Derivative Pricing with Machine Learning

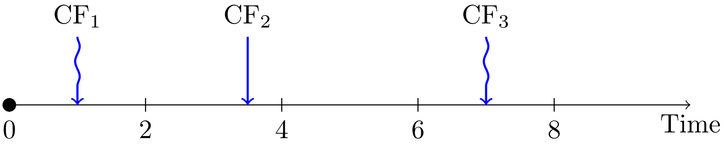
Risk Block

Sber

February 1, 2025

What is a derivative?

A derivative is a contract where parties exchange (possibly random) cash flows at specific future time points.



Additionally, one of the parties may have the right to terminate the contract under certain conditions at any time.

What is a derivative?

In general,

$$\text{price} = \mathbb{E}\left(\sum \text{Cashflow}_\text{t} \mathcal{DF}(\text{t})\right)$$

where $\mathcal{DF}$ is the discount factor (possibly stochastic). Thus, pricing can be done using Monte Carlo simulations or binomial models.

- This is challenging for derivatives of general form.
- Computational methods are often slow and cannot process an entire bank's portfolio efficiently.

Active learning

Ideally, we aim for the following inference architecture:

- The model not only predicts the derivative price but also estimates its confidence in the prediction (similar to uncertainty modeling in Gaussian Process Regression).
- If the model is confident, we use its prediction.
- If uncertainty is high, we compute the derivative price algorithmically and use the result to further train the model.

Next, we present a possible model architecture.

Linearization approach

We can separate market conditions from the derivative contract itself:

- Market conditions: forward curves, volatilities, etc. (easily vectorized).
- Derivative contract: trade description, typically in JSON format.

We can define two models:

$$\varphi : \mathrm{Markets} \to \mathcal{M} = \mathbb{R}^{\mathrm{n}}$$
$$\psi : \mathrm{Derivatives} \to \mathcal{D} = \mathbb{R}^{\mathrm{n}}$$

We optimize the models to minimize:

$$\int_{\mathrm{Derivatives}} \int_{\mathrm{Markets}} \left(\varphi(\mathrm{m}) \cdot \psi^{\mathrm{T}}(\mathrm{d}) - \mathrm{price}(\mathrm{m}, \mathrm{d})\right)^2 \mathrm{dmdd} \to 0$$

Remark

We assume access to a (not very fast) function that can compute derivative prices algorithmically in any market conditions.

Linearization approach

- Further research is needed to ensure that φ and ψ have meaningful financial interpretations, such as replicating complex derivatives using a linear combination of simpler instruments.
- This architecture is flexible: it can be combined with active learning or recurrent models for derivative embedding.

Reinforcement learning

In finance, two applications of RL are well-known but underexplored:

- Early termination rights lead to an optimal control problem, typically solved via Monte Carlo techniques. RL could offer a more general solution.
- Managing transaction costs can also be framed as an optimal control problem.

Remark

Studying these approaches requires a deeper understanding of financial mathematics.

Team composition

Expected team size: 3–6 students.
Required skills:

- Experience with Python and PyTorch.
- Probability theory.

Preferred qualifications:

- Basic knowledge of financial mathematics.
- Experience with reinforcement learning.

After the project

Opportunities include internships, full-time positions, scholarships, and support for publishing research papers.

Contacts

Vanya Vorobiov
Senior Data Scientist
ievorobev@sberbank.ru, @v0r0bi0v