Quantum Finance

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Intelligent Forecast and Trading Systems

Springer

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This book is dedicated to all readers and students in UIC taking Quantum Finance course; your enthusiasm for learning new concepts and seeking knowledge prompts me to write this book.

Preface

Motivation of This Book

Everything happens for a reason. Anything that might be happened with a cause. These two sentences seem to be very simple, but they are major motivations to drive the advances in science and technology of human history.

However, modern cosmology tells us that we live in a *multiverse*, the world we all experience is just one of the many *realities*. Quantum theory tells us that all fundamental particles in the subatomic world coexist in a particle–wave duality state. Heisenberg's uncertainty principle even tells us that we can never 100% correctly measure both the position and momentum of any quantum particle simultaneously. Chaos theory shapes the world as complex systems with all predictions are highly sensitive to its initial conditions; only a tiny observation error will lead to a totally different future. Fuzzy logic tells us to accept this as nature of reality; all we can do is to model the world as a collection of *fuzzy linguistics and events*.

Does it mean that we cannot predict the future?

The answer is definitely … NO.

The motivation of this book—quantum finance, a cross-discipline of financial engineering with the integration of quantum field theory, classical finance theory, computer science, and AI technology—is to find a scientific path to resolve this *grant puzzle*.

Quest for the Knowledge of Financial Prediction

This book is also about *an over 30-year journey of knowledge seeking on financial prediction*.

The idea of using quantum field theory and AI to solve financial problems (now called *quantum finance*) emerged when I was an undergraduate physics student at

the Hong Kong University (HKU) in 1986 studying quantum mechanics and general relativity courses. At that time, I was deeply impressed by all great minds and innovative ideas for the interpretation of the world in two totally different perspectives: the subatomic world of quantum mechanics versus the cosmic world of general relativity. Since then, I strongly believe that both the Schrödinger equation and Feynman's path integrals hold the keys to unlock the *dynamics of everything*—to truly observe the past and predict the future. They also hold the keys to resolve two major forecasting challenges in human history: weather forecast in meteorology and worldwide financial prediction in finance.

After graduation from HKU in 1989, I joined the Hong Kong Observatory of the Government of Hong Kong Special Administrative Region and worked as experimental office on weather prediction and in the building of computational weather prediction model known as numerical weather prediction (NWP) system using Fortran. Although at that time it was still based on Newton's laws of motion, fluid dynamics, and thermodynamics equations to predict weather, it gave me an opportunity to realize two important facts: (1) In order to ultimately unlock the mystery of prediction using Schrödinger equation by computer system, we need to convert (model) the Schrödinger equation wisely into other formats such that it can be easily computed by digital computers using numerical computation techniques; (2) Only Schrödinger equation and Feynman's path integral are not adequate to predict the future. In Chaps. 3–5, these two mathematical models are the keys to model the quantum dynamics of quantum financial particles (QFPs) and to evaluate the quantum price levels (QPLs), but they are not the ideal tools to predict future. In order to predict the financial market wisely and effectively, we need some other *intelligent* tools. Such motivation precipitated me to pursue M.Sc. and Ph.D. studies at Hong Kong Polytechnic University in 1994 and 1997, respectively.

During this period, I have learned and explored all different kinds of artificial intelligence (AI) technologies including artificial neural network (ANN), fuzzy logic (FL), genetic algorithms (GAs), and chaos and fractals theories. Among them, I realized in order to solve this *grant puzzle*, one must look for four *puzzle pieces* first:

(1) All these AI tools and technologies are not only closely related but also each of them has its own advantages and shortcomings. If we can integrate these AI tools and techniques wisely, we might have an opportunity to solve more complex and fundamental problems, worldwide financial prediction—for instance;
(2) All these AI tools and techniques are in fact *different faces of the same coin*; how to integrate them wisely and effectively should not only focus on the methodology but rather the fundamental structure of the AI tools themselves;
(3) How to model quantum finance effectively is another important issue. In Chap. 3, we will see that traditional Feynman's path integral although can provide a feasible solution to model quantum dynamics of financial markets, the computational complexity of this method hinders us to apply it for real-time financial market prediction. In other words, we need a totally new idea to model

quantum finance effectively, not only at the analytical level but also at the numerical computation level;

(4) Even though if we can model financial markets using quantum finance effectively, how to integrate such model with AI is another problem. In order to integrate quantum finance model and AI technologies nicely to implement worldwide financial prediction and intelligent quantum trading system, we need a *common ground* to link up these two worlds. Again, not at the methodology level, but rather at the *core* model structure itself.

