Construction of Financial Risk Assessment and Quantitative Analysis Model

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Abstract: This paper addresses issues related to risk measurement, quantitative analysis, and model construction in financial markets by proposing a risk quantification analysis model based on financial engineering. First, a financial risk measurement calculation method is established based on financial risk assessment theories and methods, providing information on risk load application, key parameter selection, and feasibility verification of the assessment model. Secondly, to eliminate uncertainty in risk assessment, a strategy for model quantification and parameter setting is proposed. Furthermore, a quantitative analysis model is constructed, taking into account both normal and extreme market conditions to more accurately describe financial risk. Finally, a financial risk quantification analysis system is developed based on this algorithm, and the effectiveness of the proposed algorithm is demonstrated through risk analysis under normal market conditions, extreme market conditions, and free boundary conditions.

1. Introduction

Financial risk assessment, known for its excellent risk prediction capabilities, high market adaptability, and rapid crisis response, is widely applied in banking, securities, insurance, and other fields[1]. In practical financial risk management applications, risk assessment often relies on model information. If the model parameters are inaccurate, it can lead to deviations in risk predictions. Moreover, the quality of risk assessment models affects the speed of risk management response, and the assessment results are also influenced by market volatility. Therefore, the accuracy of financial risk assessment is of significant practical value for achieving risk control and enhancing financial stability.

Traditional risk assessment algorithms primarily rely on statistical models for risk measurement, which are divided into qualitative and quantitative analysis methods[2]. These algorithms require substantial historical data support. Although statistical models are the most commonly used models in financial risk management, they do not accurately describe market dynamics, leading to issues such as low prediction accuracy and poor risk measurement performance in traditional risk assessment algorithms. Hence, it is essential to study the risk characteristics of financial markets to establish more precise risk quantification analysis models.

To address the current issues in financial risk assessment, such as inaccurate parameters, prediction deviations under normal and extreme market conditions, and low assessment accuracy, this paper proposes a risk quantification analysis algorithm based on financial engineering[3]. First, the theories and methods of financial risk assessment are reconstructed, and accurate risk measurement information is obtained using financial engineering principles based on this model. Next, the quantification model and parameter settings are revised to derive a risk load application strategy, followed by the proposal of a quantification analysis algorithm that comprehensively considers the impact of market conditions, using the revised model for full-spectrum risk analysis. Furthermore, more precise modeling is conducted by combining experimental phenomena under normal and extreme market conditions, and the proposed algorithm is employed to construct a risk quantification analysis model. Finally, simulation and experimentation are conducted to validate the algorithm, demonstrating the effectiveness of the proposed solution.

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2. Financial Risk Assessment Theory and Methods

2.1. Financial Risk Measurement and Calculation Methods

The Value at Risk (VaR) algorithm is a statistical measurement method used to address financial risk assessment issues[4]. In the VaR algorithm, a financial product portfolio consists of multiple assets, and by conducting multiple calculations, the risk value of the asset portfolio is determined. Below is an introduction to the calculation process and workflow of the VaR algorithm.

Each asset has value volatility and market correlation. The value volatility of an asset represents a risk measure, including the amplitude of asset price fluctuations and the market conditions under which transactions are executed. The market correlation of an asset represents the correlation coefficient used in constructing risk measures, including the correlation coefficient between asset price changes and overall market changes.

Assume the number of assets is N, and the number of market conditions is M. At this time, the number of market condition sequences that can be assigned to the VaR calculation of the assets is M. Let the i-th asset be denoted as A_i, and its value volatility V_i is expressed as

$$V_i = (V_{i1}, V_{i2}, \ldots, V_{iN}) \tag{1}$$

Where V_{ij} represents the asset i's price fluctuation sequence sorted by the starting time of market conditions j, V_{ij} represents the price fluctuation of asset i under the j-th market condition that starts execution, and V_{ij} represents the price fluctuation sequence of asset corresponding to the execution of market condition, as well as the set of market conditions, which indicates the asset price fluctuation sequence corresponding to the j-th market condition that begins execution. For example, in the market condition allocation scheme in V_i, V_{i1} represents the price fluctuation of asset i under the first market condition, and V_{i2} represents the asset price fluctuation sequence composed of market conditions 1 and 2, which is executed under market condition 2.

