Construction of Macroeconomic Complex Systems in the Age of Artificial Intelligence

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Abstract

In the era of rapid artificial intelligence development, richer data foundations have been provided for studying microeconomic agent behavior, while also enabling effective simulation and analysis of complex macroeconomic systems. These systems are typically composed of diverse microeconomic agents, including governments, households, firms, financial institutions, and international economic entities. A core challenge in macroeconomic system simulation lies in effectively integrating the behaviors and expectations of different economic agents, which generate complex market interactions. Through information transmission, these microeconomic agents form distinct transaction behaviors based on divergent expectations regarding future economic conditions and resource allocation, consequently influencing overall market dynamics. This paper extends the Dynamic Stochastic General Equilibrium theoretical framework, incorporates microeconomic mechanisms such as household utility maximization and firm profit maximization, and employs digital twin technology to explore the interaction mechanisms among multi-category microeconomic agents within macroeconomic systems. Initially, a multi-category intelligent micro-agent model is constructed; subsequently, market transaction mechanisms are integrated to simulate price fluctuations, thereby guiding expectation formation and decision-making processes related to consumption, employment, investment, and production for both firms and households, allowing macroeconomic phenomena to emerge. Finally, dynamic deduction, model validation, and policy effect analysis are conducted on the system. This approach not only provides a novel perspective for understanding the complexity of micro-level behaviors in economic processes, but also offers theoretical support and practical reference for future policy formulation. This system represents an alternative to the System of National Accounts in the artificial intelligence era, serving not merely as a description of current economic conditions but as a deduction of future economic trajectories. Its advantages are primarily manifested in two aspects: 1. In the big data era, data can be presented structurally rather than solely through

aggregates and averages; 2. By integrating artificial intelligence and a systemic game-theoretic perspective, each intelligent micro-agent, through market-based strategic interactions and expectation formation, deduces how structured macroeconomic phenomena "emerge" from micro-level agent decisions.

Full Text

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Abstract

In the era of rapid artificial intelligence development, a richer data foundation is provided for studying microeconomic entity behaviors, while also enabling effective simulation and analysis of complex macroeconomic systems. These systems typically consist of various types of microeconomic entities, including governments, residents, enterprises, financial institutions, and international economies. A core challenge in simulating macroeconomic systems is how to effectively integrate the behaviors and expectations of different economic entities, as these factors generate complex interactions in the market. Through the role of information transmission, these microeconomic entities, influenced by differing expectations regarding future economic conditions and resource allocation, develop their own trading behaviors, which in turn affect the dynamic changes of the overall market. This paper extends the stochastic general equilibrium framework, combines microeconomic mechanisms such as household utility maximization and firm profit maximization, and employs digital twin technology to explore interaction mechanisms among multi-category microeconomic entities in macroeconomic systems. First, we construct multi-category intelligent micro-entity models; second, we combine market transaction mechanisms to simulate price fluctuations; thereby guiding expectation formation and decisions on consumption, employment, investment, and production for firms and residents, emergently generating macroeconomic phenomena. Finally, we conduct dynamic 演绎, model validation, and policy effect analysis. This not only provides a new perspective for understanding the complexity of micro-level behaviors in economic processes, but also offers theoretical support and practical references for future policy formulation. This system serves as an alternative to the national accounting system in the AI era, representing not just a description of economic status, but a 演绎 of the economy's future. Its advantages are: 1. In the big data era, data can be presented structurally rather than just through aggregates and averages; 2. With AI and system game theory perspectives, intelligent micro-entities 演绎 structured macroeconomic phenomena through market 博弈 and expectations.

Keywords: Macroeconomic system; Intelligent agent based model; Economic decision-making; Market transactions; Policy effects

Macroeconomics explores how monetary, fiscal, financial, and tax policies function to influence overall price levels, unemployment rates, economic growth, and cyclical fluctuations [1]. Policymakers face increasingly challenging decision-making situations [2]. Forecasting plays an important role in economic policy formulation [3] and serves as the foundation for modeling economic phenomena [4]. However, for macroeconomic forecasting, one class of models aims to explain economic phenomena but may be insufficiently accurate in out-of-sample prediction, while another adopts simplified statistical descriptions that struggle to provide economic explanations [4]. For example, small-scale macroeconometric models, particularly stationary vector autoregression (VAR) models, cannot effectively capture complex economic relationships [5]. Similarly, the dynamic stochastic general equilibrium (DSGE) model, which dominates rational expectations and optimization methodologies [6], has certain limitations in application when dealing with complex economic phenomena, such as lack of realism [7], insufficient heterogeneity, and overly complex structures [8].