Not until 2004, I proposed the Lee-oscillator—a chaotic time-discrete neural oscillator with profound transient-chaotic property, which gave us some new hopes to resolve part of this puzzle. The interesting thing is that, when the Lee-oscillators are used to replace the neurons in any time series neural networks, such as traditional feedforward backpropagation networks (FFBPNs), they would convert the neural networks into powerful chaotic neural oscillatory networks (CNONs) with promising prediction and machine learning capabilities. In Chap. 9, such chaotic neural oscillators can be served as the *missing link* to integrate all different kinds of AI technologies effortlessly, which sheds light on the resolution of the first two puzzle pieces to model complex time series prediction problems such as real-time worldwide financial forecast. After that, it leaves us with the last two puzzle pieces.

In 2007, Dasgupta et al. published their paper titled as *Simple systematics in the energy eigenvalues of quantum anharmonic oscillators* in the *Journal of Physics A* (Chap. 3) which explained how to model Schrödinger equation as quantum anharmonic oscillators (QAHOs). More importantly, this paper nicely described how to resolve a special type of QAHO so-called λx^{2m} AHO in which at the same time I had derived the quantum finance Schrödinger equation (QFSE) as an AHO of order 4 (i.e., m = 2) quantum dynamic model (Chap. 4). By the integration of this λx^4 AHO mathematical model and the finite difference method (FDM) learnt for the implementation of the NWP model in Hong Kong Observatory years ago, I can finally construct a numerical computation model with the integration of AHO (to model quantum financial particles) and CNON (to model chaotic time series prediction) into the so-called quantum finance forecast system (QFFS).

In order to prove the applicability of this totally new AI-fintech invention in real-world financial markets, during 2012–2017, I joined Leanda Investment Group (one of the major commodity investment and trading companies in China) as the chief analyst and group CTO for the implementation and national promotion of QFFS in China. With the success of the implementation of QFFS in commodity product forecast for over 5 years in China and Hong Kong, in Mar 2017, I set up the quantum finance forecast center (aka QFFC, website QFFC.org), a nonprofit making, AI-fintech R&D, and worldwide financial forecast center aims at the R&D and the provision of an open platform for worldwide traders and individual investors to acquire free worldwide real-time financial prediction. QFFS now provides daily (weekly) financial forecasts for over 120 worldwide financial products including 9 major cryptocurrencies, 17 worldwide financial indices, 84 forex, and 19 major commodities. As of March 2019, QFFC has over 10,000+

registered worldwide members which consists of worldwide professional traders, quants, and independent investors from major fund houses and financial institutions using the free quantum finance daily forecast services.

Organization of This Book

This book is the collection of my past 20 years (1999–2019) of R&D works and practical implementation of quantum finance and related AI technology including chaotic neural networks, fuzzy logics and genetic algorithms (GAs) in financial market modeling, time series financial prediction, and intelligent agent-based quantum trading techniques and methodologies.

This book consists of two parts: Part I describes the basic concept and theory of quantum finance and related AI technology. Part II describes the current and ongoing R&D projects for the application of quantum finance technology on intelligent real-time financial prediction and intelligent agent-based quantum trading systems.

This book is organized as follows:

- Chapter 1—Introduction to Quantum Finance
  This chapter introduces the origin of quantum finance and the two different perspectives to *see* the world. It investigates the wave–particle duality and Heisenberg's uncertainty principle in quantum mechanics and how these phenomena are related to quantum finance, which leads to our study on the philosophy of quantum finance. After that, it introduces the major components of quantum finance and the quantum finance four-tier concentric sphere model.
- Chapter 2—Quantum Field Theory for Quantum Finance
  To avoid complex mathematical derivation, the chapter mainly focuses on the basic concept and physical meaning of how quantum field theory can be applied to financial engineering for the modeling of worldwide financial markets.
- Chapter 3—An Overview of Quantum Finance Models
  This chapter investigates two main branches of quantum finance models—the Feynman's path integral model and the quantum anharmonic oscillator model. It also explores the future of quantum finance which relates to intelligent finance systems' development.
- Chapter 4—Quantum Finance Theory
  This chapter starts with a basic concept of quantum finance theory—quantum anharmonic oscillator model. It focuses on the complete mathematical derivation of the author's original work of quantum finance Schrödinger equation (QFSE). It also investigates the quantum dynamics in financial markets, the notion of quantum price levels (QPLs) and their relationship with quantum finance energy levels (QFELs).
- Chapter 5—Quantum Price Levels—Basic Theory and Numerical Computational Technique