The market correlation R_i of asset A_i is expressed as

$$R_i = (P_{ij}, Q_{ik}) \tag{2}$$

Where P_{ij} is a matrix with $N+1$ rows and N columns, representing the selection probability of market conditions. P_{ij} represents the probability of choosing market condition j as the next execution market condition after completing market condition i. When $i=0$, P_{ij} represents the probability of choosing market condition j as the first execution market condition. Q_{ik} is a matrix with N rows and N columns, representing the selection probability of assets for executing market conditions. Q_{ik} represents the probability of choosing asset k to execute market condition i. The historically optimal market correlation found for each asset A_i is denoted as $R_{i,opt}$.

2.2. Interaction between Quantitative Analysis and Risk Assessment

Quantitative analysis is a crucial standard in financial risk assessment, serving as a numerical representation of risk conditions. Risk and quantification are discussed from perspectives such as probability and statistics, offering different definitions of risk assessment. Some scholars also consider risk assessment as the extent of risk management or the quantitative expression of risk control. Quantitative analysis is inherently more objective to some extent and is part of financial science aimed at risk measurement. The history of quantitative analysis can even be traced back to the early stages of financial markets, with its main activities including risk measurement, model construction, and parameter estimation. The concepts and methods of risk assessment are closely related to the stability of financial markets. Through quantitative analysis, risk assessment has become a significant responsibility in financial management. The primary contribution of quantitative analysis theory in the modern financial era is the provision of mathematical tools for risk measurement. Thus, the initial focus of quantitative analysis concepts was primarily on the numerical measurement based on risk standard attributes. The interactive effects of quantitative analysis and risk assessment are illustrated in Figure 1.

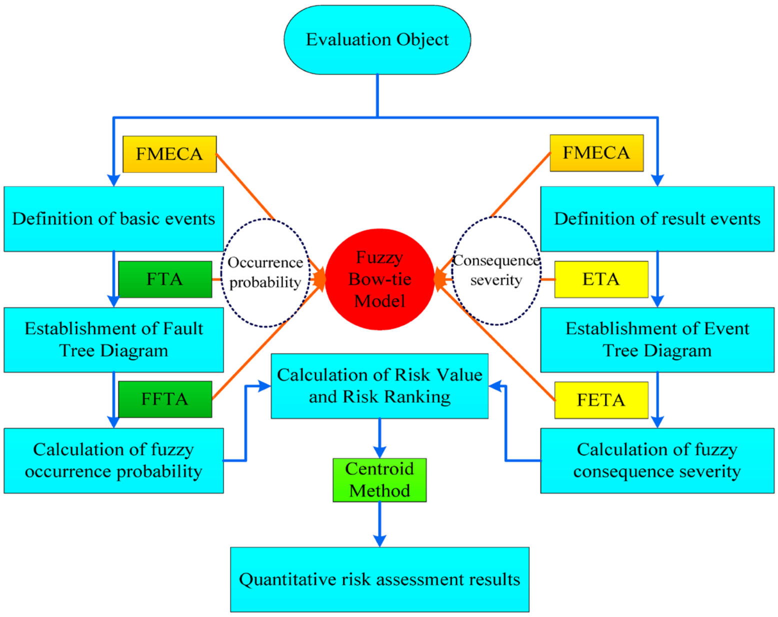

Figure 1: Interaction between quantitative analysis and risk assessment.

