BSP Project Description: Computational Finance with Matlab

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Abstract

This document outlines the end of phase I description of the project carried out by Ivaylo Krumov under the guidance of Giacomo di Tollo during his Bachelor Semester Project 5. It is about the application of numerical methods and software in the optimization of computational finance problems. The project will detail the scientific aspects, consisting of the acquisition of knowledge relevant to the scientific question at hand and to the development of the technical deliverable, and the technical aspects, consisting of the application of the acquired knowledge in optimization software.

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2. Main required competencies

The following is a list of the specific scientific and technical competencies, already possessed before the start of the project, that are essential for its success:

2.1. Scientific main required competencies

No preliminary competencies are required for the scientific aspect of this project.

2.2. Technical main required competencies

The main technical competencies needed for a successful execution of the project include fluency in Python and knowledge in data processing and analysis. Additionally, a grasp

of basic data visualization skills is essential. Finally, basic understanding of statistics software functionalities is required to analyze and interpret financial data.

3. Scientific Deliverable Description

The main scientific aspect of this project includes gaining a comprehensive understanding in the field of computational finance and developing the conceptual model of an algorithm needed to analyse real data and process some selected computational finance operations. As for the first aspect, this involves an understanding of financial mathematics, including pricing models and risk assessment, familiarity with the principles of investment analysis, portfolio optimization, and the ability to assess the performance of financial instruments. As for the second aspect it is vital to understand the theoretical basis of computational finance with MATLAB. It is aimed at providing a solid foundation for the subsequent technical deliverable and ultimately giving an answer to the scientific question: "Can we reliably use MATLAB to help optimize investment choices?" To achieve this, resources, such as the book "Numerical Methods in Finance and Economics: a MATLAB based introduction, Second Edition" by [Paolo Brandimarte (2013)], will be utilized, which serves as an essential guide for learning the basics of computational finance theory.

The primary focus of the scientific deliverable is to introduce the key concepts and methodologies that Computational Finance is based on. It is defined by an in-depth exploration of various financial models, pricing mechanisms, and optimization techniques, all of which are crucial to addressing the main scientific question.

First of all, the field of computational finance will be defined, as well as its significance in modern financial analysis. This will include an overview of financial decision-making and the role of computational tools in optimizing investment choices, in preparation for answering the scientific question.

Next, we will briefly delve into numerical methods commonly used in finance. This will require an understanding of root-finding algorithms, optimization techniques, and numerical integration methods, which are fundamental for developing reliable investment choice optimization tools in MATLAB.

Following this, the deliverable will introduce various pricing models used in finance, such as the Black-Scholes model for option pricing and the Binomial model. The mathematical foundations of these models will be explained and their applications in evaluating financial derivatives will be discussed, directly addressing how MATLAB can be utilized in accurate pricing.

Furthermore, concepts related to risk management like risk assessment, value at risk (VaR) [Joseph Andria, Giacomo di Tollo (2021)], and portfolio optimization will be explored, focusing on the tools and techniques MATLAB offers for answering the question of reliability in optimizing investment choices. In particular, during the project, a particular emphasis will be devoted to compute risk measures (e.g. VaR), since they are useful to assess the riskiness of a portfolio starting from real data.

Once these theoretical topics have been covered, the produced technical deliverable will encompass examples to demonstrate the application of numerical methods in MATLAB. Then we will use data from the real world, introduce a meaningful set of pre-processing operations. As described by [Eliana Angelini, Giacomo di Tollo, Andrea Roli (2008)], these operations include handling missing and wrong values (either ignoring or replacing them), erasing useless fields, data normalization, correlation analysis (to identify the most strongly correlated variables in the data and remove them from consideration) and proper data selection. In our contribution, we will show that these pre-processing operations are useful when defining computational finance related applications and will use them as input for the tools developed during the technical deliverable to take investment choices and to assess our scientific question. An analysis of the performance of the algorithms will be provided and the results of the analysis will then be used to this goal.

