Algorithms of Game Theory, VAR Model and Neuron Model and their Applications to Chinese regional finance

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Abstract

As a big developing country with great differences in the economic regions, the main character of economic and financial situations in China is the unbalanced development. In recent years, the enlargement of unbalanced development between different regions has become a limiting factor to the harmonious development of China. The tendency of financial development pays more attention to enlargement of the gross quantity than to the improvement of quality. This situation would be more seriously in the period of the ending of the protection period after entering the WTO. How to implement the idea of scientific development in finance, and exert function in development of regional economic, are a difficulty we faced. To solve these problems, we need to improve financial operation efficiency and pay attention to the harmony of every scale of financial system. However, policies of government always neglect the differences in regions, which will affect not only regional economic development but macro-control and financial reform.

In the situation mentioned above, this thesis discusses a harmonious financial development in Chinese regions using Game Theory, VAR model, and neuron model. One aim of this study is to find out whether the development way of regional finance in China fulfills the common relation between finance and economy from the theoretical and empirical aspects. The other aim is to provide policymakers with theoretical evidence and advices to reduce the difference in the levels of development between different regions and also to stimulate a harmonious development.

There are five parts in this thesis. The first part is introduction about the Chinese financial system and regional finance in China. The second part is game theory used in

Chinese financial systems. The third part is VAR model used in regions of China. The four one is the analysis of neuron model used in Chinese regional finance, and the last one is conclusion of the analysis.

Key words*: Game theory, VAR model, Neuron model, Regional finance*

Chapter 1

Introduction

1.1 The Chinese financial system

The financial system plays an important role in China's economic expansion. Financial systems can be organized in multiple ways that vary with respect to governments, banks, other financial intermediaries, and stock and bond markets. The optimal financial system for a given nation depends on its stage of development, its political system, its social values, and various idiosyncratic factors. Rapid economic growth has been enough to be supported by China's financial system [1]. We arrive at some results about China's financial system and its future development. First, compared with the banking systems and financial markets of developed and developing countries, a large but underdeveloped banking system have controlled China's financial system, and the banking system is primarily dominated by the four largest state-owned banks, which carry a number of non-performing loans (NPLs). In order to improve the banking system and reduce the number of the major banks' NPLs to a regular level, reforming China's financial system is very significant. The main obstacle to reducing NPLs and improving the efficiency is a lack of accurate bank-level data, which should be encouraged so there is more information about the development of non-state banks system. The banking sector becomes more competitive along of the increasing number of domestic and foreign banks systems, and the efficiency of state-owned banks can be improved [2].

Second, when non-government organizations and investors will have the majority of state-owned banks' assets, the increasing privatization of those banks will not be completed. Under state ownership, banks will not have the proper incentives when selecting borrowers; moreover, borrowers will not have proper incentives when selecting investment projects. Consequently, there will be many new NPLs in the state-owned banks' network when the government eliminates old NPLs from bank's books. To improve their capital reserves and balance sheets, the Chinese government and some banks have been injecting foreign reserves into the largest state-owned banks, which will become listed companies. According to the official data, it can suppose there are a large share of the existing NPLs for the government [3]. However, the official data may not significantly estimate the number of NPLs, leading to the belief that the basic solution to NPLs involves reforming state-owned banks and improving the banking sector.

In 1990, China established two domestic stock exchanges: the Shanghai Stock Exchange (SHSE) and the Shenzhen Stock Exchange (SZSE). However, those two stock exchanges' scale and importance are smaller than the scale and importance of the banking sector [4]. Moreover, because the financial markets are highly uncertain and influenced by internal deal, they have been ineffective in allocating economic resources. Going forward, China's financial markets are likely to bring an increasingly significant effect in the economy, and developing those financial markets is China's long-term aim. We propose that there are several ways to increase the scope and size, and efficiency of China's financial markets. Specifically, the environment should be improved (particularly with respect to legal protection from investors and trading laws) and institutions that govern contract enforcement should be developed. Second, by announcing and implementing plans, the large number of shares held by various government factor in listed companies, should be rut down through a slow sell-off.

Third, more professionals should be trained. Fourth, in strengthening the corporate governance of listed companies and improving the efficiency of financial markets domestic financial intermediaries will play an important role. Those intermediaries should be encouraged. Finally, it should be developed about new financial markets and goods [5].

According to Allen and Qian (2005), in the light of supporting the economy's overall growth, the most useful point of the financial system is not stock markets or the banking sector, but instead the factor of alternative financial channels and various forms of coalitions in local governments, investors and companies. Many financial channels are supported by various governance mechanisms. Together with those financial methods, the government has supported the development of a "hybrid sector" of non-listed and non-state companies with other types of ownership structures. Although the hybrid sector contains owned companies, it is not exclusively populated by such companies. For the following reasons, state-owned enterprise are also included in the mix sector. First, despite the state-owned stock, property rights and ambiguous ownership structures, the operation of companies owned by local governments are more similar to privately owned companies than to state-owned companies. Second, in some of these companies, the state-owned stock has been privatized. The mix sector is more developed than the state sector is, and the former contributes to economic development. It should be encouraged about these alternative channels and mechanisms, and they can co-exist with the markets and banks [6].

Finally, in my opinion, one challenge experienced by the Chinese financial system is the need to get rid of financial crises that can seriously harmful both social development and economic stability. The system needs to prevent traditional financial crises in China.

Banking sector crises can result from the increasing gather of NPLs and an unexpected fall in bank profits whereas crashes from uncertain property fantasy in the real-estate market. Simultaneously, the system must be vigilant about new types of financial crises in China such as the “twin crises” which happened in some Asian countries in 1990s. “Twin crises” involve a banking-sector/ stock-market crisis, combined with a foreign-exchange crisis. When China joined the World Trade Organization (WTO), it brought not only cheap foreign products and technology but also dramatic decline in price [7].Relying on how the central bank and the government controlled the process of revaluation, they attempt to defend the currency peg, potentially causing a classic currency crisis that can cause a banking crisis if large withdrawals are made.

1.2 Regional finance in China

In recent years, the role of money and financial markets in the regional economy has been getting more and more attention. This has been an interesting topic in the US literature, reflecting the regional attentions of a federal state. Currently, the related literature is sufficiently enormous and diverse.

Most of the contributions to the literature have emerged from macro-monetary economics. There is a shortage of interest in financial variables, and explaining regional income differences it has often caused that regional economists underestimated the force of money and financial factors in the explanation of regional-income differences. To conduct an entire analysis in real terms, regional economists often assume money neutrality.

Because regional weighting mirrors regional economic reality, differences in monetary variables have been considered exogenously determined. Therefore, monetary flows and money have been considered as resulting from regional economic differences instead of from a factor that plays a role in the widening of those differences. There is a huge empirical monetary literature, meaning that the literature has regional application and uses a regional data set. There is an important parallelism between works addressing the effect of monetary policy on the national economy and works addressing the regional impact of that policy.

1.3 Outline of this thesis

This thesis has five parts. Chapter1instroduced the Chinese financial system and Chinese regional finance. In Chapter 2, game theory is described in detail and a game-theoretic approach for the system of incentives and restraints present in China's financial systems is analyzed. In Chapter 3, the VAR model is described in detail and the effect of interest rates on real-estate prices in various regions of China is analyzed. In Chapter 4, the neuron model with dendritic nonlinearity is proposed for analyzing the main effective factor of FIR in Shanghai. Chapter 5 provides conclusions about the results of three contemporary mathematics methods to promote the development of regional finance in China.

Chapter 2

Game Theory

2.1 Introduction to Game Theory

Game theory is based on the study of mathematical models of conflict and cooperation between intelligent rational decision-makers. For analyzing situations in which two or more individuals make decisions that will influence one another's welfare, game theory provides general mathematical techniques [8]. Game theory is primarily used in economics, computer science, biology, logic and so on [9].

There are two main branches of game theory: cooperative game theory and non-cooperative game theory. A cooperative game is one in which players can make enforceable contracts [10]. Accordingly, it is a competition that involves unified players, not individual players. A non-cooperative game is one in which players cannot make enforceable contracts outside of those specifically modeled in the game [11]. Accordingly, such contracts are not defined in these games. In a non-cooperative game, players do not cooperate; any cooperation that does occur must be self-enforcing within the game [12].

Economic theory has three other main branches in addition to game theory: decision theory, general equilibrium theory and mechanism design theory [13].

Decision theory can be considered a theory of a one person-game. The focus is on preferences and the formation of beliefs. It suggests that preferences can be considered as the maximization of the expected value in risky alternatives. In decision theory, utility may rely on numbers things; on the other hand, it often relies on money income for economists. In decision analysis decision theory is usually used, and it shows the best way to obtain information before making a decision [14].

General equilibrium theory can be regarded as a specialized branch of game theory that addresses production and trade, along with a large number of individual producers and consumers. This theory is widely used in the macroeconomic analysis of basic economic policies not only to study exchange rates, interest and other prices but also to analyze stock markets. In recent years, political economy has been combined with general equilibrium theory. Whereas government and voting-behavior incentives are analyzed using game theory, it is general equilibrium theory that models game theory involving the private sector. Issues studied under the rubric of general equilibrium theory include the role of international trade agreements (for example, in the European Union), trade policy and tax policy [15].

Mechanism design theory seeks to determine the consequences of various types of rules. Naturally, it relies heavily on game theory. Whether determining how to maintain incentives, achieve other goals, or design auctions to maximize revenue, the issues include wage agreements and compensation designs that effectively spread risk [16].

2.2 The History of Game Theory

Before modern game theory, early discussions of its concepts involved two-person games. The first discussion of game theory happened in a letter written by James Waldegrave in 1713[17]. In that letter, Waldegrave provides a minimax mixed-strategy solution to a two-person version of the card game le Her, an 18th century gambling game, in 1787, James Madison performed a game-theoretic analysis of how states can be thought to express under various taxation systems [18,19]. In 1913, Ernst Zermelo proved that the optimal chess strategy is strictly determined. He believed that the optimal chess strategy is a strictly determined game and a two-player zero-sum game. The value of a strictly determined game is equal to the value of the equilibrium outcome [20-24]. This work paved the way for more general theorems [25].

Before John von Neumann’s 1928 a paper on the subject, game theory was not a unique field [26]. Modern game theory began with the existence of a mixed-strategy equilibrium in two-person zero-sum games and its proof by John von Neumann. That original proof used a Brouwer fixed-point theorem, which became a way in both game theory and mathematical economics. In 1944, John von Neumann and Oskar Morgenstern analyzed several-players cooperative games [27]. In [28], the book includes the way for finding solutions to two-person zero-sum games and provides a theory of expected utility, which allows mathematical economists and statisticians to treat decision-making under uncertainty. Von Neumann and Morgenstern showed that if a player can always arrange such fortuitous alternatives in the order of his preferences, then for each alternative it is possible to assign a number or numerical utility expressing the degree of the player's preference f-or that alternative. Although the assignment is not unique, any two such assignments must be related by a linear transformation.

During the period described below, work on game theory was primarily focused on analyzing optimal strategies for groups [29]. In the 1950s, cooperative game theory was developed by many scholars. In the 1970s, game theory was explicitly applied to biology.

In the 1950s, the first mathematical discussion of the prisoner's dilemma occurred, and an experiment was undertaken by the notable mathematicians Merrill M. Flood and Melvin Dresher. That experiment proved that there was at least one set of mixed methods that mapped back into themselves. Around that time, John Nash developed the Nash equilibrium, a criterion for the mutual consistency of players' strategies that applied to a wider variety of games than the criterion proposed by von Neumann and Morgenstern. During this time, repeated games, fictitious play, the extensive form game, and the Shapley value were developed. Besides, the first applications of game theory to philosophy and political science appeared.

In 1965, Reinhard Selten presented his solution concept of the subgame perfect equilibrium, which further refined the Nash equilibrium. A subgame perfect equilibrium are fines the Nash equilibrium used in dynamic games. A strategy profile is a subgame perfect equilibrium if it represents a Nash equilibrium of every subgame of the original game [29,30]. In 1967, John Harsanyi presented the concepts of Bayesian games and complete information. Bayesian games are games which information about the other players' characteristics is not complete, including information about those players' payoffs. Complete information is a term used in economics and game theory to describe an economic game or situation in which knowledge about other market participants or players is available to all participants, and every player knows the payoffs and strategies available to other players [31].

In the 1970s, because of the work of John Maynard Smith and his evolutionarily stable strategy, game theory was used in biology. In 1973 John Maynard Smith formalized a central concept in evolutionary game theory called the evolutionarily stable strategy (ESS). An evolutionarily stable strategy (ESS) is a strategy which cannot be invaded by any alternative strategy that is initially rare if adopted by a population in a given environment [32]. The ESS is used in behavioral ecology and economics, game theory, anthropology, philosophy, evolutionary psychology, and political science. It is not intended to address the possibility of gross external changes to the environment that result in new selective forces [33,34].

Game theory has been widely recognized as an important tool in many fields. In 2005, game theorists Thomas Schelling and Robert Aumann followed Nash, Selten and Harsanyi as Nobel laureates. Thomas Schelling worked on dynamic models that were early examples of evolutionary game theory. Evolutionary game theory (EGT) is the application of game theory to evolving populations of life forms in biology. EGT differs from classical game theory by focusing on the dynamics of strategy change as influenced not only by the quality of the various competing strategies but also by the effect of the frequency with which those various competing strategies are found in the population [34,35].