2.3. Feasibility Verification of Evaluation Models

Compared to traditional risk assessment methods, modern evaluation models emphasize the interrelationship between risk factors and the market environment, characterized by their dynamic and adaptive nature[5]. Although some scholars question whether model predictions have a direct relationship with actual market conditions, the majority advocate that modern evaluation models can rationally assess financial risk. Some scholars have proposed a capital asset pricing model that incorporates market factors and individual risk elements, which has since become a typical tool for financial risk assessment, leading to the development of the concepts of systematic and unsystematic risk. These scholars argue that risk assessment possesses objectivity and is a "scientific art." Only when a model accurately reflects market dynamics can risk assessment be effective. Consequently, effective risk assessment relies on the result of model verification. Moreover, some scholars summarize risk assessment as statistical models, which include prediction models based on historical data and simulation models based on market environments. The former focuses on historical data analysis, while the latter emphasizes market environment simulation, i.e., real-time risk assessment. Despite experiencing some practical failures, modern evaluation models, from a long-term perspective, can enhance the efficiency of risk management. As a result, the concept of model verification has gradually become a consensus in financial research and practice.

3. Construction of Financial Risk Quantitative Analysis Models

3.1. Overview of Financial Engineering

The essence of the concept of financial engineering centers on the issue of financial risk management. Financial engineering represents the application of engineering thinking in the financial domain, which emerges as a new alternative framework to overcome the deficiencies of traditional financial theories, entering the research perspective as the financial engineering framework. The basic philosophy of this framework is that financial engineering should ensure the effective implementation of risk management; set professional standards for the output of financial products and services; "capture" market risk through techniques such as mathematical modeling and statistical analysis; and employ quantitative methods to measure financial uncertainty. The financial engineering framework reconstructs financial theory and practice by emphasizing the enhancement of risk control capabilities and the construction of stability, profitability, liquidity, and risk resistance of financial products[6].

3.2. Model Quantification and Parameter Settings

The overall process of the financial risk quantification analysis algorithm is illustrated in Figure 2. Initially, the asset portfolio is initialized, followed by multiple iterations to find the optimal solution for risk management. All risk solutions identified by the financial risk quantification analysis algorithm are stored in a solution set.

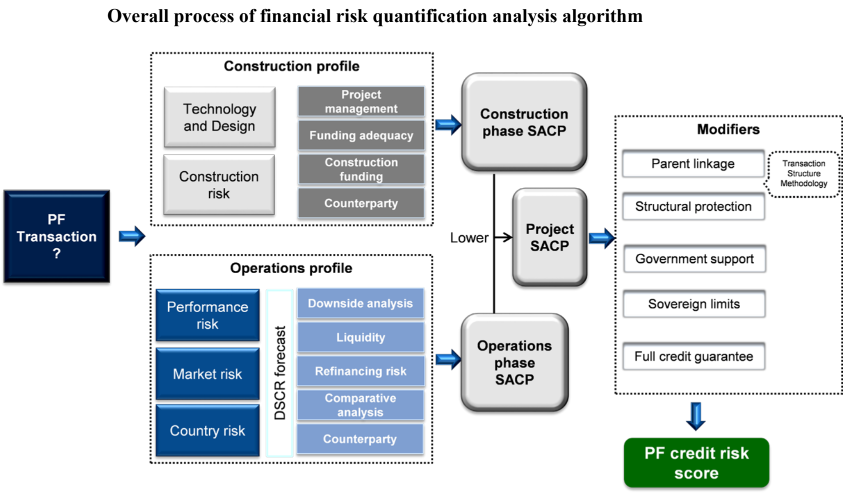

Figure 2: Overall process of the financial risk quantification analysis algorithm.

During each iteration, the financial risk quantification analysis algorithm first updates all assets. For each asset, the risk value of the asset portfolio under current market conditions is assessed for its fitness value. Then, all target values are normalized according to Equation (1). Subsequently, according to Equation (2), the asset portfolio with the best performance is selected as its risk target:

$$f_{ij}' = \frac{f_{ij} - f_{j\min}}{f_{j\max} - f_{j\min}} \tag{3}$$

$$T_i = \arg\max_j f_{ij}' \tag{4}$$

Where f_{ij} is the j-th target value of asset i under market condition ($j \in [1, N]$, where N is the number of targets). $f_{j\min}$ and $f_{j\max}$ are the minimum and maximum target values on the j-th target within the solution set. T_i is the index of the risk target for asset i.