Evidently, traditional modeling methods fail to consider that behavioral agents have bounded rationality under incomplete information [9], and heterogeneity constitutes a key aspect of expectation theory [10]. Said proposed that simulation is more reliable, as it can reproduce and explain observed phenomena from the perspective of individual characteristics [11]. Agent-based modeling (ABM) is one of the commonly used tools for analyzing complex socio-technical systems [12]. Traditional discrete-event simulation methods have limitations, while ABM offers greater flexibility and realism in economics [13-14]. Hommes (2006) noted that ABM can be easily distinguished from other models by its ability to simulate heterogeneity [15], thereby observing how heterogeneity across several interconnected dimensions affects policy transmission [16]. Simulation models can mimic the behavior of actual or anticipated human or physical systems [17-18]. Macal et al. (2006) also believed that agent-based modeling and simulation represent a new approach to modeling systems composed of interacting autonomous agents [19]. This modeling technique derives macroeconomic effects from the construction of economic agents at the micro level, representing a bottom-up research method [20]. This approach has been widely applied across various fields, such as constructing agent-based models for frontier aviation consumer market share analysis and simulation [21], building a credit network model [22], establishing a macroeconomic model to verify financial performance [23-24], as well as applications in COVID-19 simulation [25], policy simulation [26-27], ecology, and engineering decision-making [28]. Gatti (2020) noted that agent-based models have existed for decades, commonly used in hard sciences and many soft sciences, with relatively recent application in economics [29].

Haldane (2019) pointed out that interdisciplinary approaches to macroeconomic modeling are beneficial, and proposed that agent-based models complement existing macroeconomic methodologies [30]. Chen et al. (2012) explored the inadequacies of traditional macroeconomic models in analyzing economic dynamics and formulating policies during the economic crisis at that time, proposing heterogeneous agent models (ABM) as a new theoretical framework and a new tool for economic and policy analysis [31]. This led to the proposal of an Agent-based Computational Economics (ACE) model, which represents the specialization of the fundamental complex adaptive systems paradigm in economics [32]. Dawid (2014) noted that ACE emphasizes agent-level heterogeneity through its very strong microfoundations [33-34], opening new avenues for studying the distributional consequences of policies [35]. Gatti (2020) also demonstrated that the main advantage of this method is "flexibility," which enables macroeconomists to easily study the impact of "complexity" on macroeconomic outcomes [36]. Scholars such as She Zhenyu (2003), Shi Yongren (2007), Ouyang Han (2017), and Hommes (2021) have established agent-based models to simulate how agents make decisions in the economy and explored how these decisions affect the stability of economic systems [37-40].

Silver (2012) noted that macroeconomics is a complex interacting system, and adopting a combination of multiple models may be more resilient than a single approach [41]. For instance, Tesfatsion (2015) constructed a dynamic macro model that includes two major agents—consumers and firms—with intertemporal utility and profit objectives [42]. Therefore, when constructing an intelligent micro-entity-based macroeconomic system, this paper also builds models for multiple sectors, aiming to synthesize the dynamic characteristics of various economic variables to improve prediction accuracy and reliability. Muth (1961) and Lucas (1972) noted that microfoundations are typically closely connected to a specific type of self-interested behavior, manifested in optimization decisions made by economic agents under the framework of rational expectations [43-44], a concept that this paper also follows in its modeling approach. Lambrinoudakis (2019) also revealed how market participants' expectations of future returns and shocks affect corporate leverage ratios and commodity price dynamics [45], indicating that market expectations are a crucial source of information for planners, firms, and investors [46]. Therefore, market expectations are also a key consideration that must be incorporated into the modeling process.

2.1 Paper Content and Logical Relationships

The construction of a macroeconomic system is a complex and comprehensive process involving extensive participation from multiple agent categories, including residents, enterprises, financial sectors, and government departments. These agents play different roles in the macroeconomy, collectively influencing overall economic operation and development. Simultaneously, the construction of macroeconomic systems focuses on transaction processes among various agents in market categories, including buying and selling transactions in commodity markets, capital flows in financial markets, and employment and unemployment in labor markets. These transaction processes not only reflect economic connections and interactions among agents but also demonstrate the basic operational laws and mechanisms of market economies. Based on this foundation, the logical relationships in this paper are illustrated in the following diagram:

