Research Assessment Exercise 2020
Impact Case Study

University: The Chinese University of Hong Kong
Unit of Assessment (UoA): 11 Mathematics and Statistics

Title of case study: A new memory reduction simulation method widely adopted by financial practitioners

(1) Summary of the impact (indicative maximum 100 words)

This case study revealed a novel Monte Carlo simulation method developed by Professor Raymond Chan's group. Chan's memory reduction method enables financial practitioners to obtain accurate results under hardware constraints, such as derivatives options pricing, etc. The beneficiaries include local and world famous investment companies, e.g. BNP Paribas, Citic CLSA (London), CASH Algo Ltd., etc. The implementation of this innovation has delivered significant economic impact by improving the performance of option pricing by at least 12.5 times and lowering the hardware budget by 20%. This also enables efficient simulation of option pricing on personal mobile devices for the first time.

(2) Underpinning research (indicative maximum 500 words)

The Monte Carlo simulation method is largely used in financial industry, for such as derivatives options pricing, risk sensitive analysis, risk management, etc. In the high dimensional case (such as for path-dependent derivatives options) and nonlinear case (such as for American option/Knight uncertainty model), the Monte Carlo method seems to be the only efficient method for the numerical solution of the problems. Nevertheless, it requires enormous copies of simulation, and hence enormous memory to store these simulations. Professor Raymond Chan [Department of Mathematics at CUHK (1996-2018)], one of the Computational Finance pioneers, led his research group to develop effective Monte Carlo method to obtain accurate results for high dimensional and/or nonlinear pricing problems under hardware constraints since 2004.

In Monte Carlo method, the simulated paths for pricing path-dependent derivatives are all generated in the time-increasing direction according to the given Brownian motion. The optimal strategies prior to/at the expiry date depend on the running asset prices, and hence one needs to store all the intermediary asset prices on all the paths at every time point. Therefore, the total storage requirement grows like **O(MN)** [**M**: number of simulated paths; **N**: number of time points] which causes severe demand on memory and limits the accuracy of the simulation method.

Chan's group proposed a simulation method that does not require storing all the intermediate asset prices [3.1], allowing the storage to grow only like **O(N+M)**. In fact, this new method requires generating the paths twice: one in a forward sweep to establish the asset prices at the expiry date, and one in a backward sweep that computes the intermediate asset prices only when they are needed. The resulting computational cost of this method is around twice of that of the conventional method where all the intermediate asset prices are stored. The main idea is that, in the computer, the random numbers are generated using a deterministic algorithm with a given seed. Hence one can always regenerate the sequence of random numbers by remembering the seed of the first random number in the sequence, c.f. illustration in Figure 1. This method allows simulating much more paths and improving significantly the accuracy of the corresponding Monte Carlo method under the constraint of the hardware capacity. It has also been applied to various financial derivatives such as American Options and other different path-dependent options [3.1-3.5].

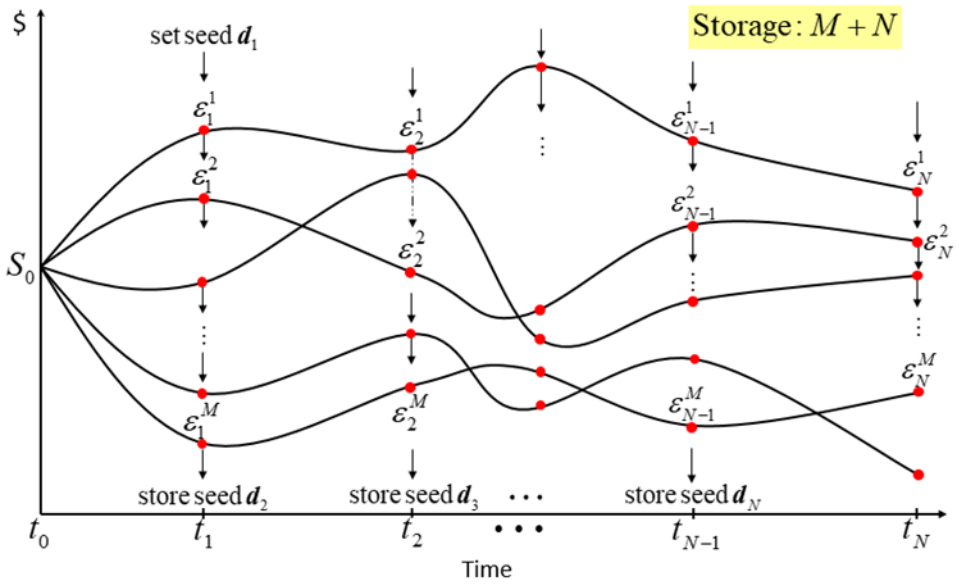

Figure 1. Chan's method: Store the seeds d_i to re-generate random numbers ε_i^j for all path j when needed.

Using the techniques developed by Chan's group, which does not need to store intermediary results, one can develop more efficient computation tools for financial derivatives, e.g. pricing American options, with much less hardware memory. This revolutionises the framework of the Monte Carlo method in option pricing. More accurate, effective simulation and analysis of options can be achieved, allowing cutting down significantly the hardware cost for the quantitative team in financial industry.

(3) References to the research (indicative maximum of 6 references)

[3.1] R.H. Chan, Y. Chen, and K.M. Yeung, A Memory Reduction Method in Pricing American Options, *J. Statist. Comput. Simulation*, 74 (2004), 501–511.