In 2007, Leonid Hurwicz, together with Eric Maskin and Roger Myerson, was awarded the Nobel Prize in Economics for having laid the foundations of mechanism design theory. Mechanism design is an engineering approach to designing economic mechanisms or incentives, toward desired objectives in strategic settings in which players act rationally. Mechanism design theory has broad applications in economics and politics, including auctions, markets, voting procedures and networked-systems. Mechanism design theory studies solution methods for a class of private-information games. Leonid Hurwicz explained that when the mechanism is the unknown, the goal function is payment in a design problem, and therefore, the design problem is the inverse of traditional economic theory, which is typically devoted to the analysis of the performance of a given mechanism [16]. Simultaneously, Leonid Hurwicz presented and developed the concept of incentive compatibility. Roger Myerson presented the notion of a proper equilibrium, which refines the Nash equilibrium and further refines the trembling hand perfect equilibrium by assuming a significantly smaller probability of that more costly trembles than less costly ones [9].

In 2012, Alvin E. Roth and Lloyd S. Shapley were awarded the Nobel Memorial Prize in Economic Sciences for the theory of stable allocations and the practice of market design. Alvin E. Roth has made significant contributions to the fields of experimental economics, market design and game theory, and is known for his emphasis on applying economic theory to solutions for real-world problems [36,37]. Lloyd S. Shapley presented the Shapley Shubik power index for weighted or block voting power, the Bondareva Shapley theorem, stochastic games, the Gale Shapley algorithm for the stable marriage problem, the Aumann Shapley pricing, and so on [38].

2.3 The application of Game Theory in Chinese financial systems

Currently, the most important issue with respect to financial institutions is how to motivate staff without providing perverse incentives. For example, with the implementation of a proper incentive system, staff will be motivated via their self-interest to create financial innovations to increase price and hedge risk. However, this system must also be designed with checks and balances in mind because it is very easy to institute a system in which perverse incentives drive individual behavior. In an effort to modernize the Chinese financial system, it is important to understand the underlying mechanism by which people respond to incentives to design better compensation schemes that maximize innovation. Using game theory, it is possible to analyze the interplay between these two drivers of human action. From this analysis it becomes possible to design better ways of compensating staff to curb undesirable behavior in the financial industry while promoting innovation within the field.

An alternative incentive system utilizes financial incentives in which employees can be rewarded with salary changes, at-risk bonuses and equity in the company. In this system, salary and benefits are usually fixed, whereas at-risk bonuses are evaluated and paid over a certain interval of time. Finally equity is provided as a long-term incentive both to keep top performers and to align these individuals' incentives with the company's performance. This system has proven to be the most effective in driving innovation, especially in the financial industry [39]. However, the system can lead to the emergence of perverse incentives in which individuals pursue short-term individual gain via excessive risk taking at the cost of long-term sustainable growth. To better understand this system, a static game model can be utilized to assess the relative contribution of each individual aspect.

2.3.1 Quantification of Long-Term and Short-Term Incentives

The first step is to quantify the sum of the long-term and short-term incentives. This can be well modeled via Equation 2.1:

$$Y_{t,s} = \partial_t + S_s \partial_{t,s} - L_s \partial_{t,l} + \varepsilon \tag{2.1}$$

In Equation 2.1, S_s is the coefficient that denotes the short-term performance of firms attributable to their managers' behavior. L_s represents the short-term cost imposed by long-term behavior, a_t represents general behavior during a financial institution's day to day operation, $a_{t,s}$ represents short-term behavior that will benefit short-term gain but damage long-term gain, $a_{t,l}$ is long-term behavior that will increase the long-time income of financial institutes in long-term while increasing their short-time management costs. Finally, two boundary conditions exist $S_s>0$, $L_s>0$.

This equation can be extended (as in Equation 2.2) through the incorporation of terms that reflect short-term behavior that leads to negative effects in the long term and long-term behaviors that lead to short-term losses. This is done by subtracting the product of S_l, which represents coefficient of managers' short-term behavior and L_s, which represents long-term loses caused by long-term behavior.

$$Y_{t,l} = \alpha_t + S_s \alpha_{t,s} - S_l \alpha_{t,s} + L_l \alpha_{t,l} - L_s \alpha_{t,l} + \varepsilon \tag{2.2}$$

Additional boundary conditions of $S_l>S_s>0$ means that under managers' short-term behavior, the long-term negative effect is greater than the improved short-term performance. L_s is the coefficient of the long-term effect led by managers' long-term behavior, $L_l > L_s > 0$ means that under managers' long-term behavior, the long-term effect is greater than the short-term cost.

2.3.2 Optimal Selection and Equilibrium

Assume that the pay of individuals is ω. The revenue function of owners equals the long term revenue of financial institutions minus cost, $\pi_t = Y_{t,l} - \omega_t$. Revenue attributed to the individual equals the income of individual minus the individual's cost caused by the individual's behavior, $X = \omega - c(a)$, where the cost function c consists of functions a_t, $a_{t,s}$, and $a_{t,l}$, which represent short-term, day to day, and long-term behaviors [40].

To find the equilibrium behavior of a financial institution's owners, those owners are assumed mean risk-neutral. Thus, using Equation 2.3, it is possible to find equilibrium behavior:

$$MaxE(\pi) = MaxE\left(y_{t,l} - \omega\right) \tag{2.3}$$

Risk-neutral means that expectations of income utility equal the expected income, i.e., $E(u(x)) = u(E(x))$, where x denotes income. Because owners are risk-neutral, the utility function is a monotonically decreasing linear function. Maximization of expected utility can be achieved through the maximization of expected income.

2.3.3 The Optimal Behavior of Managers

Managers attempt to maximize the utility derived from their income under existing constraints brought by regulation. Assuming that the marginal utility of income is modeled via $u(x) = e^{-rx}$, risk aversion can be modeled as follows: $R_\alpha(x) = \frac{\mu''(x)}{\mu'(x)}$ to model an individual's appetite for risk, $R_a(x) < 0$. Risk neutrality is modeled by

$R_a(x) = 0$, and consequently risk aversion is modeled by setting $R_a(x) > 0$. Assuming an individual's income follows a normal distribution, the following equation can be solved analytically to yield Equation 2.4.

$$E\big(\mu(x)\big) = \int_{-\infty}^{+\infty} -e^{-\gamma x} \frac{1}{\sqrt{2\pi V(x)}} e^{\frac{(x-E(x))^2}{2V(x)}} dx = -e^{-r[E(x)-\frac{rV(x)}{2}]} \qquad (2.4)$$

In this model, however, it is also important to define behavior under less than certain conditions which are denoted *CE*. The certainty equivalent of managers' income under uncertain conditions is *CE*. *u(CE)=E(u(x)),* so the overall relationship is given as followings:

$$-e^{-rCE} = -e^{-r[E(x)-\frac{rV(x)}{2}]},\ CE = E(x) - \frac{1}{2}eV(x) \qquad (2.5)$$

An individual's goal of maximizing his expected utility exists when *u(CE) =E(u(x))*; therefore, the maximization of expected utility can be solved by mathematically maximizing *u(CE)*. Because $u(x) =-e^{-rx}$ and $r>0$, $u'(x) =re^{-rx}>0$. Thus, to maximize *u(CE)*, individuals only need to take action to maximize their *CE*, which is allowed to be simplified to the following:

$$MaxCE = MaxE\big(\omega - c(\alpha)\big) - \frac{1}{2}rV(\omega - c(\alpha)) \qquad (2.6)$$

2.3.4 The Nash Equilibrium in Financial Systems

In game theory, the Nash equilibrium is a solution concept for a non-cooperative game involving two or more players, in which each player is assumed to know the equilibrium strategies of the other players, and no player has anything to gain by changing only their own strategy [41].

To reach the Nash equilibrium, which is the solution reached when both sides are non-cooperative, the following conditions must be met. Both the individual employee and the employer seek to maximize the utility associated with their incomes; each player's utility reach a point at which the two players' utilities are equal. In this system, the owner of the financial firm has the first-mover advantage because it dictates the original salary. The individual then must weigh the benefit of this salary vs. the cost of moving. The interplay between these two factors can be expressed as the following series of Equations 2.7.

$$MaxE = \left(y_{t,l} - \omega\right)$$

$$s.t. Max\left[E\left(\omega - c(\alpha)\right) - \frac{1}{2} rV\left(\omega - c(\alpha)\right)\right]$$

$$E\left(\omega - c(\alpha)\right) - \tfrac{1}{2} rV\left(\omega - c(\alpha)\right) \geq CE_0. \tag{2.7}$$

Based on this system, it is becomes possible to assess individuals' behavior under various incentive programs i.e., those that balance short-term vs. various types of long-term compensation schemes.

2.4 Analyzing Game Theory in Chinese financial systems

2.4.1 The fixed-income system

Under a fixed-income system, an individual’s income is independent of performance [42]. Therefore, income is represented as Equation 2.8:

$$\omega = \omega_0 \tag{2.8}$$

Revenue is then defined as:

$$X = \omega_0 - c(\alpha) \tag{2.9}$$

The certainty equivalent of an individual’s income is,

$$CE = E(x) - \frac{1}{2} rV(x) = \omega_0 - c(\alpha) \tag{2.10}$$

Assuming that an individual’s cost is $c(\alpha) = \frac{1}{2}\alpha_t^2 + \frac{1}{2}\alpha_{t,s}^2 + \frac{1}{2}\alpha_{t,l}^2$, to maximize *CE*, the following conditions in Equation 2.11 must be satisfied:

$$\begin{gathered} \frac{\partial CE}{\partial \alpha_t} = \frac{\partial CE}{\partial \alpha_{t,s}} = \frac{\partial CE}{\partial \alpha_{t,l}} = 0 \\ \alpha_t^* = \alpha_{t,s}^* = \alpha_{t,l}^* = 0 \end{gathered} \tag{2.11}$$

Under the fixed-income system, an individual’s hard work will increase that individual’s personal costs. Therefore, working hard will reduce an individual’s personal revenue when income is fixed. Regardless of whether an individual’s rational choice is short-term or long-term behavior, there will not be any observable incentive.

2.4.2 Contract Responsibility System

Under the contract responsibility system, the owner establishes a performance threshold. If the standard is surpassed, then individuals receive a percentage of the surplus, whereas if the threshold is not achieved, individuals will be penalized. Under this case, the overall income is represented as follows:

$$\omega = \begin{cases} s + \beta_\alpha(y_{t,s} - y_0) & y_{t,s} \geq y_0 \\ s - Min[\beta_b(y_0 - y_{t,s}), F] & y_{t,s} < y_0 \end{cases} \quad (2.12)$$

where s is the fixed income of individuals, β_a is the reward commission percentage for surpassing the threshold, β_b is the penalty for missing the target, F is the maximum penalty, and y_0 is the pre-determined operating standard.

When $y_{t,s} \geq y_0$, individuals' income is given in Equation 2.13 and their consequent revenue is defined in Equation 2.14

$$\omega = s + \beta_\partial(Y_{t,s} - Y_0) \quad (2.13)$$

$$X = s + \beta_\partial(\alpha_t + S_s\alpha_{t,s} - L_s\alpha_{t,l} + \varepsilon - Y_0) - c(\alpha_t \cdot \alpha_{t,s} \cdot \alpha_{t,l}) \quad (2.14)$$

The certainty equivalent of the individual's income is

$$CE = s + \beta_\alpha(\alpha_t + S_s\alpha_{t,s} - L_s\alpha_{t,l} - y_0) - c(\alpha_t, \alpha_{t,s}, \alpha_{t,l}) - \frac{1}{2}\gamma\beta_\alpha^2\delta^2 \quad (2.15)$$

This leads to the following constraints being placed upon the optimal choice:

$$\alpha_t^* = \beta_\alpha > 0, \alpha_{t,s}^* = \beta_\alpha s_s > 0, \alpha_{t,l}^* = -\beta_\alpha L_s < 0 \quad (2.16)$$

When $y_{t,s}<y_0$ and $y_0-y_{t,s}<F$, the individual's income is

$$\omega = s - \beta_b(y_0 - y_{t,s}) = s + \beta_b(y_{t,s} - y_0) \quad (2.17)$$

Then, the optimal choice of the individuals is

$$\alpha_t^* = \beta_b > 0, \alpha_{t,s}^* = \beta_b S_s > 0, \alpha_{t,l}^* = -\beta_b L_s < 0 \quad (2.18)$$

When $y_{t,s}<y_0$ and y_0-$y_{t,s}\geq F$, the individual's income is ω=s-$\beta_b F$, this leads to the following insight: the individuals' optimal choice is,

$$\alpha_t^* = \alpha_{t,s}^* = \alpha_{t,l}^* = 0 \quad (2.19)$$

Under this system, an individual's revenue is positively correlated to the effort that must be expended. However, this system some drawbacks: if the target is set too low, then individuals will engage in short-term behavior and reduce activities such as long-term *R&D* and systematic investment to obtain short term gains; if the target is set too high, individuals will put less effort into work because the target is too difficult to reach.