Subsequently, based on the risk targets, all risk solutions in the solution set are ranked. From these, λ risk solutions that are superior to asset i are selected as the candidate solution set. A risk solution is then randomly chosen from the candidate solution set as the learning sample L. Asset i updates its risk attributes based on the historical optimal risk solution i and the current risk solution:

$$x_{ik}^{t+1} = x_{ik}^{t} + \phi_1 \times (\zeta_1 - x_{ik}^{t}) + \phi_2 \times (\zeta_2 - x_{ik}^{t}) \tag{5}$$

Where x_{ik}^{t+1} represents the k-th risk attribute of asset i after the $t+1$-th iteration. x_{ik}^{t} denotes the value after the t-th iteration, and ϕ_1 and ϕ_2 are the learning rates. ζ_1 and ζ_2 signify the historically optimal risk solution and the risk attributes of the learning sample, respectively. Each risk attribute of the same asset employs two different learning rates. The arithmetic operations in Equation (5) are realized through the iterative process.

Subsequently, asset i constructs a new feasible risk solution based on the updated risk attributes. In each step of the feasible risk solution construction, task allocation is updated first according to the task selection probability, followed by updating the asset combination according to the asset selection probability, until the task requirements are satisfied. These steps are repeated until all tasks are allocated. Afterward, the new risk attributes of the assets are evaluated, and the historical optimal risk solution and solution set are updated. Once all assets are updated, optimization methods are employed to further enhance the quality of the risk solution. When the number of iterations reaches the specified maximum number of iterations, terminate the financial risk quantification algorithm and output the solution set as the risk solution set found by the algorithm.

3.3. Application of Risk Load

The application of risk load is a key component in the construction of financial risk assessment models, emphasizing the impact of risk factors on asset portfolios. It directly reflects the risk conditions of market volatility and asset correlation through mathematical models[7]. The development of risk load application methods is gradually taking shape, with elements such as risk factor selection, load calculation, and various evaluation systems gaining increasing attention. However, in practical applications, some financial institutions remain at a stage of simple simulation, which contradicts the logical framework and generation mechanisms of complex market environments. This discrepancy raises issues regarding the accuracy and effectiveness of risk assessments. An illustration of risk load in financial risk assessment models is shown in Figure 3.

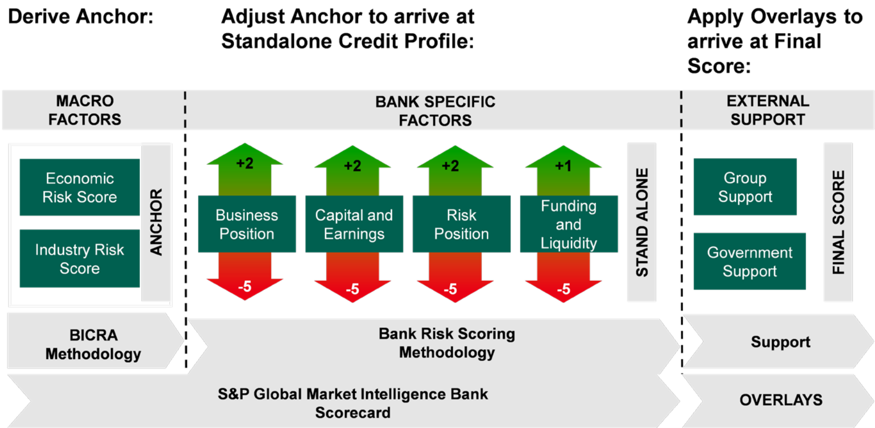

Figure 3: Schematic diagram of risk load in financial risk assessment model.