This chapter focuses on detailed mathematical and numerical derivations of quantum price levels to solve the quantum finance Schrödinger equation (QFSE) effectively using numerical computational method—the *core* of quantum finance in financial market modeling. First, it presents the basic concept of quantum price levels (QPLs) and its relationship with quantum finance energy levels (QFELs) in QFSE. Second, it shows how to interpret the quantum price return wave function in terms of probability density function (*pdf*) using finite difference method (FDM). Third, it explores how to solve QFSE using numerical computational technique and describes the computer algorithm to determine all QFEL and QPL. This chapter will be ended with the first quantum finance computing workshop for QPL evaluation on worldwide financial products using metatrader query language (MQL) in metatrader (MT) platform.

- Chapter 6—Quantum Trading and Hedging Strategies
- This chapter focuses on the practical use of quantum finance in quantum trading and hedging operations. First, it starts with the discourse of seven major trading and hedging techniques—a collection of the author 20+ years of trading experience in stock, commodity, and forex trading with numerous technical trading courses conducted in China and Hong Kong for past 10 years. Second, it presents the main concept on how to make use of quantum finance, especially on quantum price levels (QPLs), quantum forecasts to design quantum trading and hedging strategies.
- Chapter 7—AI Powerful Tools in Quantum Finance
  This chapter introduces three major AI tools in quantum finance: artificial neural networks (ANNs) on machine learning and time series prediction, fuzzy logics (FL) on fuzzy and inexact financial modeling, and genetic algorithms (GAs) on trading strategy optimization. More importantly, it shows how these AI tools are integrated with quantum finance technology to implement quantum finance forecast and intelligent agent-based program trading systems.
- Chapter 8—Chaos and Fractals in Quantum Finance
  This chapter introduces two vital contemporary finance engineering theories: chaos and fractals. It explains the duality behavior of financial markets modeled by these two theories, and more importantly, on how they are related to quantum finance for financial engineering in contemporary financial institutions.
- Chapter 9—Chaotic Neural Networks in Quantum Finance
  This chapter presents basic theory of chaotic neural oscillators and neural networks with the author's original work on Lee-oscillator, how it can be adopted with quantum field signals (QFSs) into quantum finance oscillators (QFOs) and converted into chaotic neural networks for financial prediction.
- Chapter 10—Quantum Price Levels for Worldwide Financial Products
  As Part II's first chapter on quantum finance applications, this chapter discusses R&D project to apply quantum finance technology to calculate the quantum price levels (QPLs) for over 129 worldwide financial products including: forex (84), cryptocurrency (9), major commodities (17), and worldwide financial indices (17).

- Chapter 11—Time Series Chaotic Neural Oscillatory Networks for Financial Prediction
  This chapter discusses R&D project on how quantum price levels (QPLs) can be integrated with chaotic neural oscillatory network learnt in Chap. 9 to time series chaotic neural oscillatory networks (TSCNONs) for financial prediction.
- Chapter 12—Chaotic Type-2 Transient-Fuzzy Deep Neuro-Oscillatory Network (CT2TFDNN) for Worldwide Financial Prediction
  This chapter discusses the author's latest R&D for the integration of chaotic type-2 transient-fuzzy logic with chaotic neural networks for the implementation of chaotic type-2 transient-fuzzy deep neuro-oscillatory network (CT2TFDNN) for worldwide financial prediction.
- Chapter 13—Quantum Trader—A Multiagent-based Quantum Financial Forecast and Trading System
  This chapter discusses the latest research project to apply multiagent-based real-time financial prediction and trading system using quantum finance technology.
- Chapter 14—Future Trends in Quantum Finance
  This chapter concludes all concepts and theories in quantum finance, their relations to contemporary AI technology on intelligent financial systems. It also discusses the latest research on financial engineering and the trend of quantum finance.

