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Original article

Evaluating Wave Random Path Using Multilevel Monte Carlo ☆

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Abstract

Wind waves are important due to their high energy and impact on marine activities. This phenomenon is affects directly or indirectly the construction of coastal infrastructure, shipping and recreational activities. Due to the issues presented, marine parameters are very important. In this study, we try to pay attention to wave as one of the most important marine parameters. As the movements of waves have high uncertainty, financial models can be used to simulate the wave's paths. We use the Monte Carlo method for this purpose. The Monte Carlo simulation is a flexible and simple tool that is widely used in the evaluation of random paths. To compute a random path, we require an integral discretization. In this paper, we study the valuation of European options using Monte Carlo simulation and then compare this result with multi-level Monte Carlo approach and other antithetic variables. Then, we use the multi-level Monte Carlo approach proposed by (M. B. Giles 2008) for pricing under the two-factor stochastic volatility model. We show that the multi-level Monte Carlo method reduces the computational complexity and also cost of the two-factor stochastic volatility model when compared with the standard Monte Carlo method. Also, we compare the multi-level Monte Carlo method and standard Monte Carlo method using an Euler discretization scheme and then, analyze the numerical results.

Keywords: antithetic variables technique, computational complexity, Monte Carlo simulation, multi level Monte Carlo, multi-factor stochastic volatility

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1. Introduction

The effects of water waves in coastal engineering and its impact on marine structures is very important. The waves are the most important factor in determining the geometry and composition of the coast and they also have a major impact on the design of ports, waterways and on coastal marine work. Information about the characteristics of waves such as their height and time cycle are some of the basic needs for scientists, researchers, Civil, Marine Science and Technology and Navier and fisheries Engineers and also coastal area residents. The information is important for the design, construction, implementation, installation and transfer of marine structures such as platforms, buoys, breakwaters. It is also key in estimating the amount of marine sediment to transport and also the erosion and deposition of estimates made in the vicinity of offshore structures and ports. Given that waves are generated by the wind on the water's surface, they have different heights and durations. Also, due to the impact of various factors with regard to height and the duration the waves that reach out to the offshore structures, is almost impossible to predict the parameters accurately. Therefore efforts to predict the formation of waves based on weather information and some measured variables affecting them in the desired location have to be made. Due to the random motion of waves, stochastic differential equations follow from the Brownian motion (Wiener process) Which are very similar to the behavior of stock in the financial markets.

The Monte Carlo methods are applied to calculate the expected value of a random variable. Specially, when the random variable of interest in a given stochastic differential equation, using Monte Carlo methods is more complicated when compared to other deterministic numerical methods, but they offer a better solution. Bearing in mind that financial models often require a computational complex solution, Monte Carlo methods usually enable an efficient solution and are widely used to solve them. The reason is that Monte Carlo methods are used to approximate the expected value of the sample mean. In fact, the sample mean obtained works as an unbiased estimator. Still, this method of course leads to a statistical error. Confidence interval obtained using the Monte Carlo method includes the standard deviation and inverse square root of the estimator. There are two ways to reduce the error in the standard Monte Carlo approach. First one is to increase the number of simulations and the second one is to reduce the variance of the estimator. The first approach involves squaring the number of simulations and that is computationally expensive. Thus, the second one is usually used for this reason To reduce the variance and accordingly reduce the computational complexity, various approaches have been proposed by (Glasserman 2004). These methods are known as variance reduction techniques. Some of these techniques are based on building more sophisticated estimators and others are based on enhanced random number generators. Here, we will discuss techniques based on building more sophisticated estimators, such as control variates and antithetic variables. .

Recently, the work of (Heinrich 2001), and (Kebaier 2005) suggest it as a statistical method and Romberg introduced two levels. This idea was further extended by Giles (M. B. Giles 2008) and the so-called multi-level Monte Carlo (MLMC) method was presented, which allows one to significantly accelerate the Monte Carlo classic method and approach.

This method is typically expressed by a multi-level control variate technique. By choosing the time step sizes and the number of simulations for each level, the complexity of computation is reduced when compared to the crude Monte Carlo approach. In other words, to calculate the expected value with an accuracy of $\mathcal{O}(\mathcal{E})$, the computational cost of $\mathcal{O}(\mathcal{E}^{-3})$ is reduced to $\mathcal{O}(\mathcal{E}^{-2}(\log \mathcal{E})^2)$. (M. B. Giles 2008).

In this paper, we first improve the option prices under the geometric Brownian motion. To implement this, we use the multi-level Monte Carlo method and antithetic variates as a variance reduction technique. Pei Yuen Lee (2011) studied the multi-level Monte Carlo simulation for pricing options in terms of efficiency. He implemented the method using the Euler and the Milstein schemes. Dominik Huth (2012) presented multi-level Monte Carlo results based on Asian, Barrier, and American options in the Black-Scholes model.

Then, we studied the multi-level Monte Carlo

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