2.4.3 Salary + Bonus

This system consists of an annual salary with a performance based bonus. In this system, an individual's income can be expressed as:

$$\omega = s + \beta Y_{t,s} + \alpha Y_{t,l} \quad (2.20)$$

In this system, s is an individual's fixed income, β is the ratio of benefit based on annual benefit, and α is the ratio of bonus based on risk level of income. From this, it is possible to define an individual's revenue as follows:

$$X = S + \beta\left(\alpha_t + S_s\alpha_{t,s} - L_s\alpha_{t,l} + \varepsilon\right) + \alpha\left(\alpha_t + S_s\alpha_{t,s} - S_l\alpha_{t,s} + L_l\alpha_{t,l} - L_s\alpha_{t,l} + \varepsilon - c(\alpha t \cdot \alpha t,s \cdot \alpha t,l)\right. \quad (2.21)$$

with the associated certainty equivalent of

$$CE = S + \beta\left(\alpha_t + S_s\alpha_{t,s} - L_s\alpha_{t,l}\right) + \alpha\left(\alpha_t + S_s\alpha_{t,s} - S_l\alpha_{t,s} + L_l\alpha_{t,l} - L_s\alpha_{t,l}\right)$$

$$-c\left(\alpha_t \cdot \alpha_{t,s} \cdot \alpha_{t,l}\right) - \frac{1}{2} r(\beta^2 + \alpha^2)\sigma^2 \quad (2.22)$$

From this, the optimal strategy can be defined as followings:

$$\alpha_t^* = \beta + \alpha > 0, \alpha_{t,s}^* = \beta S_s + \alpha(S_s - S_l), \alpha_{t,l}^* = \alpha(L_l - L_s)\beta L_s \quad (2.23)$$

When $(\beta+\alpha)S_s>\alpha S_l$, $a_{t,s}>0$, individuals will focus upon maximizing short term results;

When $(\beta+\alpha)S_s>\alpha S_l$, $a_{t,s}<0$, individuals will be ambivalent toward short-term results;

When $\alpha L_l>(\beta+\alpha)L_s$, $a_{t,l}>0$, individuals will focus upon long term performance; and

When $\alpha L_l>(\beta+\alpha)L_s$, $a_{t,l}<0$, individuals will be ambivalent toward long-term performance.

From this, it becomes clear that utilizing this framework, one can neither dis-incentivize bad behavior nor prioritize long-term growth over short-term results.

2.4.4 Stock option

Under this system, an individual’s revenue consists of a fixed-income component and stock-option component. This allows the income stream to be defined as follows:

$$\omega=s+\beta Max\ (0, \lambda\pi-E) \quad (2.24)$$

In this framework s is the fixed income, β is the ratio of the vesting of stock options to total stocks, E is the strike price of the stock options, λ is the correlation coefficient of the stock price and the long-term gains of financial institutions, and $\lambda>0$.

When $\lambda\pi-E\leq 0$, an individual’s income is $\omega= s$. Under this condition, the optimal behavior is defined as follows:

$$\alpha_t^* = \alpha_{t,s}^* = \alpha_{t,l}^* = 0 \quad (2.25)$$

When $\lambda\pi$-$E>0$, the individual's income is

$$\omega = \frac{1}{1+\beta\lambda}\left(s + \beta\lambda y_{t,l} - \beta E\right) \tag{2.26}$$

An individual's revenue is

$$x = \frac{1}{1+\beta\lambda}\left[s + \beta\lambda\left(\alpha_t + S_s\alpha_{t,s} - S_l\alpha_{t,s} + L_l\alpha_{t,l} - L_s\alpha_{t,l} + \varepsilon\right) - \beta E\right] - c(\alpha_t, \alpha_{t,s}, \alpha_{t,l}) \tag{2.27}$$

The certainty equivalent of an individual's income

$$CE = \frac{1}{1+\beta\lambda}\left[s + \beta\lambda\left(\alpha_t + S_s\alpha_{t,s} - S_l\alpha_{t,s} + L_l\alpha_{t,l} - L_s\alpha_{t,l}\right) - \beta E\right]$$

$$-c\left(\alpha_t, \alpha_{t,s}, \alpha_{t,l}\right) - \frac{1}{2}\gamma\left(\frac{\beta\lambda}{1+\beta\lambda}\right)^2\delta^2 \tag{2.28}$$

Therefore, under this condition, the best options for action are,

$$\alpha_t^* = \frac{\beta\lambda}{1+\beta\lambda} > 0, \alpha_{t,s}^* = \frac{\beta\lambda(S_s - S_l)}{1+\beta\lambda} < 0, \alpha_{t,l}^* = \frac{\beta\lambda(L_l - L_s)}{1+\beta\lambda} > 0 \tag{2.29}$$

Under this system, individuals will be naturally incentivized to optimize their long and near-term behavior while avoiding short-term payoffs that might have negative long-term consequences.

2.5 Conclusion

Based upon the numerical analysis, it becomes clear that stock options are the most effective method of motivating consistent behavior not only in the near term but taking the film's long-term performance into account. This is because stock options align it the employee's interests with the firm's long-term interests, allowing capital markets instead of an easily manipulated regulatory system to provide individuals with oversight. The reason for this conclusion is that a firm's stock price, which is a major component of one's compensation, reflects an evaluation of whether one's activities are beneficial to the company. In summary, the stock-option system is an effective way to enhance the incentive effect and operational efficiency. It should play a key role in reforming the Chinese financial industry to be more innovative and forward looking.

Chapter 3

The VAR model with applications

3.1 Introduction of the VAR model

The vector auto regressive model (VAR model) is a usually used econometric models proposed by Christopher Sims. This model is usually used for multivariate time series prediction and forecasting the random disturbance in the dynamic effect of a variable system. We can avoid the structure-modeling problem for each value of all of the endogenous variables.

The general mathematical formulation for the VAR model is as follows:

$$y_t = A_1 y_{t-1} + \cdots + A_p y_{t-p} + Bx_t + \varepsilon_t \qquad t=1, 2, 3, \cdots, T \tag{3.1}$$

Here, y_t is an endogenous variable vector, x_t is an exogenous variable vector, $A1, \cdots Ap$ and matrix B are the estimated coefficient, and ε_t the is error vector. The model can be formulated as a matrix:

$$\begin{pmatrix} y_{1t} \\ y_{2t} \\ y_{3t} \\ \vdots \\ y_{kt} \end{pmatrix} = A_1 \begin{pmatrix} y_{1t-1} \\ y_{2t-1} \\ y_{3t-1} \\ \vdots \\ y_{kt-1} \end{pmatrix} + A_2 \begin{pmatrix} y_{1t-2} \\ y_{2t-2} \\ y_{3t-2} \\ \vdots \\ y_{kt-2} \end{pmatrix} + \cdots + B \begin{pmatrix} x_{1t} \\ y_{2t} \\ x_{3t} \\ \vdots \\ x_{kt} \end{pmatrix} + \begin{pmatrix} \varepsilon_{1t} \\ \varepsilon_{2t} \\ \varepsilon_{3t} \\ \vdots \\ \varepsilon_{kt} \end{pmatrix}, \quad t = 1,2,3, \cdots T \tag{3.2}$$

Typically the VAR *(p)* model with the *k* time-series variable has *k* equations. It can be converted to a simple form as

$$\widetilde{y_t} = A_1 \widetilde{y_{t-1}} + A_p \widetilde{y_{t-p}} + \widetilde{\varepsilon_t} \tag{3.3}$$

Equation (3.4) can be abbreviated as follows:

$$A(L)\widetilde{y_t} = \widetilde{\varepsilon_t} \tag{3.4}$$

$A(L) = I_k - A_1 L - A_2 L^2 - \cdots A L^p$, which is parameter matrix of lag operator L.

$\widetilde{\boldsymbol{\varepsilon}_t}$ is the white-noise time series, and $E(\widetilde{\varepsilon_t}) = 0, E(\widetilde{\varepsilon_t}\widetilde{\varepsilon_t}) = \Sigma$. The above equation is also known as the impact of the simplified form vector. Equation (3.4) is known as the unrestricted VAR model.

3.2 Empirical analysis

Because of the influence of the planned economy, both China's economic development and its financial market system remain imperfect. Indirect finance continues to dominate in China, and bank credit is an important source of real-estate funds. Monetary policy will have a significant impact on the real-estate industry, even with small changes. China's national monetary policy is uniform; there is no distinction among the regions. However, differences in geographical location, environment and cultural backgrounds result in different economic conditions and financial environments. Therefore, the effects of unified monetary policy on the regional real-estate market will be vary. Because interest-rate policy is an important tool of monetary policy, the interest rate is chosen as a substitute for monetary policy to analyze the effect of interest rates on housing prices in different areas.

Based on domestic and foreign research, along with the housing price model proposed by Katinka Hort (1998) [43], we know both that interest-rate changes will have a significant impact on the real-estate industry and that this effect can be empirically analyzed with the econometric model. In this paper, using collected data from four representative Chinese cities (Beijing, Shanghai, Changsha, and Hefei), real-estate market models for each city are established separately for empirical analysis.

3.2.1 Variable selection

This part analyzes differences in the interest's effect on housing prices levels. We first study the of the interest-rate adjustments on various city prices. Christiano, Eichembaum and Evans (1999) show that to build the impact model of the asset price reaction, we only need to add the asset price to the VAR model of macroeconomic variables and monetary policy tools [44]. Considering the availability of data, we selected area GDP, interest rate, and price level and real-estate price as the research variables. These four variables first need to be seasonally adjusted; next, and then the seasonal factors can be removed from the original sequence. This thesis uses the variable *X-11*method to adjust the variables.

3.2.2 Unit root test

In this theis, we use the ADF unit root test (augmented Dickey-Fuller test for a unit root) method for a stationary test on relevant variables [45].

In statistics and econometrics, ADF test is for a unit root in a time series sample. This test is an augmented version of the Dickey–Fuller test for a larger, more complicated set of time-series models. The augmented Dickey-Fuller statistic, used in the test is a negative number. The more negative is the number, the stronger the rejection of the hypothesis that there is a unit root at some level of confidence [46].

This paper collected all quarterly data from 2006 to 2012. However, because the data are released in accordance with fair value, it may include factors such as inflation. For that reason, this article corrected the data for the fourth quarter of 2005 with comparable data using a logarithm. The results of the ADF test are shown in Table 3.1.

The above results show that every sequence test t statistic is greater than the significance level of 10% critical value, so we cannot reject the null hypothesis that there is a unit root and the above four sequences are not stationary series. After the first-order differential analysis, the t statistic of the four variables is smaller than the significance level of 1% critical value. This shows that the first order differential sequence has unit root and is smooth. Thus, the four groups of variables for these four cities *I (1)* are the first-order sequences.

Table 3.1 The ADF test results of the GDP, HPI, CPI and R of Beijing, Shanghai, Changsha and Hefei.

		D(LOG(GDPSA))	LOG(GDPSA)	D(LOG(HPISA))	LOG(HPISA)	D(LOG(CPISA))	D(LOG(CPISA))	D(LOG(RSA))	LOG(RSA)
Beijing	Test form	(C,T,1)	(C,T,0)	(C,T,6)	(C,T,0)	(C,T,1)	(C,T,1)	(C,T,1)	(C,T,0)
	ADF value	-5.041808	-3.58759	-4.800637	-1.453637	-7.62952	-1.576355	-5.53946	-1.147762
	Prob.	0.0020	0.36357	0.00044	0.8205	0.0000	0.7757	0.0003	0.9103
	results	steady	unsteady	steady	steady	steady	unsteady	steady	unsteady
ShangHai	Test form	(C,T,1)	(C,T,0)	(C,T,1)	(C,T,0)	(C,T,1)	(C,T,1)	(C,T,1)	(C,T,0)
	ADF value	-6.557077	-4.33933	-5.570548	-3.14678	-8.008468	-1.58966	-5.912341	-2.499877
	Prob.	0.0000	0.4205	0.0006	0.5743	0.0000	0.7704	0.0003	0.3548
	results	steady	unsteady	steady	unsteady	steady	unsteady	steady	unsteady
ChangSha	Test form	(C,T,1)	(C,T,0)	(C,T,1)	(C,T,0)	(C,T,1)	(C,T,1)	(C,T,1)	(C,T,0)
	ADF value	-4.414461	-1.661949	-6.864427	-2.25127	-3.862361	-2.334441	-5.812566	-1.745594
	Prob.	0.00187	0.7402	0.0000	0.4444	0.00702	0.4024	0.0001	0.7025
	results	steady	unsteady	steady	unsteady	steady	unsteady	steady	unsteady
HeFei	Test form	(C,T,1)	(C,T,0)	(C,T,6)	(C,T,0)	(C,T,3)	(C,T,1)	(C,T,1)	(C,T,0)
	ADF value	-4.31182	-3.22923	-4.7394	-1.29368	-5.24178	-1.47235	-4.33973	-1.78467
	Prob.	0.0011	0.4537	0.0030	0.6401	0.0012	0.7830	0.0020	0.6840
	results	steady	unsteady	steady	unsteady	steady	unsteady	steady	unsteady

3.2.3 Johansen cointegration test

In statistics, the Johansen test, which is named after Soren Johansen, is a procedure for testing the cointegration of several, say *k*, *I (1)* time series [47]. This test permits more than one cointegrating relationship based on the Dickey-Fuller test for unit roots in the residuals from a single estimated cointegrating relationship [48].

The above analysis result shows that these variables are first-order sequences *I (1)*. Therefore, the Johansen cointegration test method can be used to test each variable in the model series. The inspection results are in Table 3.2.

The results show that there are cointegration relationships in the variable sequences of Beijing, Shanghai, Changsha and Hefei under the significance level of 5% (or 1%). In other words, there are long-term stable relationships among estate price, price level, area GDP and interest.

3.2.4 Granger causality test

The Granger causality test is a statistical hypothesis test for determining whether one time series is useful in forecasting another. The Granger causality test was first proposed in 1969. Clive Granger thought that in order to predict the future values of a time series, causality could be tested by measuring the ability in economics [49].