3.4. Key Detail Parameter Selection

From the perspective of financial risk assessment, the selection of key detail parameters is a foundational aspect of model construction and a core indicator of the accuracy of risk assessment. Therefore, parameter selection is primarily driven by risk factor analysis. Key detail parameters are the main components of risk assessment models and serve as the principal control elements in quantitative risk analysis. Currently, parameter selection is enhanced from a risk control perspective to improve model precision, primarily through three approaches: The first step is parameter optimization: It is necessary to clarify the optimal matching of parameters between market environment and asset characteristics. The second step is parameter standardization. They should establish standards for parameter selection and evaluation, and make these parameter standards publicly available to the industry to achieve standardized control of parameter selection. The third step is redesigning internal processes for parameter selection. In recent years, financial institutions and others have employed technological innovations to enhance the quality of parameter selection and improve the efficiency of risk assessment. However, compared to ideal models, the precision of current parameter selection still requires further improvement.

4. Quantitative Analysis of Financial Risk under Different Parameter Settings

4.1. Experimental Scheme Design

This section presents the mathematical modeling for the quantitative analysis of financial risk.

Given a set of N assets $A=\{A_1,A_2,...,A_N\}$ and a set of M market conditions $C=\{C_1,C_2,...,C_M\}$, the definitions are provided as follows:

1) Assets: The i -th asset is denoted as $A_i : A_i=(V_{i1},V_{i2},...,V_{iM})$, where V_{ij} represents the price fluctuation of asset i under the j -th market condition, and V_{ij} represents the volatility of the asset i 's value under market condition j. In the context of smart manufacturing, the different value volatilities of an asset refer to its value fluctuation under various market conditions, indicating the number of different value volatilities it can provide.

2) Market Conditions: The j -th market condition is denoted as C_j, defined as $C_j=(P_{j1},P_{j2},...,P_{jN})$, where P_{ij} indicates the probability of price fluctuation of asset i under market condition j, P_{ij} represents the standard deviation of price fluctuation, P_{ij} is the correlation coefficient of price fluctuation, and P_{ij} denotes the influence degree of price fluctuation of asset i on i under market condition j.

3) Asset Portfolio: Each market condition can be executed by an asset portfolio, composed of a single asset or multiple assets. A maximum of N portfolios can be formed from N assets. The set of these portfolios is denoted as $A=\{A_1,A_2,...,A_N\}$, with the i -th portfolio denoted as A_i, defined as follows: $A_i=(V_{i1},V_{i2},...,V_{iM})$, where V_{ij} represents the price volatility of asset j in portfolio i.

4) Execution Time of Asset Portfolio: The execution time of an asset portfolio under a market condition is denoted as T_{ij}, defined as:

$$T_{ij}=V_{ij}\times P_{ij} \tag{6}$$

Where T_{ij} represents the execution speed of asset portfolio i under market condition j. This formulation is based on real-world applications, such as in smart manufacturing, where multiple assets collaborate to execute market conditions. The j -th value volatility of an asset portfolio refers to the total value volatility speed of assets executing the j -th market condition, and the execution time is determined by the slowest market condition execution speed.

5) Completion Time of Asset Portfolio: The completion time of the market condition for an asset portfolio is denoted as T_i, defined as:

$$T_i=\sum_{j=1}^{M}T_{ij} \tag{7}$$

Where T_i is the execution time of all market conditions for portfolio i.

Based on the above definitions, the mathematical model for the quantitative analysis of financial risk with market condition constraints is formulated as follows:

$$\min T_i(A) \;=\; \min\max T_i \tag{8}$$

Where A is a feasible solution to the problem, T_i is the objective function (the maximum completion time of all market conditions), C is the constraint between market conditions and asset portfolios, P is the constraint between market conditions and asset portfolios, and V is the constraint of market conditions (the time when market conditions start to execute is greater than the completion time of all asset portfolios).

4.2. Risk Analysis under Normal Market Conditions

Indeed, financial risk assessment is an indispensable "standard tool" in risk management. In the mechanism of risk management, quantitative analysis serves as a standard, effective tool for risk assessment and plays a crucial role in risk management. This makes quantitative analysis not only a concept of risk management but also one of risk control. Consequently, financial risk management, primarily driven by "quantitative analysis," has become the core mechanism of risk management. The practical evolution of financial risk management generally follows a path gradually formed on the basis of risk assessment, despite this path involving attempts at risk management. From risk assessment to risk management, risk consistently centers around risk control. Although risk assessment should aim at risk management to meet the requirements of risk control, a dilemma arises when risks are amplified, leading to the phenomenon of risk management. Overall, there remains room for improvement in financial risk assessment concerning risk management, and its risk control also requires further enhancement, which is a significant task for financial risk assessment. Risk analysis under normal market conditions is illustrated in Figure 4.