Readers of This Book

This book is both a textbook and professional book tailored for

- Undergraduate and master-degree students for various courses on quantum finance/computational finance/AI/fintech/machine learning;
- Researchers and scientists working in the field of financial engineering and intelligent systems, AI, computational finance, econophysics, data science, and computational intelligence;
- Professional traders/quants/independent investors who would like to learn the basic concept and theory of quantum finance, more importantly on how to use this innovative AI-fintech technology to implement intelligent financial forecast and program trading systems;
- Lecturers and tutors who would like to teach students quantum finance with related AI technologies, and to conduct labs to teach students on how to design and implement intelligent financial forecast and trading systems.

How to Use This Book?

This book can be served as both textbook and research monograph for various undergraduate and postgraduate courses on quantum finance and related AI/AI-fintech courses.

Basically, Part I (Chaps. 1–9) covers all basic concepts and theory about quantum finance and related AI technology can be conducted as a self-contained undergraduate/postgraduate course on quantum finance.

Part II (Chaps. 10–14) covers all advance studies and applications of quantum finance, which can be adopted as the selected topics on various advanced AI/fintech courses for postgraduate and research studies.

In UIC, starting from early 2019, the author launched a new free elective course, namely, "Quantum Finance" for Year 3/4 undergraduate students of different disciplines including computer science, financial mathematics, data science, and statistics. In terms of course syllabus, this course covers Chaps. 1–9 in the 14-week study, and Chaps. 10 and 11 as workshops and term projects for the implementation of QPL-based quantum finance forecast systems. Besides, students and course instructors can use MQL workshops provided by QFFC.org enabling students to learn MQL programming and how to develop simple program trading programs.

For advanced studies such as postgraduate AI courses or M.Phil./Ph.D. studies, Chaps. 11–13 provide advanced topics on how to combine quantum finance theory with contemporary type-2 fuzzy logic, chaotic neural oscillators, and reinforcement learning agent theories for further R&D on quantum finance and related studies.

Last but not least, for quantum finance application developers such as quants and financial analysts make use of the QFSDK provided by QFFC.org to develop quantum finance applications. They can directly read Chaps. 10 and 11 first as technical reference for QPLs' calculation to implement quantum finance forecast system for their own interesting financial products and revert to Part I to learn the basic concepts and theories.

Companion Website—Quantum Finance Forecast Center (QFFC.org)

Quantum finance forecast center (QFFC.org) is a nonprofit making, AI-fintech R&D and worldwide financial forecast center that aims at R&D and the provision of an open platform for worldwide traders and individual investors to acquire free worldwide financial products' quantum finance forecast.

As a companion website, QFFC provides a web portal for readers and worldwide quantum finance system developers to learn and develop quantum finance systems with the following:

- Interactive quantum finance computing workshops (QFCWs) provide step-by-step online tutorials and programming workshops for readers to apply the knowledge learnt from this book.
- Quantum finance software development kit (QFSDK) is a C-library fully integrated with MT platform which consists of all related quantum finance and AI tools and functions for quantum finance developers to build their own quantum finance forecast and intelligent agent-based trading and hedging systems. In other words, this book can be also used as the guidebook and main reference to learn the basic concept and theory of quantum finance technology.

Zhuhai, China Raymond S. T. Lee

Acknowledgements

While it only required around 6 months to write this book, the whole journey of quantum finance—from seeking concepts and knowledge to the actual implementation—took me almost 30 years, started when I was still an undergraduate at HKU since 1986 studying quantum mechanics and general relativity courses to currently teach quantum finance to my fellow students at UIC.

I would like to express my gratitude to the following people for their support and assistance.

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Zhuhai, China
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Raymond S. T. Lee

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About the Author

Dr. Raymond S. T. Lee founder of quantum finance forecast center with over 20 years of IT consultancy, R&D experiences in AI, chaotic neural networks, intelligent fintech system, quantum finance, and intelligent e-commerce systems, had successfully commercialized his AI-fintech invention at business sectors in China and Hong Kong.