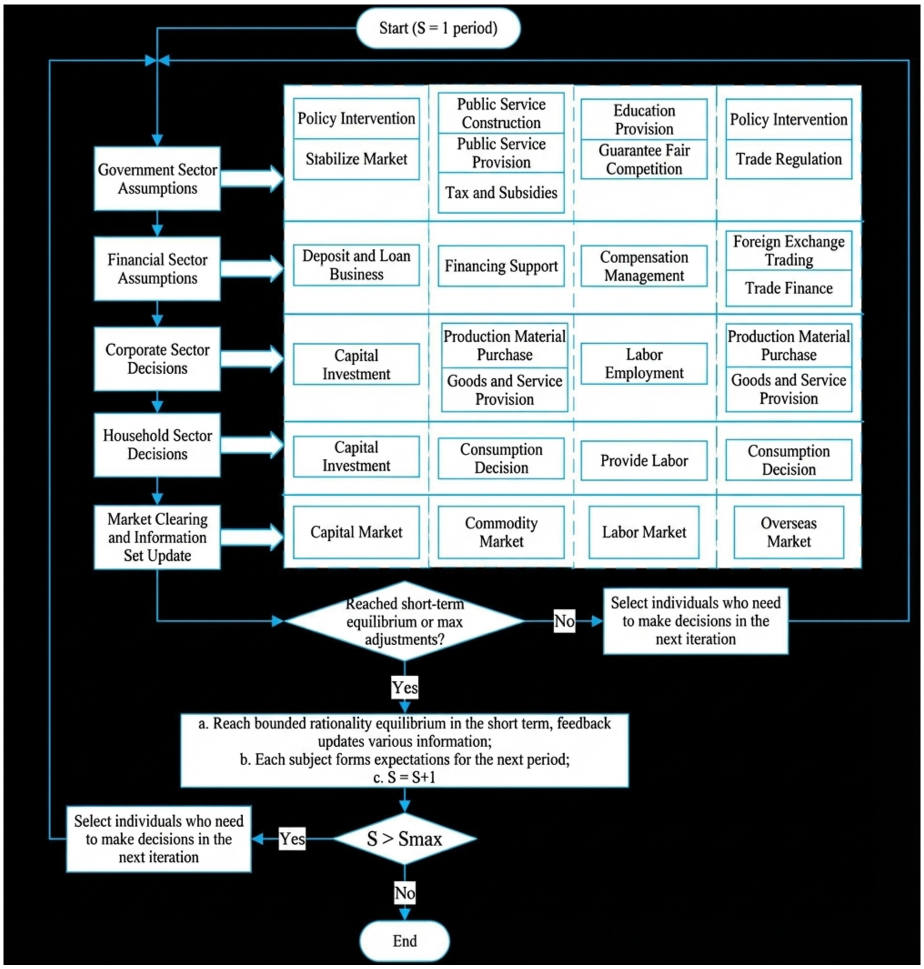

Figure 1: Figure 1

This paper will construct two core models: a resident sector model and an enterprise sector model, featuring multiple heterogeneities in income, consumption preferences, production capacity, and investment philosophy, simulating how residents and firms make optimal decisions based on personal expectations and external information to achieve benefit maximization. Additionally, a market sector model will be constructed to simulate transaction processes in commodity, labor, and financial product markets, reflecting supply-demand relationships and price changes, providing a platform for buying, selling, investment, and labor exchange.

2.2 Model Design Points

To compensate for deficiencies of some economic models in describing and predicting real-world economic phenomena, this paper's model introduces intelligent micro-entities as the basic analytical unit, which not only better approximates the complexity and diversity of real economies but also more accurately reflects actual economic operation conditions and dynamic changes. This primarily depends on several key points:

(1) Multiple Heterogeneities
Differences among micro-level agents in characteristics, behaviors, and interaction rules enable the simulation system to more realistically reflect complex reality. Introducing multiple heterogeneities enhances the effectiveness of system simulation, particularly in complex systems, providing reliable foundations for policy evaluation and optimization.

(2) Complex Adaptability
Micro-level agents adjust their strategies according to environmental changes and other agents' behaviors, enabling the simulation system to better reflect actual dynamic adaptation processes. The introduction of complex adaptability enhances predictive capability for dynamic environments, providing more comprehensive decision-making support for policymakers and enterprise managers.

(3) Sequential Two-Period Decision-Making
Sequential two-period decision-making refers to a process where decision-makers make interrelated decisions at multiple time points based on current states. This method involves uncertainty, where decisions in the first period directly affect the second period, allowing decision-makers to gradually adjust strategies to adapt to uncertain environments and achieve long-term objectives.

(4) Short-Term Bounded Rationality Equilibrium
In complex economic environments, decisions made by residents and enterprises due to limited information and resources form an equilibrium state. Residents conduct consumption and investment based on utility maximization principles, while enterprises formulate production and pricing strategies based on profit maximization principles. This bounded rational economic decision-making behavior shapes short-term economic equilibrium.

