What I need to achive:

Working algorithm / simulation

(can be more simplified)

Future perspective

Data Strategy

What data do we use

What challenges are there?

How does RL fit with ALM?

ALM as an optimalization problem

RL model for ALM does not compete with the Market. As the bank is the only one aware of its position.

Train / Test split – How can we test the model?

Feature engineering

Indicators for interest rate movements

Historical rates

Volatility

Hyperparameter optimalization

Batch Size

N\_steps

Gamma

Learning Rate

Ent\_coef

Clip\_range

…



PPO

RL Model



Action Space

Buy or Sell

Tenor

Amount

Needs to be extended to be able to buy or sell multiple swaps at each time step.

Action space is flattened into a discrete value to link to SB3.

Bank Model

Fixed interface: init, step, reset, observation space, action space

Bank Envionment

Observation Space

Zero rates

Projected Cashflows

For a particular position date

Observation space is flattened to a Box (Continuous value between low and high value).

Gym Environment

Bank Model

Generate

NPV / NII / BPV

visualize

Generate Cashflow model

Cashflows

Feature engineering the observation space:

Cashflows are grouped per Month. Zero curves are given as a matrix (rate date, tenor). For simple model no other data is included.

Includes methods:

generate\_mortgage\_contracts

generate\_swap\_contract

generate\_nonmaturing\_deposit

generate\_funding

clear\_swap\_contracts

fixing\_interest\_rate\_swaps

calculate\_npv

calculate\_nii

calculate\_risk

calculate\_bpv

plot\_contracts

plot\_cashflows

reset

step

apply\_action

get\_reward

Interpolate

Zero Rates

Mortgage Rates

visualize

Bank Accounts

Funding

Mortgage Contracts

Forward Rates

Second iteration of the Bank Model

Introduction

As this model and the steering was becoming increasingly difficult and it became more and more unlikely, I would be able to get a working model ready – I decided to try a more simplified approach.

Considering the stochastic nature of the market and portfolio movements which are input for the ALM decision-making process, the task will be modeled as a Markov Decision Process (MDP). The training process involves observing portfolio movements and bond prices, taking action to attract funding, and calculating rewards. By interacting with the environment the agent will over time, learn a strategy to optimize rewards.

In the new model, the actor would still try to steer the interest profile of the bank. But instead of using swaps to modify the interest profile, we will now use bonds to fund the mortgages. By giving the actor the option to directly buy the bonds the actor can directly change the interest profile of the bank. For an even simpler model, I decided to implement a buy-and-hold strategy. So, the actor only has to decide on the needed funding and the tenor of the bonds.

The bank model holds a list of mortgages and associated funding deals. As time goes on at each time the bank will try to sell mortgages based on a fixed probability distribution in 1-, 5-, 10-, and 20-year mortgages. To generate a more stochastic pattern, a random factor is applied to sell up to 10% more or less mortgages each month.

The model will need to find a strategy to issue fixed coupon bonds to fund the mortgage portfolio that will optimize the Net Interest Income (NII) while staying within the Risk limits set

Goal

The goal of the model will be to optimize return, while staying within a limited risk threshold. We can minimize the risk by matching the duration of the cashflows from the mortgages while keeping enough liquidity to fund new mortgages.

This Risk can be divided into 2 separate measures:

1. How close does the duration of the assets match with the duration of the liabilities?
2. Is there a risk of insufficient liquidity?

We optimize return by financing the mortgages as cheaply as possible. Generally, short-term funding will be cheaper than long-term funding. However – this may cause an issue when the gap between the cashflow repricing dates for funding and mortgages gets to large.

I want to add the yield curve development and the consequence of the yield curve for investment decisions. By adding the interest component, we can see if our agent can create extra profit by not fully matching the duration in certain market circumstances. For this, we need realistic long-term simulations for bank interest rates and zero curves.

The goal of the model will now be to maximize the interest income over time. Interest income will be measured as the interest received on the mortgages minus the interest paid on the funding for a specific time. The risk of mismatching the assets and liabilities will now not be calculated as an absolute goal. A certain risk level will be acceptable.

There are several ways we can hedge the interest risk arising from our business model. Cashflow hedging involves aligning the cashflows from the bonds and the mortgages thereby hedging interest rate risk as fixed rate interest is converted to variable rate. The hedge ratio for cash flow hedging is determined based on the projected future cash flows of the mortgage portfolio and the swap contract. It aims to offset changes in interest rates by ensuring that the interest income and interest expense remain closely aligned. This approach provides a level of predictability and stability in cash flow generation, thereby reducing the impact of interest rate movements on the financial institution’s earnings. In practice, banks use Base Point Value Hedging. With basis point value hedging, the hedge ratio is determined based on the BPV of the mortgage portfolio and the swap contract. The BPV measures the sensitivity of the mortgage portfolio’s value to changes in interest rates. By actively adjusting the hedge ratio, financial institutions aim to offset the impact of interest rate fluctuations on the market value of the mortgage portfolio. For this simplified model we will calculate the cashflow hedge ratio for the projected future cashflows.