Table 3.2 The cointegration test of Beijing, Changsha, Changsha, Hefei.

Cites	Co-integration Test	Hypothesized	Eigenvalue	Trace Statistic	5% Critical Value	Prob**
	Trace Statistic	None*	0.804180	66.64920	47.85613	0.0004
		At most 1	0.434533	24.25465	29.79707	0.1899
		At most 2	0.303904	9.431968	15.49471	0.3269

Beijing		At most 3	0.000500	0.012994	3.841466	0.9090
	Max-Eigen Statistic	None*	0.804180	42.39456	27.58434	0.0003
		At most 1	0.434533	14.82268	21.13162	0.3015
		At most 2	0.303904	9.418974	14.26460	0.2529
		At most 3	0.000500	0.012994	3.841466	0.9090
Shanghai	Trace Statistic	None*	0.804180	66.64920	47.85613	0.0004
		At most 1	0.434533	24.25465	29.79707	0.1899
		At most 2	0.303904	9.431968	15.49471	0.3269
		At most 3	0.000500	0.012994	3.841466	0.9090
	Max-Eigen Statistic	None*	0.804180	42.39456	27.58434	0.0003
		At most 1	0.434533	14.82268	21.13162	0.3015
		At most 2	0.303904	9.418974	14.26460	0.2529
		At most 3	0.000500	0.012994	3.841466	0.9090
Changsha	Trace Statistic	None*	0.804180	66.64920	47.85613	0.0004
		At most 1	0.434533	24.25465	29.79707	0.1899
		At most 2	0.303904	9.431968	15.49471	0.3269
		At most 3	0.000500	0.012994	3.841466	0.9090
	Max-Eigen Statistic	None*	0.804180	42.39456	27.58434	0.0003
		At most 1	0.434533	14.82268	21.13162	0.3015
		At most 2	0.303904	9.418974	14.26460	0.2529
		At most 3	0.000500	0.012994	3.841466	0.9090
Hefei	Trace Statistic	None*	0.801269	74.38893	63.876103	0.005083
		At most 1	0.540063	32.377977	42.915247	0.368300
		At most 2	0.338355	12.184649	25.872107	0.799087
		At most 3	0.054095	1.445948	12.517983	0.992430
	Max-Eigen Statistic	None*	0.801269	42.010954	32.118317	0.002264
		At most 1	0.540063	20.193327	25.823211	0.232222
		At most 2	0.338355	10.738702	19.387040	0.540446
		At most 3	0.054095	1.445948	12.517983	0.992429

A time series *X* is said to Granger-cause *Y* if it can be shown, usually through a series of *t*-tests and *F*-tests on lagged values of *X*, and with lagged values of *Y* also included, that those *X* values provide statistically significant information about future values of *Y* [50].

In the Granger causality test, the lag order reaction is very sensitive, so we usually choose the biggest lag order number [46,51]. In this part, for Beijing, Shanghai, Changsha and Hefei, we adopt multiple lags for the Granger causality test.

Table 3.3 Granger causality test results for Beijing, Shanghai, Changsha, and Hefei.

Beijing				
Null Hypothesis	Prob.	Prob.	Prob.	Prob.
	Lags:2	Lags:3	Lags:4	Lags:5
D(LOG(RSA))does not Granger Cause D(LOG(HPISA))	0.92569	0.87734	0.89922	0.41149
D(LOG(HPISA)) does not Granger Cause (LOG(RSA))	0.84803	0.43737	0.68201	0.39800
Shanghai				
Null Hypothesis	Prob.	Prob.	Prob.	Prob.
	Lags:2	Lags:3	Lags:4	Lags:5
D(LOG(RSA))does not Granger Cause D(LOG(HPISA))	0.78371	0.89641	0.25824	0.50129
D(LOG(HPISA)) does not Granger Cause (LOG(RSA))	0.73383	0.99717	0.98907	0.96647
Changsha				
Null Hypothesis:	Prob.	Prob.	Prob.	Prob.
	Lags:2	Lags:3	Lags:4	Lags:5
D(LOG(RSA))does not Granger Cause D(LOG(HPISA))	0.33664	0.96733	0.87356	0.20928
D(LOG(HPISA)) does not Granger Cause (LOG(RSA))	0.23691	0.42273	0.66179	0.84733
Hefei				
Null Hypothesis:	Prob.	Prob.	Prob.	Prob.
	Lags:2	Lags:3	Lags:4	Lags:5
D(LOG(RSA)) does not Granger Cause D(LOG(HPISA))	0.93020	0.33269	0.71120	0.75809
D(LOG(HPISA)) does not Granger Cause (LOG(RSA))	0.04465	0.05611	0.00568	0.01123

The Granger causality test is based on the VAR model. The lag order reaction is very sensitive, so we usually choose the biggest lag order number (44) (45). In this thesis, we adopt multiple lags for granger causality test related to Beijing, Shanghai, Changsha and Hefei.

The Granger causality test results in Table4.3 show the relationship between interest rates and housing prices in Beijing, Shanghai, Changsha and Hefei. According to the results of the study, when the significance level is under 5%, the effect of interest rates housing price is obviously in Changsha, and the influence is a one-way relationship. In Shanghai, Beijing and Hefei, housing price's response to the interest-rate change is not very sensitive. Therefore, the impact of interest rates on housing prices exhibits variability.

3.2.5 Impulse response function

To make a reasonable explanation of the estimated parameters, we usually consider the influence of various variables when an error term is changed or model is shocked by impulses. A better analysis of the system impulse response function would be, more intuitive with respect to the impulse response figure [24].

The impulse response function, of a dynamic system is its output when presented with a brief input signal known as called an impulse. More generally, an impulse response function refers to any dynamic system's reaction to some external change. In both cases, the impulse response function describes the system's reaction as either a function of time or a function of some other independent variable that parameterizes the system's dynamic behavior [2]. The impulse response function can define the response of a linear time-invariant system for all frequencies.

Therefore, we use a pulse response function to depict the influence of interest rates with a one standard deviation increase of the impact on urban housing.

Because of the impact of rising interest rates, the four cities' real-estate prices will fall. However, the extent and time of the four cities' declines are very different. Beijing will reach its maximum of -0.1% in the 9th season; Shanghai will reach its maximum of -0.08% in the section 8-9 season; Changsha will reach its maximum of -0.005% in the second quarter and Hefei will reach its maximum of -0.2% in the second quarter. According to the impulse response shown in the figure, the effect of the interest rate's period of convergence on Beijing and Shanghai's housing prices is longer, whereas the effects on prices in Changsha and Hefei converge relatively more slowly and for the first nine quarters tend to be 0. As can be seen from the figure, the change in interest-rate policy will generally have a negative impact on prices that is substantially the same as found in domestic research. Four cities' housing-price changes caused by the interest-rate policy show obvious differences in their responses, thus proving the existence of differences among the cities. The depth and breadth of the degree of the interest-rate's influence in Beijing and Shanghai are large. In Hefei and Changsha, however, real-estate prices have a relatively weak impact for only a short duration.

3.2.6 Conclusion

This thesis established a four-variable VAR model using four representative cities in China (Beijing, Shanghai, Changsha and Hefei). With statistical software Eviews5.0, we have conducted an empirical analysis of the responsiveness of housing prices to interest-rate changes in those four cities.

First, according to the results of a stability test, four variables in each city are *I (1)*, which shows the time-series with first-order differential stability. This is the basis for establishing the Johansen test. Second, the four cities in each variable Johansen cointegration test result show that at different levels of significance, the four variables in each city are more or less related to cointegration. In the third step, a Granger causality test of housing prices and interest rates test shows that price causality on interest rates in Beijing and Shanghai is unidirectional and very significant. The causal relationship between interest rates and housing prices in Changsha and Hefei is not obvious. Finally, by analyzing the impulse response function of the four cities, we conducted a detailed study of the price effects experienced in various cities attributable to interest-rates changes, finding that the impact of interest-rate changes on housing prices in the four studied cities exhibits many variations.

3.3 Conclusions and Recommendations

In this section, we study real-estate prices through the lens of supply and demand. By taking monetary policy conducive to real-estate market influence as the breakthrough point, we have analyzed the influence of interest-rate changes on housing prices that leads to differences among cities. Four representative Chinese cities are selected to provide data for the research sample; the VAR model is used to analyze impacts on housing prices caused by interest-rate policy changes in those four cities. This thesis has the following conclusions:

1) Higher interest rates would have a negative impact on property prices. In a short time, higher interest rates will quickly reduce real-estate market demand. Because supply has not changed, prices will fall; and if the time is longer, increased interest rates will affect supply and demand in the real-estate market. However demand response is more sensitive than supply response. Thus, the impact of interest-rate changes on prices will gradually change to weak until zero is reached.

2) The strength and depth of the impact of higher interest rates on housing prices in the four studied cities have obvious differences. Price responses in Beijing and Shanghai to changes in interest-rate policy are more sensitive than in Changsha and Hefei, where the convergence period is also longer. Among these four cities, Hefei's price adjustment attributable to interest-rate policy is at the lowest level, and its convergence is the shortest; the respond of rates in Changsha to interest-rate changes is slightly higher than in Hefei.

3) The more developed the economy, the more developed the financial markets and the

higher the proportion of its housing consumption. Interest-rate changes in reaction to housing prices are also more sensitive.

Based on the above analysis and study, we proposed the following actions to extend the steady development of the real-estate market:

1. Accelerating the advancement of interest-rate mercerization and the improvement of the financial system;

2. Achieving a balance between the flexibility and consistency of monetary policy;

3. Expanding regulation of local policy, coordinating local policies and increasing the consistency of central authorities' policies; and

4. Optimizing the structure of the real-estate market and avoiding operational and financial risks.

Figure caption

Figure 3.1 The effect of interest rates' pulse responses to housing prices in Beijing.

Figure 3.2 The effect of interest rates' pulse responses to housing prices in Shanghai.

Figure 3.3 The effect of interest rates' pulse responses to housing prices in Changsha.

Figure 3.4 The effect of interest rates' pulse responses to housing prices in Hefei.

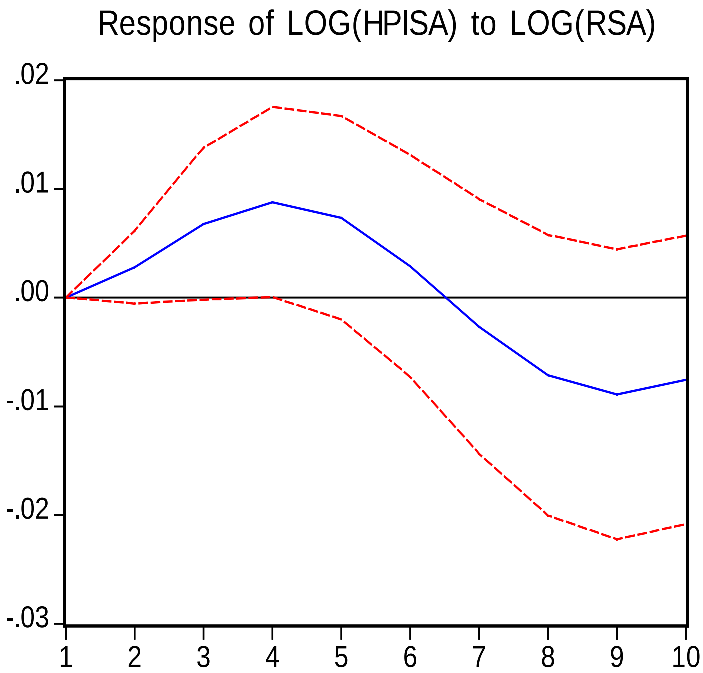


Figure 3.1 The effect of interest rates' pulse responses to housing prices in Beijing.

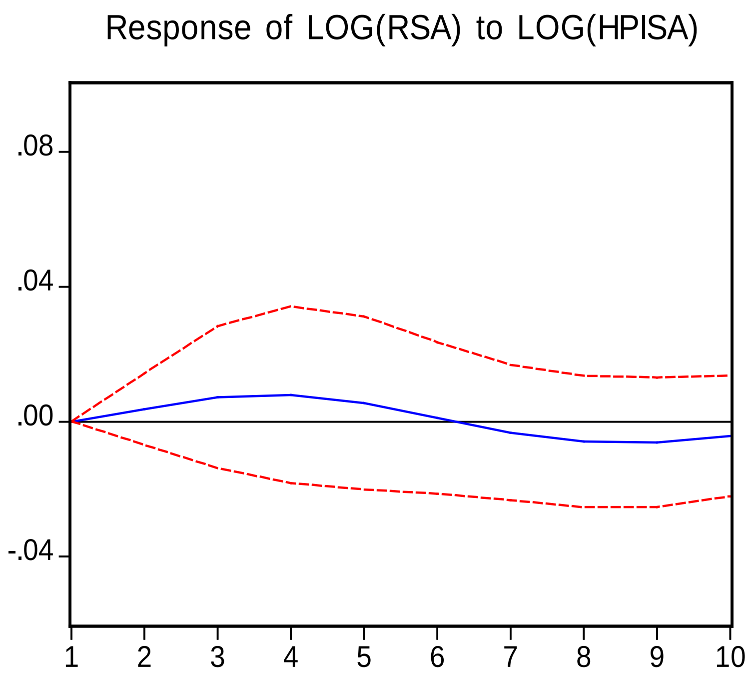


Figure 3.2 The effect of interest rates' pulse responses to housing prices in Shanghai.