[3.2] R.H. Chan, K.C. Ma, and C.Y. Wong, Enhanced Tilley's Bundling Algorithm Using Memory Reduction Monte Carlo Method, *Calcolo*, 42 (2005), 37–46.

[3.3] R.H. Chan, C.Y. Wong, and K.M. Yeung, Pricing Multi-asset American-Style Options by Memory Reduction Monte Carlo Methods, *Appl. Math. Comput.*, 179 (2006), 535-544.

[3.4] R.H. Chan and T. Wu, Memory-Reduction Method for Pricing American-Style Options under Exponential Levy Processes, *East Asian J. Applied Math.*, 1 (2011), 20–34.

[3.5] R.H. Chan, S.T. Lee and X. Li, Financial Mathematics, Derivatives and Structured Products. *Springer* (2019)

(4) Details of the impact (indicative maximum 750 words)

The primary impact of this research is that it changes significantly the practice of the Monte Carlo method in quantitative finance, by improving its accuracy and efficiency. The Monte Carlo method is largely applied in financial industry, especially in derivative market, where good estimation of the option prices and risk measure plays a crucial role. The proposed memory reduction method can improve significantly its accuracy and efficiency in many situations, and brings important impacts in different aspects.

Impact on commerce

Improving research implication through industrial collaboration

The Department of Mathematics at the CUHK has a long history in developing mathematical theories to solve social/industrial problems. Professor Chan has built a research group in

financial mathematics, having intense interactions with the financial industry, including some from **Fortune Global 500** (BNP Paribas, Citic CLSA etc.) since 2010. There were regular meetings/seminars between the academic group and the industrial partners. The industry practitioners bring real challenges from their field which usually inspire new research subjects for academia. Meanwhile, the research results shared by academic people help the financial practitioners to improve their methodologies [3.1, 5.1]. The case study is an outstanding example of the fruits from these interactions. The initial research subject has been inspired by the questions raised by quants from the company CASH Algo. The research results lead to several publications on academic journals, and the new memory reduction method is then implemented and applied successfully in the financial companies such as CASH Algo, BNP Parisbas, Citic CLSA (London), Luoshu (Shanghai), among many others.

Impact on economy and industrial environment

From research to impact

With more people gaining knowledge in evaluating derivatives prices, standard derivatives are not able to make money. More sophisticated options and structured products have to be invented. However, the complicated terms of the products make accurate pricing considerably more difficult and inaccurate. The 2008 financial meltdown is a case in point.

Nature and extent of the impact

The conventional method had a very high requirement on the hardware in order to generate accurate simulation. With Chan's novel method, the simulation efficiency and accuracy have been highly enhanced, illustrated below in detail.

Enhancing simulation accuracy and performance: As an immediate impact, this new innovation was adopted by CASH Algo Ltd. (a local quant-finance company) to develop strategies in financial market since 2013 [5.1]. Chan's method was highly appreciated, quoting from Executive Director of CASH Algo "*a vanilla implementation of Monte Carlo simulation can exhaust all the memory resources in our pricing server if the server covers 4 different stock options in real time. If we applied the memory reduction method, the server can easily handle* ***more than 50 different stock options*** *… It is* ***at least 12.5x better performance*** *…*"

The significance of the memory reduction was also revealed in other companies. After the publication of the series of papers, many other international financial companies, including **Fortune Global 500**, have quickly adopted this new memory reduction method. Managing Director at BNP Paribas Hong Kong said, "*With this method, one can treat* ***at least 10 times more tasks*** *at the same time under the* ***same hardware constraints***. [5.2]"

Relieving the hardware constraints: The enhanced computation accuracy and efficiency is also crucial for industry to elevate the competitiveness. Citic CLSA (London) Equity derivative trader director said: "*By using the proposed memory reduction technique, we improved largely our capacity of pricing options by Monte Carlo under the computers' capacity constraint…. this memory reduction method is still extremely useful to us, especially … the multi-task, multi-factor market situation*." [5.3]

This method also exerts the economic impact by reducing industrial hardware cost. CEO of LuoShu Investment Management Corporation (Shanghai) said: "*By applying the proposed method…we can now tackle* ***at least 10 times*** *more American option pricing task … allows* ***reducing about 20% budget*** *in hardware*."[5.4]

Enabling mobilized simulation on personal devices: Apart from reducing the company hardware budget, Chan's method significantly reduced the hardware requirement. For the first time, mobilized efficient simulation for option pricing has become possible. Practitioners can run the simulation on their personal devices such as laptops or even mobile phones to obtain

the latest result for option pricing. *"With Chan's memory method, our traders can respond to the fast-changing financial market immediately by* ***operating our system on their mobile device for accurate option pricing anytime, anywhere****. In many situations, quick response to market change is a very crucial tactic for our company to* ***increase market share and stand out from our competitors****."* [5.4]

(5) Sources to corroborate the impact (indicative maximum of 10 references)

[5.1] Acknowledgement letter from CASH Algo Ltd. (2017)

[5.2] Acknowledgement letter from BNP Paribas. (2019)

[5.3] Acknowledgement letter from Citic CLSA. (2019)

[5.4] Acknowledgement letter from LuoShu Investement Management. (2019)