We will simply calculate for each year: Mortgages repayed / Bonds matured

Simulating Interest Rates

In order to make a descision.. To come up with realistic cost for the mortgages and funding

Simulating interest rates is a whole research field by itself, so this can quickly become very complicated. The Vasicek model (1977) is often used in research. This is a one-factor model and will not be able to capture the correlation between curve points over time. The Vasicek interest rate model is a stochastic model used in finance to describe the behaviour of interest rates over time. It was introduced by Oldrich Vasicek in 1977 and is widely used in the field of quantitative finance. The model assumes that interest rates are driven by mean-reverting processes and can be represented by a stochastic differential equation.

The Vasicek model is defined by the following stochastic differential equation:

dr(t) = a(b - r(t)) dt + σ dW(t)

where:

* r(t) is the short-term interest rate at time t.
* a is the speed of mean reversion. It determines how quickly the interest rate returns to the long-term mean.
* b is the long-term mean or the equilibrium interest rate to which the short-term rate reverts.
* σ is the volatility or the random shock that affects the interest rate.
* W(t) is a Wiener process or Brownian motion, representing the random noise in the model.

Key assumptions of the Vasicek model include:

* The short-term interest rate follows a mean-reverting process, where it tends to move towards the long-term mean b over time.
* The volatility of the interest rate is constant.
* Interest rates are continuous and smooth over time.

There are other more advanced models used as well, to better capture the dynamics of the market. The Hull-white model is an extension of the Vasicek model that introduces a stochastic term structure for interest rates, making it more suitable for modelling the yield curve at different tenors.

The Hull-white model is a two-factor model. In addition to the mean-reversion component it introduces a second factor to account for the volatility of the interest rate. This helps to capture more realistic interest rate movements, especially the term structure of the interest rates. This is what we need to get a realistic scenario for future interest rates.

It's important to note that while the Vasicek model and the Hull-White model are relatively straightforward and widely used due to their simplicity, they do have limitations and may not fully capture all characteristics of real-world interest rate movements. More sophisticated models like the Cox-Ingersoll-Ross (CIR) model and the Heath-Jarrow-Morton (HJM) framework have been developed to address some of these limitations. For this study I think the Hull-White model gives enough depth to the model to come to an effective simulation of interest rate movements.

The bank environment maps the bank model to the reinforcement learning environment.

State (Observation space)

The observation space will be the future cashflows, bank interest rates, and swap rates. The swap rates and bank rates give the model an indication of the cost and benefit of the swaps and mortgages. It may not be of interest for the model to know the cost of the mortgages – as in this simulation the actor does not have any control over the mortgages sold.

Our agent can observe multiple features to better learn in an interactive environment.

* A question is how we should match the different types of data in the observation space. In this case, cashflows per year and swap rates.

Action Space

The action space describes the allowed actions that the agent can take in the environment. The action space will be multi-continuous. The total amount of funding that can be acquired at each timestep can be divided in several time buckets.

For each time bucket the model can decide how much of the funding should be allocated to each time bucket. For this model, the future maturities will be bucketed in 1,5,10,20 and 30 years. Each year represents future cashflows for that year. The amount that the actor can fund in total will be a fixed amount. So the action space is defined as a ∈ { 0.0 .. 1.0 } x { 0.0 .. 1.0} x … { 0.0 .. 1.0} (n buckets). The action will be normalized to express the percentage of funding for each tenor. The normalized action will then be used to allocate the funding. For simplicity’s sake, we allow the model to fund any amount and not be limited to a specific trade size.

Reward

We calculate the reward at each timestep as a combination of factors. First of all we get a reward based on the Net Interest Income. For this, we calculate the interest receivable on the outstanding mortgages minus the interest payable on the bonds.

The actor will need to attract enough funding to be able to sell the mortgages. A penalty is given if the actor does not have enough cash to sell more mortgages.

Third – a penalty is given if the actor does not match the duration of the bonds and mortgages within a certain threshold. The goal will be to minimize the combination of the absolute difference in cashflows for each time bucket (the mismatch in the duration). So, a negative reward will be given to these cash flow differences.

Feedback

To see how how the training is going, we will include some monitoring parameters. During training would like to monitor the following at the end of each episode:

* Total reward
* Total NII
* Total Risk penalty
* Mortgage size per tenor
* Current liquidity
* The mismatch between cashflows (mortgages and funding) for each tenor
* Total liquidity penalty