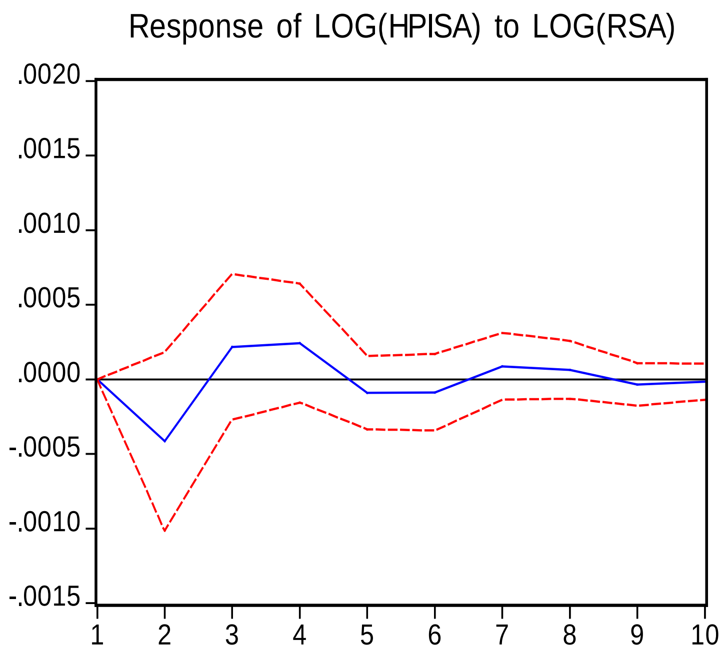


Figure 3.3 The effect of interest rates' pulse responses to housing prices in Changsha.

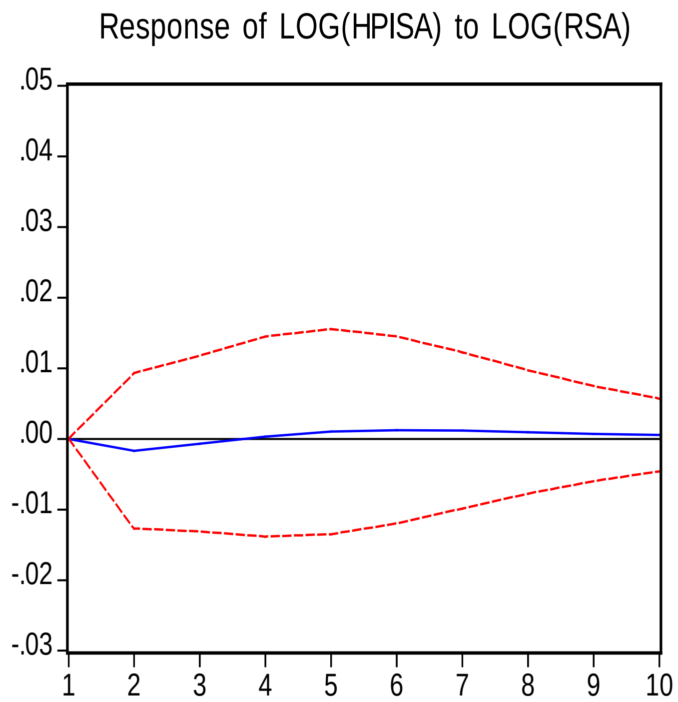


Figure 3.4 The effect of interest rates' pulse responses to housing prices in Hefei.

Chapter 4

Neuron model and its application

In recent decades, artificial intelligence technology has been the focus of numerous research efforts. The major global IT enterprises (i.e., Microsoft and Google) have designated research departments, devoted vast human and material resources to artificial intelligence, and made significant progress in image identification and speech recognition. In October 2015, the latest artificial intelligence program AlphaGo defeated the European Go champion (professional stage grading II) Fan Hui five times in succession. This was the first time a professional Go player had been outperformed by artificial intelligence, thus demonstrating the potential of artificial intelligence technology. There are currently two developmental directions in artificial intelligence technology. One is to develop an “expert system” from top to bottom and the other is to develop an artificial neural network (ANN) from top to bottom. At present, research is primarily focusing on the development of an ANN from top to bottom. As the name suggests, an ANN is a neuron-based model that simulates transmission and treatment between each neuron in the brain. However, as the research evolves, investigations will gradually diverge from the traditional biological neuron to considerations of “nonlinearity, distribution, parallel computing, self-adaption, and self-organization.” The basic unit in the current neural network is the traditional McCulloch-Pitts neuron model, which can only realized computation ability of the cell body. This single neuron cannot solve nonlinear calculation problems alone. However, recent research indicates that the nonlinear interactions of synapses in the dendrite can be found. In other words, a single neuron can also undertake very complicated computations related to dendrites activity.

4.1 Brain

The brain, with its role in producing a human’s thought, sensation, action, memory, and feeling of the world, is the most complex organ in the human body. This jelly-like mass of tissue with a weigh of around 1.4 kg and a volume of around 1.5L contains a staggering one hundred billion nerve cells or neurons as well as more than 10^{14} synapses [52,53]. Because the structure and functions of the human brain are extremely complex, research into and the integration of its molecular and cellular systems and related behaviors are necessary to bring its mysteries to light.

4.1.1 Neural network and neurons

“An ANN is an information processing system that roughly replicates the behavior of the human brain by emulating operations and connectivity of biological neurons [54].” Most ANN can adjust their internal data on the basis of outside information. The modern neural network is a nonlinear data modeling tool used to reflect complex relationships between inputs and outputs. “ANNs have various alternative features such as massive parallelism, distributed representation and computation, generalization ability, adaptability, and inherent contextual information processing [55-62].”

However, the backbone of many ANNs, to the present day, is attributed to the original work of McCullough & Pitts (1943). The node of a neural network, also called a neuron, is the focus of the McCulloch-Pitts Model which is widely used in traditional neural networks to solve a range of complicated problems by incorporating multilayer networks. However, the neuron’s structure is too simple to solve the Exclusive OR problem alone. As such, the McCulloch-Pitts model cannot reflect the real importance of neurons in the nervous system.

Recently, progress has been made in analyzing the detailed characteristics of these nerve cells, and the local information processing in dendrites has been characterized [63-65]. The results demonstrate that the neuron possess exceptionally powerful computation capabilities. In other words, dendrites act as small-scale computing devices for detecting and amplifying specific types of input. This newly identified property of dendrites adds an important new factor to our understanding of computation in the brain.

In 2000, Tang et al. proposed a neuron model based on dendritic mechanisms [66]. In this model, in order to reflect the physiological morphology and functions of nerve cells, nonlinear interaction of the dendrites can be expressed by the logic operations AND, OR, and NOT. Moreover, this neuron model can heighten and fix active dendrites and synapses, filter out redundant ones by training to form a mature dendrite structure, and preserve the necessary synapses [67].

4.1.2 Chapter outline

In this thesis, I propose a neuron model with dendritic nonlinearity for solving a real world problem, using its outstanding nonlinearity capability to analyze the effect of the China's regional financial interrelation ratio (FIR).

In section 4.1, I introduce the functions, features, and relationships of the brain, neural networks, and neurons. In section 4.2, I describe in detail the McCulloch-Pitts and Koch-Poggio-Torre model. In 4.3, I describe in detail the description of the new neuron model known as the Neuron Model with Dendritic Nonlinearity (NMDN). In section 4.4, I use the NMDN to analyze the China's regional financial interrelation ratio for the first time. In section 4.5, I draw my conclusions.

4.2 Review of neuron models

The brain is a large-scale information processing system consisting of 10^{11} neurons with perhaps 10^{15} interconnections between them [68]. The astrocytes, oligodendrocytes, microglia, and ependymal cells are considered as the four types of glia cells in brain [69,70]. Although the shape and size of neurons differ, their structures are unique, and consist of three parts the cell body, dendrite, and axon. Incoming signals from other neurons or sensors received by the dendrite are computed at the synapse and transmitted to the cell body. When the input into the cell body exceeds the holding threshold, the neuron will fire, and a signal is transmitted to other neurons via the axon.

4.2.1 Neuron

A neuron, also known as a nerve cell, is the basic unit of the nervous system, which includes the brain and spinal cord. Together these comprise the central nervous system (CNS) and the ganglia of the peripheral nervous system (PNS), which have the specialized role of receiving, integrating, and transmitting information [68].

As stated above, a typical neuron comprises a cell body (soma), dendrites, and an axon (Fig.4-1). "Dendrites arise from the cell body, often extending for hundreds of micrometers, branching multiple times, and giving rise to a complex "dendritic tree." An axon is a special cellular extension arising from the cell body at a site called the axon hillock and travels for a distance, as far as one meter in humans or even more in other species [70]." While the cell body of a neuron frequently generates multiple dendrites, it never generates to more than one axon, although the single axon may branch hundreds of times before terminating. At the majority of synapses, signals are sent from the axon of one neuron to a dendrite of another.

Moreover, during the past few years, there has been an explosion of interest in dendrites, driven by the development of powerful new imaging and recording techniques. “There is increasing evidence that dendrites substantially enhance the neuron’s computational power by introducing nonlinear interactions between the synapses and subcompartments of the cell [71].” In other words, “additional linear and nonlinear mechanisms in the dendritic tree are likely to serve as computational building blocks, which combined together playing a key role in the overall computation performed by the neuron [72].”

4.2.2 McCulloch-Pitts Model and Koch-Poggio-Torre model

An artificial neuron is a mathematical function conceived to model biological neurons. Artificial neurons are the constitutive units of ANN.

In 1943, McCulloch and Pitts proposed the first simple neuron model (Fig. 4-2), now known as the McCulloch-Pitts Model, in which the dendrites and synapses are independent and have no effect on each other. Apart from their functions with respect to synaptic weight and transmission, the cell body is treated as the main calculation unit. The McCulloch-Pitts Model receives one or more inputs and sums them to produce an output. The sums of each node are weighted, and the sum is passed via a nonlinear function known as an activation function or transfer function [73]. The transfer functions usually are sigmoid in shape (Fig. 4-3). In addition, the standard transfer function is given by

$$output = \frac{1}{1+e^{\sum \omega_i x_i - \theta}} \tag{4.1}$$

where ω_i and θ are the weights and threshold respectively, and x_i is the input.

Moreover, Minsky and Papert have shown that some rather elementary computations cannot be performed by one layer of McCulloch-Pitts cells [74]. Since the computation by dendrites is not considered in this model, the morphology of the neurons is identical.

However, Koch, Poggio, and Torre proposed a new kind model [64]. They examined the dendritic architecture that influences the cell processing function, and using cable theory as a basis, they analyzed the interaction of excitatory synaptic input and steady-state shunting inhibitory input in the retinal ganglion cells. They found that nonlinear synaptic interactions in these cells. They also showed that logic operations can be combined with the less formal computation concepts used by physiologists to design a model of a retinal ganglion neuron, with directional selectivity for moving visual inputs.

Fig. 4-4 shows a δ-cell dendrite with excitatory (●) and shunting-type inhibitory (■) inputs, and its highly branched logical operations. The logical relations can be given by:

$$(e_1 \text{ AND NOT } i_1) \text{ OR } (e_2 \text{ AND NOT } i_2) \text{ OR}$$

$$\{[(e_3 \text{ AND NOT } i_3) \text{ OR } (e_4 \text{ AND NOT } i_4)$$

$$\text{OR } (e_5 \text{ AND NOT } i_5) \text{ OR } (e_6 \text{ AND NOT } i_6)] \text{ AND NOT } i_7\}$$

Moreover, Koch et al. considered the main problem to be addressing the correct synapses to the corresponding dendrite. Recent research has also identified hundreds of neurons, each of which has a unique shape of dendritic tree. Slight morphological differences likely result in great functional variation. Type-specific dendrite morphology has important functional implications in determining which signals a neuron receives and how these signals are integrated [75]. However, there is no clear understanding that the dendritic computation can itself provide a constraint for targeting synaptic inputs at the appropriate locations [72,76,77]. In addition, in the early stages, redundant synapses and dendrites are found in the nervous system, unnecessary ones are filtered out, and those that are necessary are strengthened and fixed to form a mature neural network [78]. The morphologies of the dendrites in these neurons remain uncertain and, as yet, there is no effective method for their determination. The manual analysis of neuronal morphology is time-consuming, labor-intensive, and subject to human error and bias [79].

4.3 Neuron Model with Dendritic Nonlinearity

In 2000, Tang et al. proposed a neuron model based on the dendritic mechanisms of the conventional Koch-Poggio-Torre model [66], that reproduces the interaction between synapses and dendrites, and the elimination and generation of synapses, to form a mature dendrite structure that has a special function. In this model, in order to reflect the physiological morphology and functions of nerve cells, the logical operator AND, OR, and NOT are realized. Thus, a nonlinear interaction of the dendrites can be expressed by logic operations AND, OR, and NOT [66]. It is called neuron model with dendritic nonlinearity (NMDN). In the NMDN, in order to maintain generality, an assumption is made that there are nonlinear interactions between all inputs, and thus all inputs are initially connected to all branches, and that the number of mature dendritic branches, and the location and type of synapses on these dendritic branches, are all unknown and will be synthesized through learning. This neuron model can be successfully trained to solve directionally selective problems, depth rotation problem, and it is also used for solving the detection of breast cancer and the prediction of Shanghai stock market's overreaction [67,80-86].

