(t)$	μ_q ϕ_q σ_q	0.026 (0.037) 0.045 (0.229) 0.013
Wage growth $w(t) = \psi_w q(t-1) + \mu_w + \epsilon_w(t)$	$w(t)$	μ_w ψ_w σ_w	0.039 (0.005) 0.134 (0.178) 0.010
Long term interest rate $L(t) = (1-\kappa_L)L(t-1) + \kappa_L(\mu_l - \mu_q) + \epsilon_L(t)$ $l(t) = L(t) + q(t)$	$l(t)$	μ_L κ_L σ_L	0.028 (0.017) 0.392 (0.217) 0.018
Short term interest rate $S(t) = S(t-1) + \kappa_s(L(t-1) - S(t-1)) + \epsilon_s(t)$ $s(t) = S(t) + q(t)$	$s(t)$	κ_S σ_S	0.171 (0.242) 0.015
cash $c(t) = (s(t) + s(t-1))/2$	$c(t)$		
Domestic equity dividend yield $\ln y(t) = \ln(\mu_y) + X_y(t)$ $X_y(t) = \phi_y X_y(t-1) + \epsilon_y(t)$	$y(t)$	μ_y ϕ_y σ_y	0.040 (0.001) 0.301 (0.214) 0.141
Domestic dividend growth rate $d(t) = q(t) + \mu_d + \tau_{d,1}\epsilon_y(t) + \tau_{d,2}\epsilon_y(t-1) + \epsilon_d(t) + \theta_d\epsilon_d(t-1)$	$d(t)$	μ_d θ_d $\tau_{d,1}$ $\tau_{d,2}$ σ_d	0.031 (0.023) 0.328 (0.165) 0.372 (0.134) -0.608 (0.131) 0.075
International equity total return $n(t) = \mu_n + \psi_n e(t) + \epsilon_n(t)$	$n(t)$	μ_n ψ_n σ_n	-0.018 (0.037) 0.865 (0.237) 0.132
Domestic bond $b(t) = \psi_{b,1}l(t) + \psi_{b,2}l(t-1) + \psi_{b,3}s(t) + \psi_{b,4}s(t-1) + \epsilon_b(t)$	$b(t)$	$\psi_{b,1}$ $\psi_{b,2}$ $\psi_{b,3}$ $\psi_{b,4}$ σ_b	-2.807 (0.255) 3.739 (0.261) -0.206 (0.227) 0.258 (0.221) 0.010
International bond $o(t) = \mu_o + \psi_o b(t) + \tau_o\epsilon_q(t) + \epsilon_o(t)$	$o(t)$	μ_o ψ_o τ_o σ_o	0.024 (0.008) 0.788 (0.104) 0.222 (0.297) 0.016
House price $h(t) = \alpha_h h(t-1) + \alpha_q q(t-1) + \epsilon_h(t)$	$h(t)$	α_h $\alpha_{h,q}$ σ_h	0.228 (0.181) 1.793 (0.526) 0.055
Unemployment rate $u(t) = u(t-1) + \kappa_u(\mu_u - u(t-1)) +$ $\alpha_q(q(t) - q(t-1)) + \alpha_s(S(t) - S(t-1)) + \epsilon_u(t)$	$u(t)$	μ_u κ_u $\alpha_{u,q}$ $\alpha_{u,s}$ σ_u	0.046 (0.011) 0.171 (0.049) -0.246 (0.060) -0.345 (0.074) 0.003

Table 4: Calibrated SUPA parameters

References

ASFA. (2018). ASFA 2018 Retirement Standard. Available at: http://www.superannuation.asn.au/resources/retirement-standard.

Bostock, M., Ogievetsky, V., & Heer, J. (2011). D3 Data-Driven Documents. *IEEE Transactions on Visualization and Computer Graphics*, *17*(12), 2301–2309. doi:10.1109/TVCG.2011.185

Box, G. E. P., & Jenkins, G. (1990). *Time Series Analysis, Forecasting and Control*. San Francisco, CA, USA: Holden-Day, Inc.

Chen, W., Wang, Y., Koo, B., O'Hare, C., Langrené, N., Toscas, P., & Zhu, Z. (2019). Using stochastic economic scenario generators to analyse uncertain superannuation outcomes. *SSRN Electronic Journal*. doi:10.2139/ssrn.3362700

Daley, J., Coates, B., Wiltshire, T., Emslie, O., & Nolan, J. (2018). Money in retirement: More than enough. *Grattan Institute Report No. 2018-17*.

De Ravin, J., Liu, E., van Rooyen, R., Scully, P., & Wu, S. (2019). Spend your decennial age: A rule of thumb for retirement. *Actuaries Summit*.

Forsyth, P. A., Vetzal, K. R., & Westmacott, G. (2019). Management of Portfolio Depletion Risk through Optimal Life Cycle Asset Allocation. *North American Actuarial Journal*, *23*(3), 447–468. doi:10.1080/10920277.2019.1570469. eprint: https://doi.org/10.1080/10920277.2019.1570469

Sneddon, T., Reeson, A., Zhu, Z., Stephenson, A., Hobman, E., & Toscas, P. (2016). Superannuation drawdown behaviour. *JASSA, No. 2, 2016: 42-53*.

Sneddon, T., Zhu, Z., & O'Hare, C. (2016). Modelling defined contribution retirement outcomes: A stochastic approach using Australia as a case study. *Journal of Actuarial Practice*.

Wilkie, A. D. (1984). A stochastic investment model for actuarial use. *Transactions of the Faculty of Actuaries*, *39*, 341–403.

Wilkie, A. D. (1995). More on a stochastic asset model for actuarial use. *British Actuarial Journal*, *1*(5), 777–964.

Zhang, R., Langrené, N., Tian, Y., Zhu, Z., Klebaner, F., & Hamza, K. (2019a). Dynamic portfolio optimization with liquidity cost and market impact: A simulation-and-regression approach. *Quantitative Finance*, *19*(3), 519–532. doi:10.1080/14697688.2018.1524155. eprint: https://doi.org/10.1080/14697688.2018.1524155

Zhang, R., Langrené, N., Tian, Y., Zhu, Z., Klebaner, F., & Hamza, K. (2019b). Skewed target range strategy for multiperiod portfolio optimization using a two-stage least squares Monte Carlo method. *Journal of Computational Finance*. doi:10.21314/jcf.2019.368