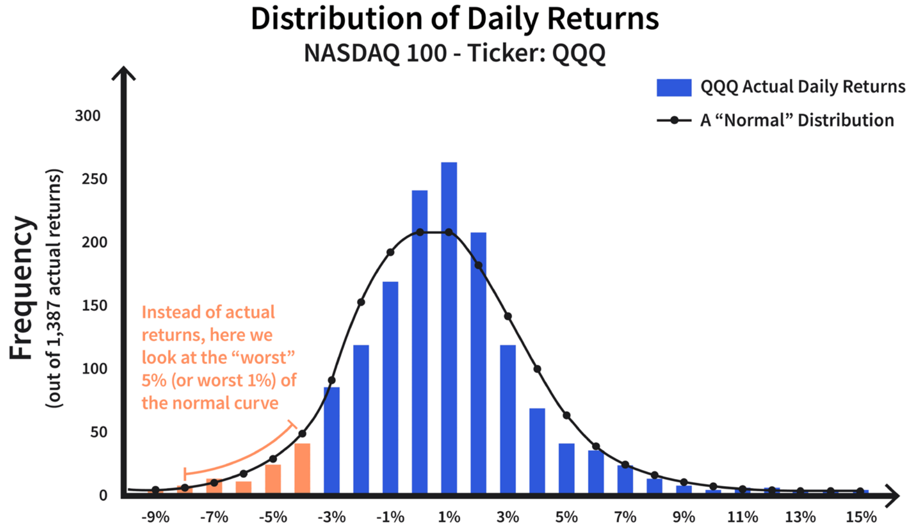

Figure 4: Risk analysis under normal market conditions.

4.3. Risk Analysis under Extreme Market Conditions

From a historical perspective, risk assessment has long constrained the ability to manage risk. Since the 21st century, quantitative analysis, integrating information technology, has reshaped risk management through data mining[8]. However, the drawbacks of traditional risk assessment models continue to limit the accuracy of risk management. This is not only due to the incompleteness of data but also due to the impact of market complexity, indicating that risk assessment still needs improvement. Within the framework of risk management, quantitative analysis is regarded as a direct approach to risk control. Yet, the actual effectiveness of data-driven quantitative analysis in risk control remains debatable. Additionally, difficulties in data processing lead to a lack of precision in risk assessment. Consequently, quantitative analysis does not always achieve the objectives of risk control. It is evident that quantitative analysis is not only a technical challenge but also faces issues in risk management.

4.4. Risk Analysis under Free Boundary Conditions

From the perspective of risk management, risk assessment fails to accurately provide the risk information needed for effective risk management. Risk management primarily evaluates risk assessment based on satisfaction; however, risk assessment lacks relevant information and mechanisms for risk management. The core of this issue may lie in the imperfections of risk assessment. In risk management, risk assessment is often described as "risk identification," and its ability to identify risks directly reflects the effectiveness of risk management. Nevertheless, risk assessment largely concerns information such as risk indicators and is relatively scarce. Typically, risk assessment is difficult to obtain or measure. Asymmetric risk information and the imperfections in risk assessment directly lead to obstacles in risk management.

5. Conclusions

This paper proposes a novel financial risk assessment method based on the issue of financial risk quantification analysis. Initially, we reconstruct the theory and methodological model of financial risk assessment, leveraging key detailed parameter information from these models. Subsequently, we refine the quantitative model and parameter settings, applying principles of financial engineering to conduct a quantitative analysis of financial risk. Following this, we construct a financial risk quantification analysis model based on experimental observations, utilizing financial engineering algorithms to complete the analysis. Theoretical analysis, simulations, and experimental results demonstrate the effectiveness of the proposed financial risk assessment method.

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