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.



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

Bankmodel II

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. In this 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.

Goal

Try to optimize return, while staying within a limited risk threshold. The actor will try to optimize the return, while minimizing Risk. We can minimize the risk by matching the duration of the cashflows from the mortgages while keeping enough liquidity to fund new mortgages.

We optimize return by financing the mortgages as cheaply as possible. Generally, short-term funding is cheaper. We reduce risk by matching the duration between the bonds and the mortgages.

In the first model, we look only at Risk. The risk will be determined by the duration gap between assets and liabilities. In each timestep we will no longer try to calculate the actual BPV Profile – but just measure the absolute difference between assets and liabilities per time bucket.

In the second model I want to add the yield curve development. By adding the interest component we can see if we 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.

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 model includes a factor for the (long-term) mean reversion of the interest rates. The Cox Ingersoll Ross (CIR) model is another model that is used. 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 yied curve at different tenors. It is a one-factor model, but it incorporates a time dependent mean reversion term to capture the term structure of interest rates.

The Vasicek interest rate model is a stochastic model used in finance to describe the behavior 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:

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

The solution to the Vasicek model provides the distribution of the short-term interest rate over time and can be used for various purposes in finance, such as pricing interest rate derivatives, analyzing interest rate risk, and valuing fixed-income securities.

It's important to note that while the Vasicek model is relatively straightforward and widely used due to its simplicity, it has 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.

Top of Form

The Hull-White model is another popular stochastic model used in finance for simulating interest rates and is an extension of the Vasicek model. It was introduced by John C. Hull and Alan White in 1990. Like the Vasicek model, the Hull-White model is a one-factor model that assumes interest rates follow a mean-reverting process.

Theta is the mean reversion level – this is the long term equilibrium interest rate to which the short rate reverts over time.

Kappa is the the mean reversion speed. The represents the speed at which the short rate reverts to the mean reversion level.

Sigma is the volatility of the interest rates. Larger values of sigma impy a higher volatility.

However, there are some key differences between the two models:

1. Number of Factors:
   * Vasicek Model: The Vasicek model is a single-factor model, meaning it assumes that the interest rate is driven by only one source of randomness represented by the Wiener process (Brownian motion).
   * Hull-White Model: The Hull-White model is a two-factor model. In addition to the mean-reverting component, it introduces a second factor to account for the volatility of the interest rate. This second factor helps to capture more realistic interest rate movements, especially the term structure of interest rates.
2. Volatility of Volatility:
   * Vasicek Model: The Vasicek model assumes that the volatility (σ) of the interest rate is constant over time.
   * Hull-White Model: The Hull-White model allows for time-varying volatility, meaning that the volatility itself can change over time. This enables the model to better match the empirical observation that interest rate volatility may vary depending on the current interest rate level and other market conditions.
3. Mean Reversion:
   * Vasicek Model: The mean-reversion parameter (a) in the Vasicek model is constant, implying that the speed at which interest rates revert to the long-term mean is fixed over time.
   * Hull-White Model: In the Hull-White model, the mean-reversion parameter can be made time-dependent. This allows for greater flexibility in modeling the dynamics of interest rates, as the mean reversion can change as rates move up or down.
4. Calibration to Market Yield Curves:
   * Vasicek Model: The Vasicek model may have difficulty precisely fitting the entire term structure of interest rates, especially when dealing with market yield curves that exhibit non-constant volatility.
   * Hull-White Model: The two-factor structure of the Hull-White model makes it easier to calibrate the model to observed market yield curves since it provides more degrees of freedom to fit the term structure of interest rates accurately.

In summary, the Hull-White model improves upon the Vasicek model by incorporating an additional factor for the volatility of interest rates and allowing for time-varying parameters. This makes the Hull-White model more flexible and better suited for capturing the complex dynamics of interest rates, particularly in the context of interest rate derivatives pricing and risk management. However, it also comes with increased computational complexity compared to the simpler Vasicek model.

The Bank Model

The bank model holds a list of mortgages and associated funding deals. Initially, we generate the mortgages based on a probability distribution in 1, 5, 20, and 30 years mortgages. These mortgages start somewhere in the past but are all still active. Thus simulating an active mortgage portfolio. *Do we really need ‘initial mortgages’ ? This would also mean we need initial funding – and this is something we want the model to find out. Lets remove initial funding.*

The model allows us to buy bonds for a specific tenor. The start date of the bond would be today (so we receive the money directly), and the money would need to be repaid after x years.

At each time step, we increase the position by 1 month. We also add one month of mortgages. The number of new mortgages can fluctuate by +/- 10% but the mean will remain steady over time.

In order to perceive the state of the bank we can calculate the future cashflows. Future cashflows are bucketed on a yearly basis in order to limit the state space in the simulation.

At each iteration, the bank model is reset. The mortgages are initialized and the funding deals are removed.

We calculate the reward at each timestep as a combination of factors. We need to attract funding for the mortgages. Logically you would only fund what you need – so match the funding with the mortgages. We need a little more cash. If we are unable to pay for new mortgages, we will not be able to issue more mortgages. The actor will be ‘encouraged’ to match the duration of the funding with the mortgages by the reward it will receive. So for the reward, we punish the model if the funding does not match the mortgages.

In all other cases, the actor will receive a reward for the mortgages outstanding -/- the funding required.

To see how it is going, I would like to monitor the following each step:

* Number of mortgages sold
* Current liquidity
* The mismatch between cashflows (mortgages and funding)

The Bank Environment

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

Observation space

The observation space will now be the current cashflows – and possibly previous cashflows (to predict movement in the portfolio). We don’t need to know the entire swap curve as rates are not so relevant to the actor.

Action Space

The action space will be multi-discrete. On each time bucket the model can decide to buy, sell or hold. The amount we can sell may be an option. Probably the simplest would be to automatically assign this as a fixed step. We can also automatically assign this as the difference between assets and liabilities.

Mortgage cashflows can be distributed over the next 20 years. (We will not look at interest percentage, prepayment schedule, and duration of the loan). We are just focused on matching the assets with our liabilities. Each timestep will represent a months period, 12 time-steps per year. Cashflows will be bucketed per year for analyses.

The new business would (approximately) need to cover the replacement of the loans that have expired. These new loans will be distributed over the other time buckets –with a fixed duration of 1, 5, 10 or 20 years. To cover these mortgages the agent can buy, hold or sell bonds with a duration of between 2 till 20 years.

Let’s say we can only issue bonds for a fixed amount – for each time bucket - per timestep. As such we are not actually measuring ‘time’ other than time steps (calendar months).

Reward

The actor will need to attract enough funding to fulfill future cash flow requirements. 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. We can later make this a bit more advanced by only counting it as a negative reward if the mismatch is larger than the risk appetite limit. Additionally, a (fixed) penalty will be incurred directly every time the actor buys or sells a bond.

In the initial model, we don’t calculate Net Interest Income or any other measure of result. So we don’t need to take into account the interest rates of the mortgages and the actual funding cost of the bonds.