He attained his B.Sc. (Physics) from Hong Kong University in 1989, and M.Sc. (Information Technology) and Ph.D. (Computer Science) from Hong Kong Polytechnic University in 1997 and 2000, respectively.

After graduation from Hong Kong University, he joined the Hong Kong Observatory of the Government of the Hong Kong Special Administrative Region as a meteorological scientist on weather forecasting and developing numerical weather forecast system from 1989 to 1993.

From academic perspective, he had worked at the Department of Computing of Hong Kong Polytechnic University (HKPolyU) as Lecturer, and promoted as Assistant Professor in 2000 and Associate Professor in 2005, respectively. During this time, he had published over 90+ publications and author of six textbooks and monographs covering the fields at AI, chaotic neural networks, AI-based fintech systems, intelligent agent technology, chaotic cryptosystems, ontological agents, neural oscillators, biometrics, weather simulation, and forecasting systems.

From commercial perspective, he was invited to join Leanda Investment Group in China (2012–2017) as Group CTO and Chief Analyst to implement his self-invented and patented AI-fintech invention—quantum finance forecast system on major commodities in China for 1,000+ investors.

In March 2017, he set up the quantum finance forecast center (aka QFFC) (http://qffc.org), a nonprofit making, AI-fintech R&D, and worldwide financial forecast center, that aims at the R&D and provision of a wholly FOC and open platform for worldwide traders and individual investors to acquire free knowledge of worldwide 129 financial product forecasts based on the state-of-the-art AI, chaotic neural networks and quantum finance technologies. At present, QFFC has over 10,000+ registered worldwide members, which consists of worldwide professional traders,

quants, and independent investors from major fund houses and financial institutions using the free quantum finance daily forecasting services.

Upon the completion of the fully automated quantum finance forecast system, he joined Beijing Normal University-Hong Kong Baptist University United International College (UIC) in China as Associate Professor in 2018 to further his R&D works on quantum finance and to contribute his knowledge on quantum finance, AI-fintech, chaotic neural networks, and related intelligent forecast systems to the fellow students and the community in China.

Abbreviations

ANN	Artificial Neural Networks
CBTF	Chaotic Bifurcation Transfer Function
CDNONRS	Chaotic Deep Neuro-oscillatory Network with Retrograde Signaling
CNON	Chaotic Neural Oscillatory Network
CT1-FNON	Chaotic T1 Fuzzy Neuro-oscillatory Network
CT2TFDNN	Chaotic T2 Transient-Fuzzy Deep Neuro-oscillatory Network with Retrograde Signaling
CT2TFL	Chaotic T2 Transient-Fuzzy Logic
CT2TFLS	Chaotic T2 Transient-Fuzzy Logic System
CT2TFMF	Chaotic T2 Transient-Fuzzy Membership Function
CTU	Chaotic Transfer Unit
DNN	Deep Neural Network
EC System	Evolutionary Computing System
FFBPN	Feedforward Backpropagation Networks
FFS	Fuzzy Financial Signals
FFSCM	Fuzzy Financial Signals Crossover Module
FFSFEM	Fuzzy Financial Signals Fitness Evaluation Module
FFSMM	Fuzzy Financial Signals Mutation Module
FFSPGM	Fuzzy Financial Signals Population Generation Module
FFSV	Fuzzy Financial Signal Vector
FLS	Fuzzy Logic System
FOU	Footprint Of Uncertainty
FSGM	Financial Signal Generator Module
GA	Genetic Algorithms
HFAPT	High-Frequency Algorithmic Program Trading
IT2FLS	Interval Type-2 Fuzzy Logic System
IT2-FNN	Interval Type-2 Fuzzy-neuro Network
LORS	Lee-oscillator with Retrograde Signaling
MQL	MetaQuotes Language

MT4	MetaTrader4
NGPSM	New Generation Population Selection Module
PCA	Principal Component Analysis
QAOM	Quantum Anharmonic Oscillatory Model
QFFS	Quantum Finance Forecast Centre
QPL	Quantum Price Level
RMSE	Root Mean Square Error
STR	State Transition Region
SVM	Support Vector Machine
T2FL	Type-2 Fuzzy Logic
T2FLS	Type-2 Fuzzy Logic System
T2FMF	Type-2 Fuzzy Membership Function
TOP10-FFSSM	TOP-10 Fitness FFS Selection Module