4.3.1 Model

As shown in Fig. 4-5, NMDN have dendritic structure and the interaction between synapses. The dendritic branches receive signals at the synapses (▲) and then perform a simple multiplication of their own signals. At the junction of the branches, the outputs of the branches are summed and sent to the cell body (soma). When the input of the soma exceeds the threshold, the cell fires a signal to the other neurons via the axon.

Synaptic Function: The synaptic Function is described by the sigmoid function. The output of the synapse whose address is from the i-th (i=1, 2,…, n) input to the j-th (j=1, 2,…, m) branch is given by:

$$Y_{ij} = \frac{1}{1+e^{-k(\omega_{ij}x_i-\theta_{ij})}} \tag{4.2}$$

where ω_{ij} and θ_{ij} are the connection parameters, and k is a positive constant.

With respect to the values of ω_{ij} and θ_{ij}, four kinds of synaptic connections can be defined, as follows (Fig. 4-6):

1. 0-constant connection (⓪) (either $0 < \omega_{ij} < \theta_{ij}$ or $\omega_{ij} < 0 < \theta_{ij}$): No matters how the input changes from 0 to 1, the output is always 0.

2. 1-constant connection (①) (either $\theta_{ij} < 0 < \omega_{ij}$ or $\theta_{ij} < \omega_{ij} < 0$): No matter how the input changes from 0 to 1, the output is always 1.

3. Excitatory synapse (●) ($0 < \theta_{ij} < \omega_{ij}$): No matter how the input changes from 0 to 1, the output equals the input.

4. Inhibitory synapse (■) ($\omega_{ij} < \theta_{ij} < 0$): No matter how the input changes from 0 to 1, the output reverses the input.

The excitatory and inhibitory synapses are actual connection states in neurons. However, not all inhibitory synapses and excitatory synapses necessarily exist in the same branch of an actual dendrite. Therefore, an input is assumed to be initially connected to all branches, but in fact, some inputs may not be connected to some branches. The 1-constant connection has no influence on the multiplication output. The 0-constant connection, since the output of the branch is always 0, has no influence on the summation. In other words, this is equivalent to there being no existing branch. As the values of ω_{ij} and θ_{ij} change, the type of synaptic connection become apparent based on the changes that occur.

Multiplication Function: The multiplication function, as implied by the name, performs a simple multiplication on various synaptic connections of the branch. The output of the j-th branch is given by:

$$Z_j = \prod_{i=1}^{n} Y_{ij}. \tag{4.3}$$

Summation Function: As mentioned above, the summation of the signals sent from the branches is approximated by the following:

$$V = \sum_{j=1}^{m} Z_j. \tag{4.4}$$

Soma Function: The soma function can be described as a sigmoid operation as follows:

$$O = \frac{1}{1+e^{-ksoma(V-\gamma)}} \tag{4.5}$$

where $ksoma$ is a positive constant and γ is the threshold.

4.3.2 Learning

Because the functions of the NMDN are all differential, I use the error back-propagation learning rule, a supervised learning procedure, as the learning procedure. During learning, the output vector being produced by the input vector is compared with the target vector. The learning goal is to reduce the difference between the output and target vectors by modifying ω_{ij} and θ_{ij}. Last, the synapses will converge as one of four synaptic connections.

The error between the target and output vectors can be expressed by the following:

$$E = \frac{1}{2}(T - O)^2 \tag{4.6}$$

where T is the target, and the O is the output.

In the NMDN, modifications are made only to the connection parameters ω_{ij} and θ_{ij} of the connection function during learning. During the learning procedure, these parameters are corrected to decrease the error. If the gradient descent learning method is used to decrease the value of E, the connection parameters should be corrected as shown in the following formulas:

$$\Delta\omega_{ij}(t) - \eta \frac{\partial E}{\partial \omega_{ij}} \tag{4.7}$$

$$\Delta\theta_{ij}(t) - \eta \frac{\partial E}{\partial \omega_{ij}} \tag{4.8}$$

where η, a learning constant, is positive.

$$\omega_{ij}(t+1) = \omega_{ij}(t) + \Delta\omega_{ij}(t) \tag{4.9}$$

$$\theta_{ij}(t+1) = \theta_{ij}(t) + \Delta\theta_{ij}(t) \tag{4.10}$$

where $\omega_{ij}(t+1)$ and $\theta_{ij}(t+1)$ represent the following values of ω_{ij} and θ_{ij} after modification, and $\omega_{ij}(t)$ and θ_{ij} are their current values. Thus, the partial differentials of E with respect to ω_{ij} and θ_{ij} can be computed, respectively, as:

$$\frac{\partial E}{\partial \omega_{ij}} = \frac{\partial E}{\partial O} \cdot \frac{\partial O}{\partial V} \cdot \frac{\partial V}{\partial Z_j} \cdot \frac{\partial Z_j}{\partial Y_{ij}} \cdot \frac{\partial Y_{ij}}{\partial \omega_{ij}} \tag{4.11}$$

$$\frac{\partial E}{\partial \theta_{ij}} = \frac{\partial E}{\partial O} \cdot \frac{\partial O}{\partial V} \cdot \frac{\partial V}{\partial Z_j} \cdot \frac{\partial Z_j}{\partial Y_{ij}} \cdot \frac{\partial Y_{ij}}{\partial \theta_{ij}}. \tag{4.12}$$

4.4 Application to China Region finance

In recent years, as the Chinese economy has gradually joined the global economy and there has been an obvious acceleration in the integration of China's financial industry toward globalization and liberalization. Finance is the core of the modern economy. The depth and breadth of the development of financial resources play key roles in either restricting or promoting growth. However, recent trends in China's regional financial development are imbalanced. There are great differences in the financial development and growth patterns between provinces. China's regional financial development, with a strong focus on Chinese characteristics in particular, has gradually become an important area of research. Most empirical studies use financial interrelation ratios as important indicators. In this thesis, we chose China's regional financial interrelation ratio, which is a complicated problem involving many different factors. Until now, there has been no academic consensus about its related factors and influence modes. In this chapter, I use the neuron model to analyze China's regional financial interrelation ratios.

4.4.1 Related work on FIR

The ratio of gross financial assets (liquid assets, loans, and securities) to real wealth (plant, machinery, stocks, buildings and land) is Raymond Goldsmith's financial interrelation ratio (FIR). The FIR explains the relationship between financial development and the growth of physical investment. In other words, the FIR is an important indicator for measuring financial development.

4.4.2 Data

The determination of which factors are decisive in regional financial development is a problem that attracts many researchers. In this study, we use GDP, local general budget expenditure (Gexp), local general budget revenue (Grev), total import and export (I&E), insurance premium income (Insurance), fixed asserts investment (Investment), and domestic retail sales (sales) from 1978 to 2014 as input data for the NMDN. The FIR can be obtained as follows:

$$FIR_{it} = \frac{Deposit_{it}+Loan_{it}}{GDP_{it}} \qquad (t = 1 \cdots 36) \tag{4.13}$$

Deposit represents the number of deposits into financial institutions, and loan is the number of loans from financial institutions.

4.4.3 Simulation Parameters

As mentioned above, there are three parameters in the NMDN, which are k, ksoma, and ϒ. In addition, the number of branches and the threshold value can be considered as important parameters in the simulation. Table 4.1 shows the ranges of the parameters in the NMDN.

Table 4.1 Ranges of NMDN simulation parameters.

M(branch)	k	ksoma	ϒ	ϴ
45, 35, 25, 15, 5	10, 7, 5, 3, 1	10, 7, 5, 3, 1	0.001, 0.005, 0.01, 0.05, 0.1	0.9, 0.7, 0.5, 0.3, 0.1

Table 4.2 Orthogonal array for parameters

Experimental runs	Parameters(Levels)					MSE
	Branch(5)	K(5)	Ksoma(5)	η(5)	ϴ(5)	
1	45	10	10	0.1	0.9	0.0586
2	45	7	7	0.05	0.7	0.0086
3	45	5	5	0.01	0.5	0.0091
4	45	3	3	0.005	0.3	0.0289
5	45	1	1	0.001	0.1	0.1109
6	35	10	7	0.01	0.3	0.0319
7	35	7	5	0.005	0.1	0.0459
8	35	5	3	0.001	0.9	0.0464
9	35	3	1	0.1	0.7	0.0272

10	35	1	10	0.05	0.5	0.0133
11	25	10	5	0.001	0.7	0.1097
12	25	7	3	0.1	0.5	0.0136
13	25	5	1	0.05	0.3	0.0516
14	25	3	10	0.01	0.1	0.0295
15	25	1	7	0.005	0.9	0.1792
16	15	10	3	0.05	0.1	0.0634
17	15	7	1	0.01	0.9	0.0666
18	15	5	10	0.005	0.7	0.1790
19	15	3	7	0.001	0.5	0.0930
20	15	1	5	0.1	0.3	0.0204
21	5	10	1	0.005	0.5	0.0897
22	5	7	10	0.001	0.3	0.1859
23	5	5	7	0.1	0.1	0.0576
24	5	3	5	0.005	0.9	0.1600
25	5	1	3	0.01	0.7	0.1898

In order to tune the parameters for optimal NMDN performance, optimal parameters must be found. Factor analysis can be used to find optimal parameter values, as indicated by experimental results [87]. In contrast to a full factorial analysis, the Taguchi method [88] uses orthogonal arrays to reduce the number of experimental runs, thereby effectively controlling the costs associated with time, manpower, and materials. Choosing the proper orthogonal arrays that are most suitable for simulating interest is the most important problem. Due to Table 4.1, I selected the L25 (5_5) orthogonal array. I repeated the parameter estimation process 100 times, and set the epoch as 2000. Table 4.2 shows the results of experiments. To achieve optimal performance, the results show the parameters values as follows: branches are 45, k is 7, ksoma is 7, ϒ is 0.05, and Ɵ is 0.7. Therefore, I selected these values for comparison of the NMDN with the back propagation neural network (BPNN). They were both implemented in MATLAB 2013b (MATLAB Neural Network Toolbox, version 8.1 is for BPNNs) on a 3.4-GHz Intel Core-i5 computer with 8 GB of RAM.

Table 4.3 Structures of NMDN and BPNN.

	NMDN	BPNNs	
Input	Branch	HL*	Output
7	45	79	1

*HL: the Hidden layer node

Table 4.4 The simulation parameters.

Types	error	Epochs	Learning constant	Parameters		
				k	ksoma	theta
BPNNs-purelin	0.0001	2000	0.005	NA*		
BPNNs-logsig						
NMDN				7	7	0.7

NA*: not applicable

In the simulation, for the purposes of analysis, I chose different quantities of branches. If the number of inputs is N and the number of branches is M, the formula for modifying the ω_{ij} and θ_{ij} of the NMDN is $2\mathrm{M} \times \mathrm{N}$. Moreover, if the number of inputs is N and the number of hidden layer nodes is M, the formula for modifying the weights and threshold is $\mathrm{M} \times \mathrm{N} + \mathrm{M} + 1$. Table 4.3 shows the structure of the BPNN and NMDN. Table 4.4 shows the parameters in the simulation. Moreover, the transfer function of BPNN output layer was set to “logsig” and “purelin”.

4.4.4 Performance of evaluation

There are quite a few criteria defined in the literature to evaluate the performance of a model. The MSE, RMSE, and MAE are the most widely used and will be used to comparing the performance of NMDN and BPNNs in this thesis. As shown in Table 4.5, the performance of NMDN is better than BPNN. Moreover, the p value is less than 0.01 shows the significance on statistics.

Table 4.5 The evaluation between NMDN and BPNNs.

Evaluation	NMDN-45	BP_purelin-79	Two tailed P value	BP_logsig-79	Two tailed P vale
MSE	0.0086	0.0089	4.0602E-19	0.0191	1.1928E-10
RMSE	0.0828	0.0927	2.7797E-22	0.1214	2.5369E-10
MAE	0.0674	0.0743	2.4233E-21	0.1020	2.0224E-08

4.4.5 Performance of convergence rate and stability

The determination of the convergence rate is one of the most prominent strategies for evaluating the performance of neural networks. As shown in Fig. 4-7, I determined the average mean squared error convergence curve for 100 experimental repetitions, respectively, with 45 NMDN dendritic branches and 79 BPNN hidden layer nodes. In addition, the mean error is defined as in Eq. 4.14. R and S are defined as the number of experimental repetitions and of the training data, respectively. It is clear that the convergence rate of the NMDN is higher than that of the BPNN. The initial and final errors of the NMDN are also obviously less than those of the BPNN. As such, we can conclude that the NMDN performs better than the BPNN with lower computation consumption.

$$\text{Mean Error} = \frac{1}{R}\sum_{a=1}^{R}\left[\frac{1}{2}\sum_{b=1}^{S}(E_b - O_b)^2\right] \quad (4.14)$$

In this thesis, the initial and final errors are used to compare the stability performances. Stability is another important evaluating strategy. As shown in Figs. 4-8 and 4-9, the initial and final mean squared errors of the NMDN, after 100 experimental repetitions, reveal only a few light fluctuations and the initial errors of the NMDN are significantly less than those of the BPNN. However, the BPNN’s range of variation is much larger than that of the NMDN, and its frequency is higher. Moreover, although the NMDN fluctuates more than the BPNN, the performance of the NMDN is superior.

Table 4.6 shows the average initial and final errors of the NMDN and BPNN, which provides further evidence of the superior stability performance of the NMDN. I also statistically analyzed the dataset of the initial and final errors by generating box and whiskers plots [89] in Figs. 4-10 and 4-11, respectively. This is another certification of the better stability of the NMDN.

Table 4.6: Average initial and final errors of the NMDN and BPNN.