4. Technical Deliverable Description

The first aspect on the technical deliverable is get knowledge about the language MATLAB. This includes the knowledge of MATLAB's computational finance functionalities, data handling, and the ability to develop and integrate functions for financial modeling. It is essential to have the competence to introduce modules, establish input-output relationships among them, and ensure the reliable use of MATLAB for the optimization of investment choices. It is also useful to possess an understanding in software engineering principles, so that the final software product is successfully delivered.

The technical deliverable of this project combines the practical implementation and application of the scientific principles explored in the scientific deliverable. It is designed to show the utilization of MATLAB and computational finance concepts to develop a software solution for investment choice optimization. Therefore, in this section the code of the produced software will be described in-depth step by step.

The software will be structured into several modules, each dedicated to specific functions. These functions will be explained in detail, highlighting their roles in the overall system. Input-output relations among these modules will also be clearly defined.

Overall, the technical deliverable will provide a demonstration on how MATLAB's computational finance capabilities are utilized for financial modeling, including the implementation of pricing models and risk assessment. This will involve practical examples, such as option pricing, portfolio risk analysis and structural functions.

The principal modules are the following:

- Modeling uncertainty - creating a model for uncertainty by exploring discrete-state, discrete-time models (e.g. the binomial model), the concept of recombining lattices, continuous distributions, continuous-time models, and

stochastic processes (e.g. the Wiener process), which are essential components in continuous-time models.

- Basic financial assets - in particular, exploration of bonds (coupons, zero-coupon bonds, bond pricing), stocks (dividends, dividend policy, total return, rate of return) and derivatives (forward/future contracts, call/put options)
- Equilibrium pricing in a pure exchange economy - the theoretical balance where supply and demand for goods and assets meet. In this setting, there are no production activities, and agents trade based on their preferences. Equilibrium prices are determined by matching these preferences and resources.
- Arbitrage in a binomial model - the exploitation of price discrepancies between related financial assets to ensure risk-free profit. This is a discrete-time model, in which traders take advantage of price inefficiencies by forming portfolios of assets that offset each other's risks, guaranteeing a certain return regardless of market movement.
- "Putting all of your eggs in one basket" - this is a metaphor, which puts emphasis on the risks of focusing investments or resources into a single or very limited number of assets. This practice leaves one vulnerable to potential losses if that singular asset fails, which is why spreading investments across various assets is considered to greatly reduce the risk of significant losses.
- St. Petersburg paradox - a famous financial paradox, which revolves around a simple game where a player pays an entry fee, flips a coin, and wins increasingly larger amounts if the coin lands heads, with the possibility of infinite winnings. However, the paradox lies in the fact that most individuals are unwilling to pay a high entry fee for this game, despite the theoretically infinite expected value. This paradox serves as a challenge to traditional economic theories based solely on expected monetary value, highlighting the role of risk aversion in decision-making.

A solid part of the deliverable will be devoted to understand the structure of data and to define a structured function, as already mentioned by [Joseph Andria, Giacomo di Tollo, Jaan Kalda (2022)]: the deliverable will implement the function proposed therein and propose some extension based on the nature of data used.

As for the software design, the user will be prompted to a box that allows him to select the module that will be invoked. Every module will be implemented as a MATLAB function. The user will be asked to choose data from a list of possible sets, and will receive the result of the function in Standard Output. The program will not exit after the first execution.

References

[Paolo Brandimarte (2013)] Numerical Methods in Finance and Economics: a MATLAB based introduction, Second Edition

[Joseph Andria, Giacomo di Tollo, Jaan Kalda (2022)] The predictive power of power-laws: An empirical time-arrow based investigation. Chaos, Solitons & Fractals Volume 162, September 2022, 112425

[Joseph Andria, Giacomo di Tollo (2021)] An Empirical Investigation of Heavy Tails in Emerging Markets and Robust Estimation of the Pareto Tail Index In: Mathematical and Statistical Methods for Actuarial Sciences and Finance Springer, Cham. https://doi.org/10.1007/978-3-030-78965-7_4

[Eliana Angelini, Giacomo di Tollo, Andrea Roli (2008)] A neural network approach for credit risk evaluation The Quarterly Review of Economics and Finance, Volume 48, Issue 4, 2008, ISSN 1062-9769, https://doi.org/10.1016/j.qref.2007.04.001.