	Initial error	Final error
NMDN-45	0.1275±0.0529	0.0048±0.0097
BPNN-purelin-79	11.0864±12.1686	0.0088±0.0034
BPNN-logsig-79	0.2148±0.1597	0.0139±0.0051

4.4. 5 Computation of factor proportion

Fig. 4-12 shows the curves after learning. As mentioned above, I chose seven factors as the input data. So, in order to analyze the effect of each factor, I added a 1% momentum to each factor, respectively. Then, I input the difference of the outputs of the adjusted data into the learned NMDN and obtained the original simulated output of the NMDN using Eq. 4.15:

$$\text{d\_}change_{jt} = out_{jt} - out_t \qquad (4.15)$$

where j is the factor and t is the data. In the NMDN, d_change may be positive or negative. In order to calculate the proportion, the positive and negative d_change values are summed, respectively, as follows:

$$factor\_pos_j = \sum_t \frac{d\_change_{jt}}{out_t} \quad (d\_change > 0) \qquad (4.16)$$

$$factor\_neg_j = \sum_t \frac{d\_change_{jt}}{out_t} \quad (d\_change < 0) \qquad (4.17)$$

The proportion of the j-th factor's effect can be given by:

$$fac\_pos_j = \frac{factor\_pos_j}{|\sum_j factor\_pos_j| + |\sum_j factor\_neg_j|} \quad (4.18)$$

$$fac\_neg_j = \frac{factor\_neg_j}{|\sum_j factor\_pos_j| + |\sum_j factor\_neg_j|} \quad (4.19)$$

Fig. 4-13 shows the factor proportions for Shanghai, whereby Gexp, Insurance, and Sales contribute most to the FIR. However, GDP, Grev, I&E, and Investment cause a negative to FIR. Moreover, Gexp and Insurance make a complete positive contribute to the FIR. These analysis results may offer a very important guidance for the development of finance research.

4.4.6 Performance of Dendrite Morphology

As mentioned above, dendrite morphology is a distinctive characteristic of the NMDN, and four types of synaptic connections are defined. The excitatory and inhibitory synapses are actual neuron connection states. However, the 0-constant connection is used to eliminate branches. Fig. 4-14 shows the simplified dendrite morphology when all the existing 0-connection have been eliminated.

Through learning, the dendritic morphology is simplified to that shown in Fig. 4-14, and non-0-connection branches have emerged. Due to the location of the synapse, only the excitability synapse can indicate a positive effect, while the inhibit synapse can indicate a negative influence. That is to say, NMDN also holds its characteristics during simulation.

4.5 Conclusion

In this chapter, a neuron model with dendritic nonlinearity (NMDN) is proposed for analyzing China's regional financial interrelation ratios to identify the contribution proportion of seven factors. We also compared the NMDN with the classic BPNN in its terms of the accuracy and convergence rate and stability. The NMDN shows superior performance, based on the average results from 100 repeated experiments. The error curve demonstrates the better convergence rate of NMDN than that of the BPNN. The initial and final errors indicate that the NMDN is more stable than the BPNN. Based on these comparisons, I can conclude that the performance of the NMDN as a single neuron model is much better than that of the BPNN.

Finally, the results prove that neurons have a huge computing capability and that the computation of the brain is currently undervalued [90]. In reality, while the ability of a single neuron cannot surpass that of the entire nervous system, it is expected that the NMDN will be used as the single neuron model of choice in future neural networks. I also recommend that the proposed model be used by economic researchers to advance their research.

Figure caption

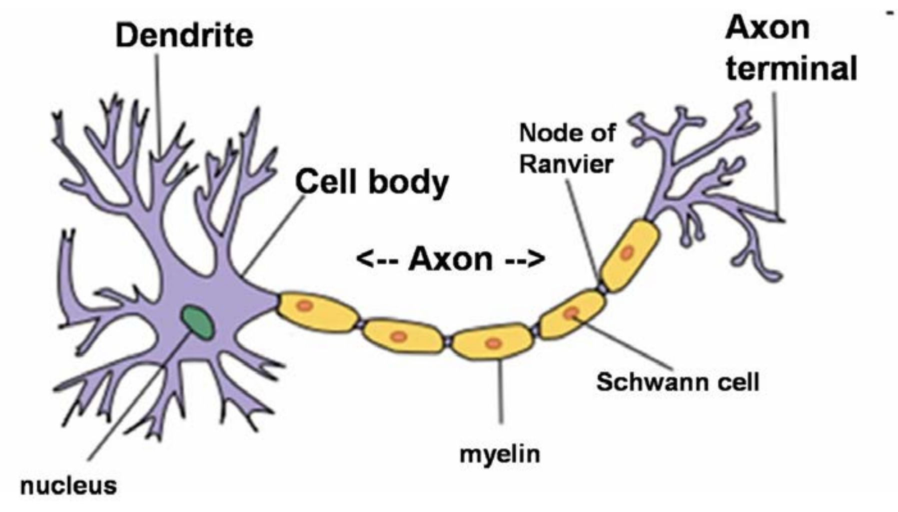


Fig. 4-1 The Structure of the Neuron [81].

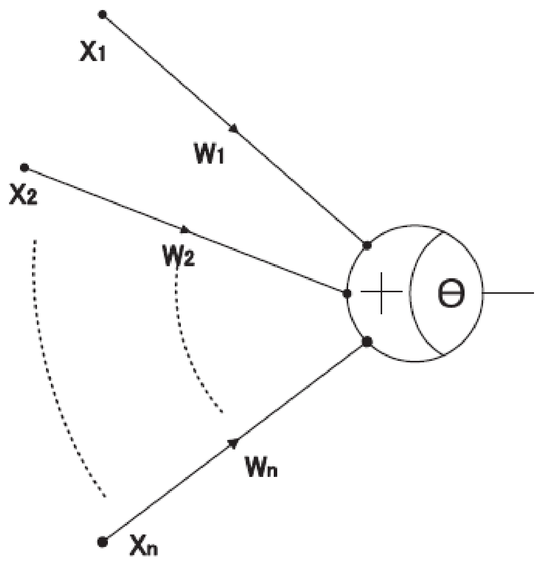


Fig. 4-2 McCulloch-Pitts Model.

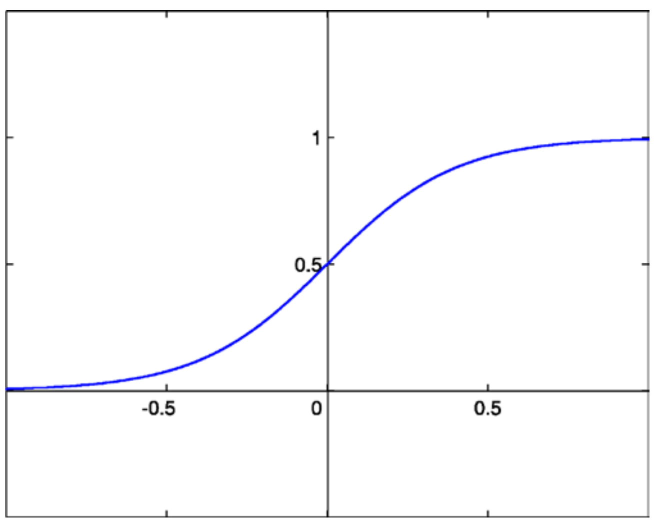


Fig. 4-3 Sigmoid shape.

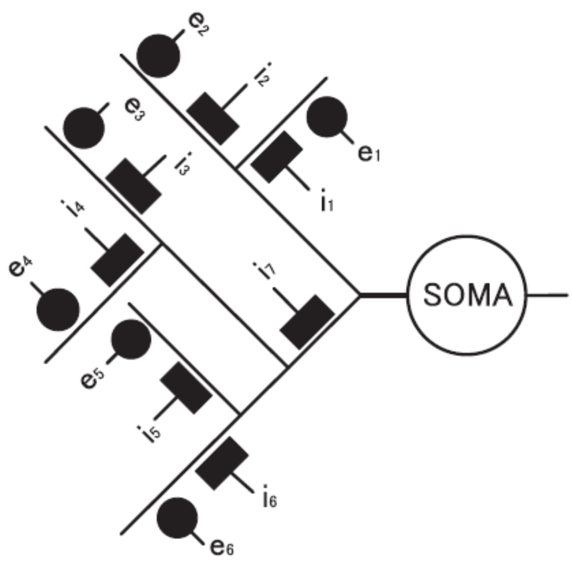


Fig. 4-4 Example of δ-cell dendrite with its highly branched pattern in term in terms of logical operations.

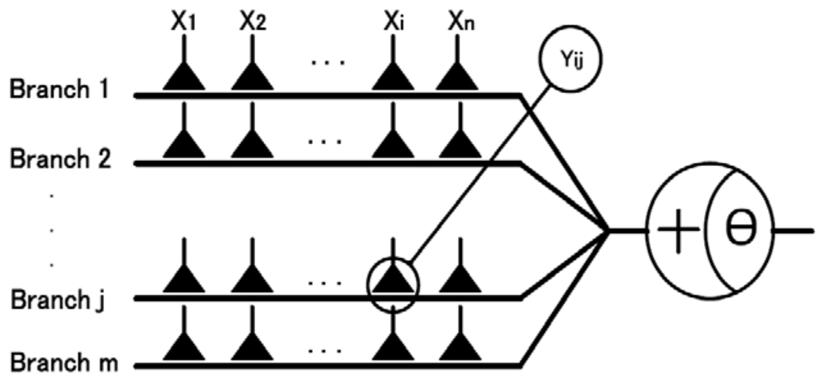
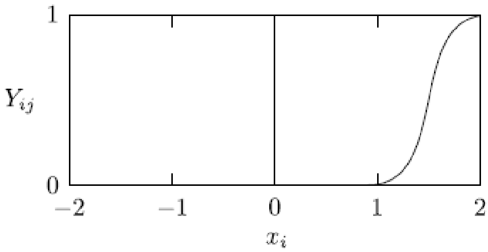
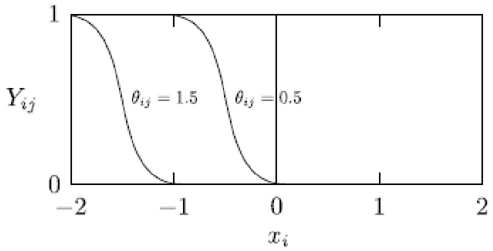


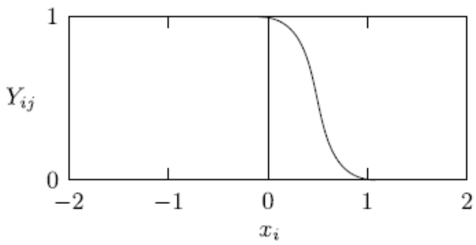
Fig. 4-5 Neuron Model with Dendritic Nonlinearity.



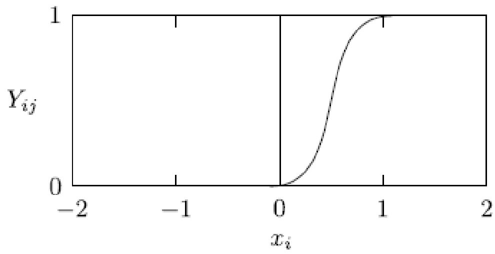
(a) 0-constant connection
$0 < w_{ij} < \theta_{ij}$ (e.g.
$w_{ij} = 1.0,\ \theta_{ij} = 1.5$).



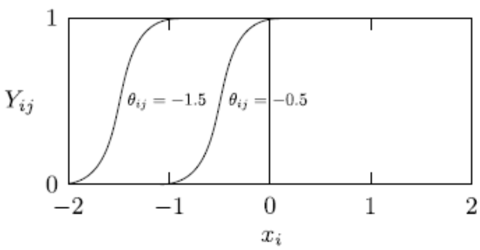
(b) 0-constant connection
$w_{ij} < 0 < \theta_{ij}$ (e.g.
$w_{ij} = -1.0,\ \theta_{ij} = 0.5$ or 1.5).



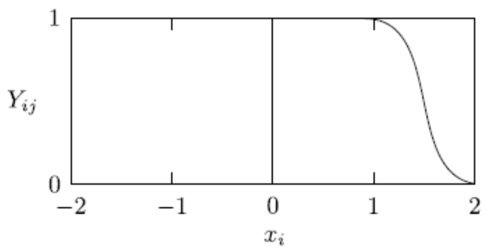
(c) Inversed connection $w_{ij} < \theta_{ij} < 0$
(e.g. $w_{ij} = -1.0,\ \theta_{ij} = -0.5$).



(d) Direct connection $0 < \theta_{ij} < w_{ij}$
(e.g. $w_{ij} = 1.0,\ \theta_{ij} = 0.5$).



(e) 1-constant connection
$\theta_{ij} < 0 < w_{ij}$ (e.g.
$w_{ij} = 1.0,\ \theta_{ij} = -0.5$ or -1.5).



(f) 1-constant connection
$\theta_{ij} < w_{ij} < 0$ (e.g.
$w_{ij} = -1.0,\ \theta_{ij} = -1.5$).

Fig. 4-6 Synaptic connections on different ω_{ij} and θ_{ij}.

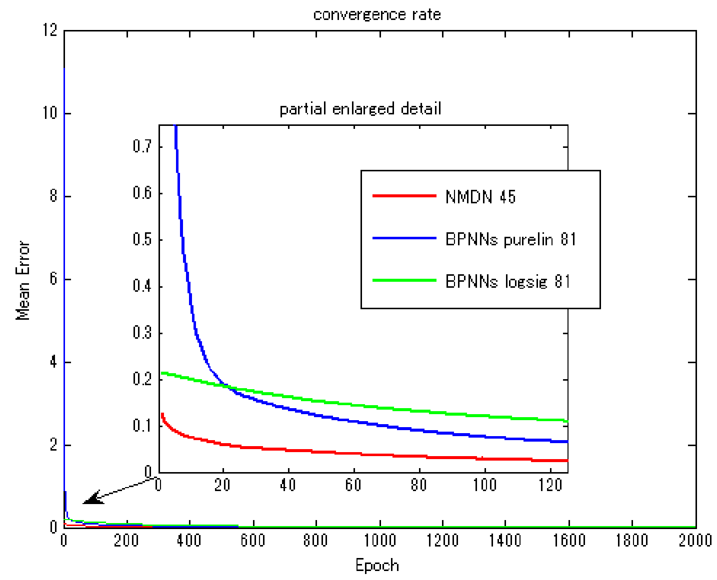


Fig. 4-7 The convergence rate on NMDN and BPNNs.

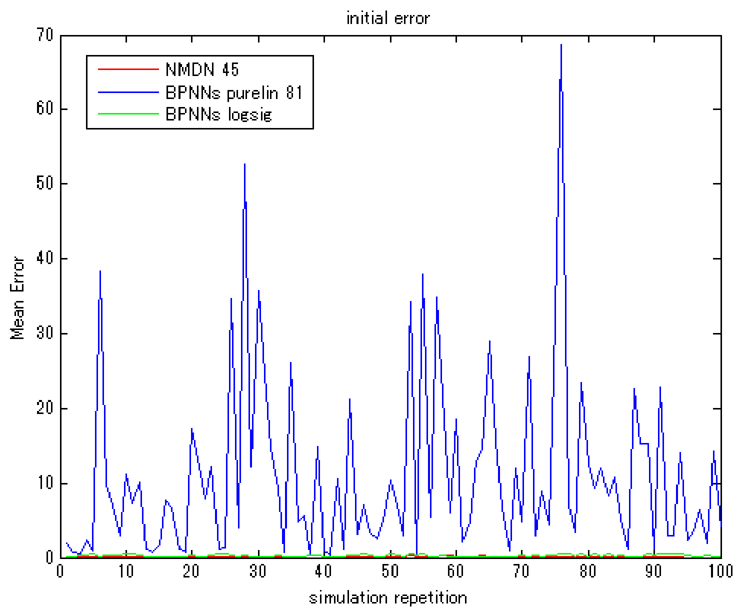


Fig. 4-8 The initial errors of NMDN and BPNNs.

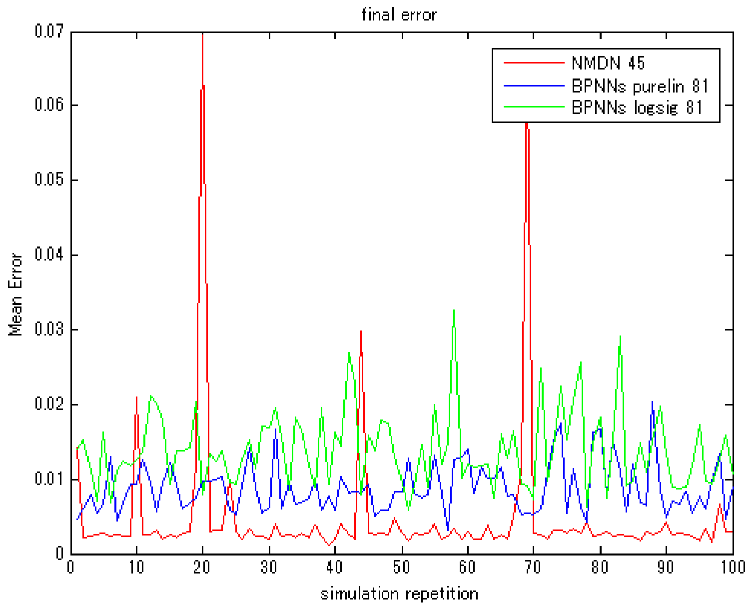


Fig. 4-9 The final errors of NMDN and BPNNs.

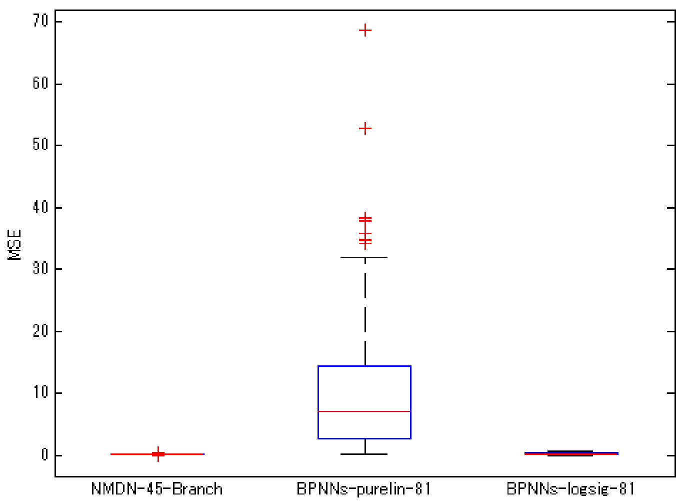


Fig. 4-10 The whisker and box for initial error in NMDN and BPNNs.

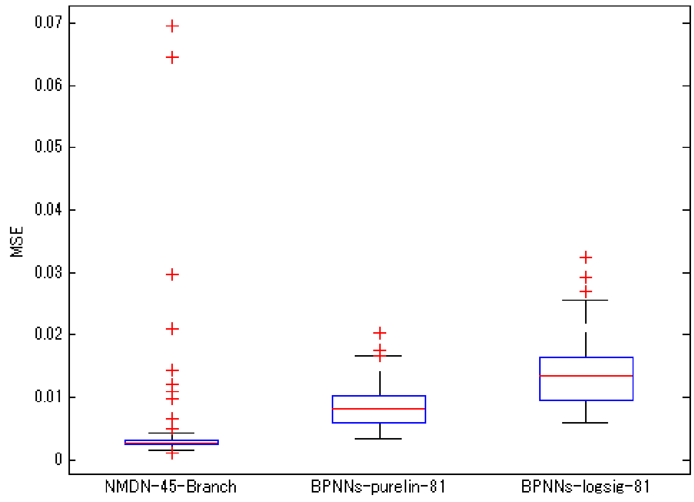


Fig. 4-11 The whisker and box for final error in NMDN and BPNNs.

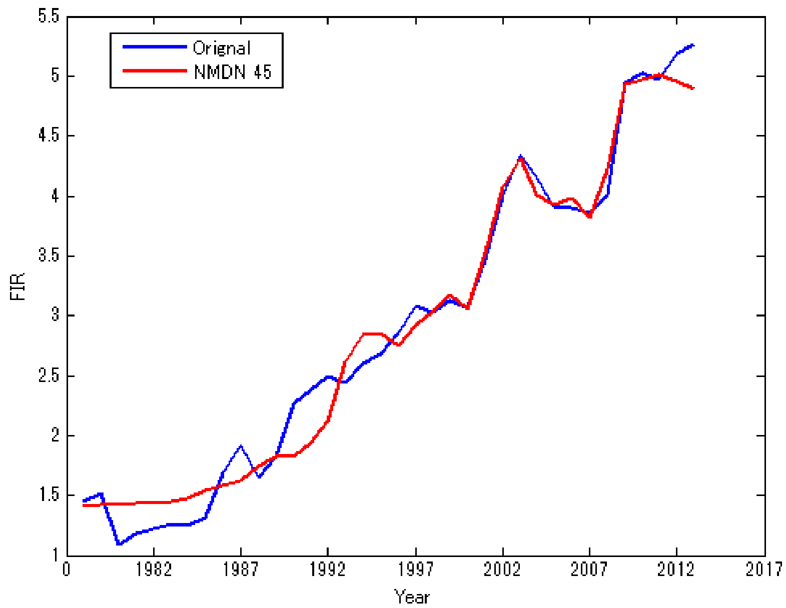


Fig. 4-12 The curves after learning.

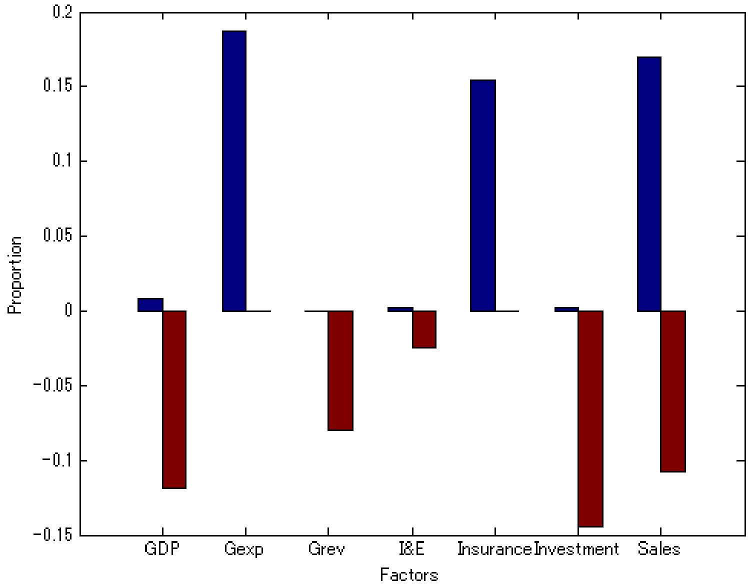


Fig. 4-13 The factor proportion of Shanghai.

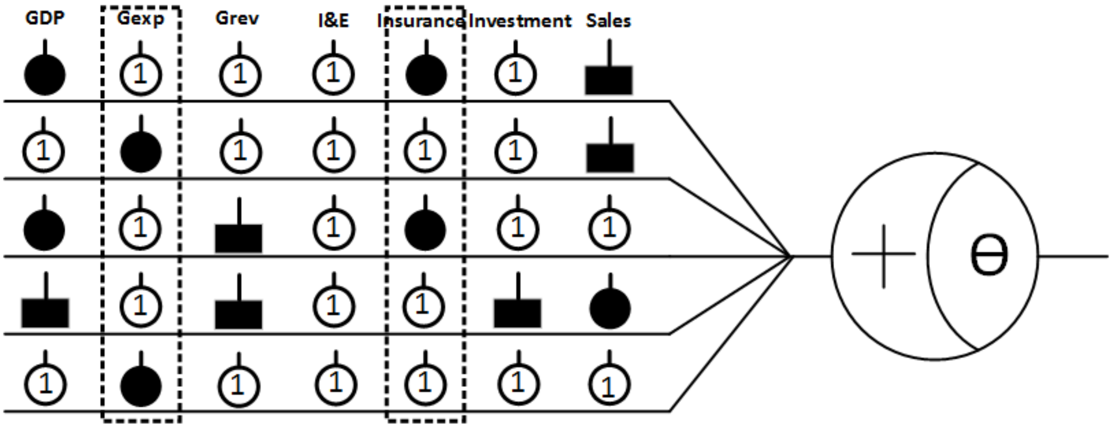


Fig. 4-14 The simplified dendritic morphology.

Chapter 5

Conclusion

In this thesis, three contemporary mathematics methods of game theory, the VAR model and the neuron model are proposed to analyze regional finance in China.

Using game theory, it is possible to analyze the interplay between these two drivers of human action. It becomes possible to design better ways of compensating financial-industry staff to curb undesirable behavior while continuing to promote innovation in the field. Based upon a numerical analysis, it becomes clear that stock options are the most effective method of motivating consistent behavior not only in the near term but also in taking the firm's long-term performance into account. This is because stock options align an employee's interests with the firm's long-term interests. This approach allows capital markets instead of an easily manipulated regulatory system to provide oversight to individuals because the firm's stock price, which is a major component of individual compensation, reflects an evaluation of whether an individual's activities are beneficial to the company. In summary, the stock-option system is an effective way to enhance both the incentive effect and operational efficiency; it should play a key part in reforming the Chinese financial industry to become more innovative and forward looking.

Using the VAR model, this thesis selects four representative cities in China (Beijing, Shanghai, Changsha and Hefei) for which sample data were used to analyze the effect of interest rates on real-estate prices. Four major economic variables, including city GDP, the housing sales price index, the real interest rate and the consumer price index are used in this research, which employs the most recent VAR model. According to the research results, higher interest rates have a negative impact on property prices. However, the strength and depth of higher interest rates' impact on housing prices also show a more obvious difference between cities. The more developed the economy, the more developed its financial markets, the higher proportion of its housing consumption.

The Neuron model with Dendritic Nonlinearity (NMDN) is proposed for analyzing the financial interrelation ratios (FIR) of Shanghai to try to find the main proportion among 7 factors effecting FIR. NMDN is also compared with the NMDN is also compared with the classic BPNNs, and the result shows that NMDN holds a very huge computation ability. And, the simulation results reveal that the ripened dendritic morphology can indicate the the Local general budget expenditure (Gexp), fixed asserts investment (investment) and Domestic retail sales (Sales) are found to make huge contribution to the FIR, however, GDP, Local general budget revenue (Grev), Total import and export (I&E) and fixed asserts investment (investment) cause a negative to FIR, and the evolved dendritic morphology can also indicate which factor will make a positive effect on the FIR. We also believe that the proposed model can be a choice to the economic researchers for their further research.

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