3.1.1 Resident Attributes

Below we assume the definition of a resident class in object-oriented programming, such that each resident possesses multiple heterogeneities. The parameter vector for resident in period s includes: Residents Seti Setc Setk Setn Setp Anticipation Delta, with specific meanings as follows:

(1) Personal Characteristics:
- `consumer_{id}`: Resident identifier; smaller numbers in the model indicate higher priority decision-making rights
- `patience`: Patience value; different patience values represent the magnitude

of price adjustment when residents fail to match goods or labor in the market, with the same resident having different patience values for consumer goods or labor
- `s`: Period number, representing the moment when residents choose to enter the market to trade goods or labor; within a period, some residents will place orders while others will not, and placed orders may be for consumer goods or labor
- `v`: Adjustment count; each resident may experience unsuccessful matching after entering the market, thus they choose whether to adjust order information, meaning residents will adjust their posted goods information (such as price or quantity) for the v-th time

(2) Commodity Attributes:
Setc = [c_1, c_2, …, c], representing the set of consumption categories residents can purchase, where each component c represents the existing quantity of consumer goods

(3) Asset Attributes:
Setk = [k_1, k_2, …, k], representing the set of asset categories residents can invest in, where each component k represents the quantity of asset products before decision-making

(4) Labor Attributes:
- `trade`: Market number where the resident's industry is located
- `n`: Labor quantity already provided by the resident before the current decision
- `fixed_{worked}`: Fixed workload, representing the fixed output required daily according to contract after successfully matching with long-term labor
- `ability_{index}`: Work ability index, representing each resident's inherent work capacity; residents with ability index > 80 enjoy the right to change industries
- `overtime_{coefficient}`: Overtime coefficient, referring to the ratio of expected wage rate to regular wage level when residents invest more labor in the short term

(5) Preference Attributes:
Setp = $\{\beta, \sigma_1, \sigma_2, \sigma_3, \lambda_1, \lambda_2, \lambda_3\}$
- β: Utility discount factor
- $\lambda_1, \lambda_2, \lambda_3$: Relative risk aversion coefficients for utility functions regarding consumption, labor, and future wealth respectively; >0 indicates risk aversion, <0 indicates risk preference, =0 indicates risk neutrality
- $\sigma_1, \sigma_2, \sigma_3$: Weight coefficients

(6) Expectation Attributes:
Anticipation = {eProb, eValue, eWage, ePc}
- `eProb`: Subjective expectation of market conditions/economic development probability; each component represents the likelihood of each market condition occurring: eProb = ($eprob_1$, $eprob_2$, …, eprob)
- `eValue`: Subjective expectation of asset price matrix, where p   represents the

expected price of asset j under economic condition i
- `ePc`: Subjective expectation of consumer goods price matrix, where p_c represents the expected price of consumer good j under economic condition i
- `eWage`: Subjective expectation of market wage rates, where each component represents the expected wage rate under each market condition: eWage = ($ewage_1$, $ewage_2$, …, ewage)

(7) Consumer Goods Allocation Index:
Delta = (δ_1, δ_2, …, δ), representing parameters in the utility function for the process of allocating consumption amounts across various consumer goods

3.1.2 Resident Model

In the market, each resident faces information asymmetry and participates in dynamic games through prior actions and information to make "comprehensive decisions." They combine experience, expectations, and assets to evaluate future economic environments, risks, and returns, making optimal strategy choices and behaviors based on utility maximization principles. This decision-making reflects comprehensive consideration of current and future information.

3.1.3 Resident Economic Decision-Making

During the decision-making process, residents are independent of each other, assuming market prices have been determined, and then allocating various resources. The two-step decision process is: First, based on individual utility maximization principles and according to market prices and self-expectations, determine optimal total consumption amount, asset investment quantity, and labor supply; second, allocate the prioritized total consumption amount across various needed consumer goods categories.

(1) First Decision: Allocation among total consumption, asset investment, and labor supply
According to microeconomic principles, residents pursue utility maximization, thus the decision-making process is assumed to be equivalent to solving the following utility maximization problem.

1) Objective Function
The objective function is the sum of current period utility and discounted utility of next period's expected wealth. The current personal utility function u_1 is a function of consumption and labor, representing satisfaction with current personal status. u_2 represents satisfaction derived from next period's expected wealth. Decision variables include the incremental consumption amount Δcashc to be determined, incremental labor supply Δn , and incremental asset purchases Δk , where new expected state variables in each utility function equal current state variables plus decision increments: c + Δc , n + Δn .

2) Constraint Economic Meanings:
(a) The sum of all new expenditures originates from new labor income and ex-

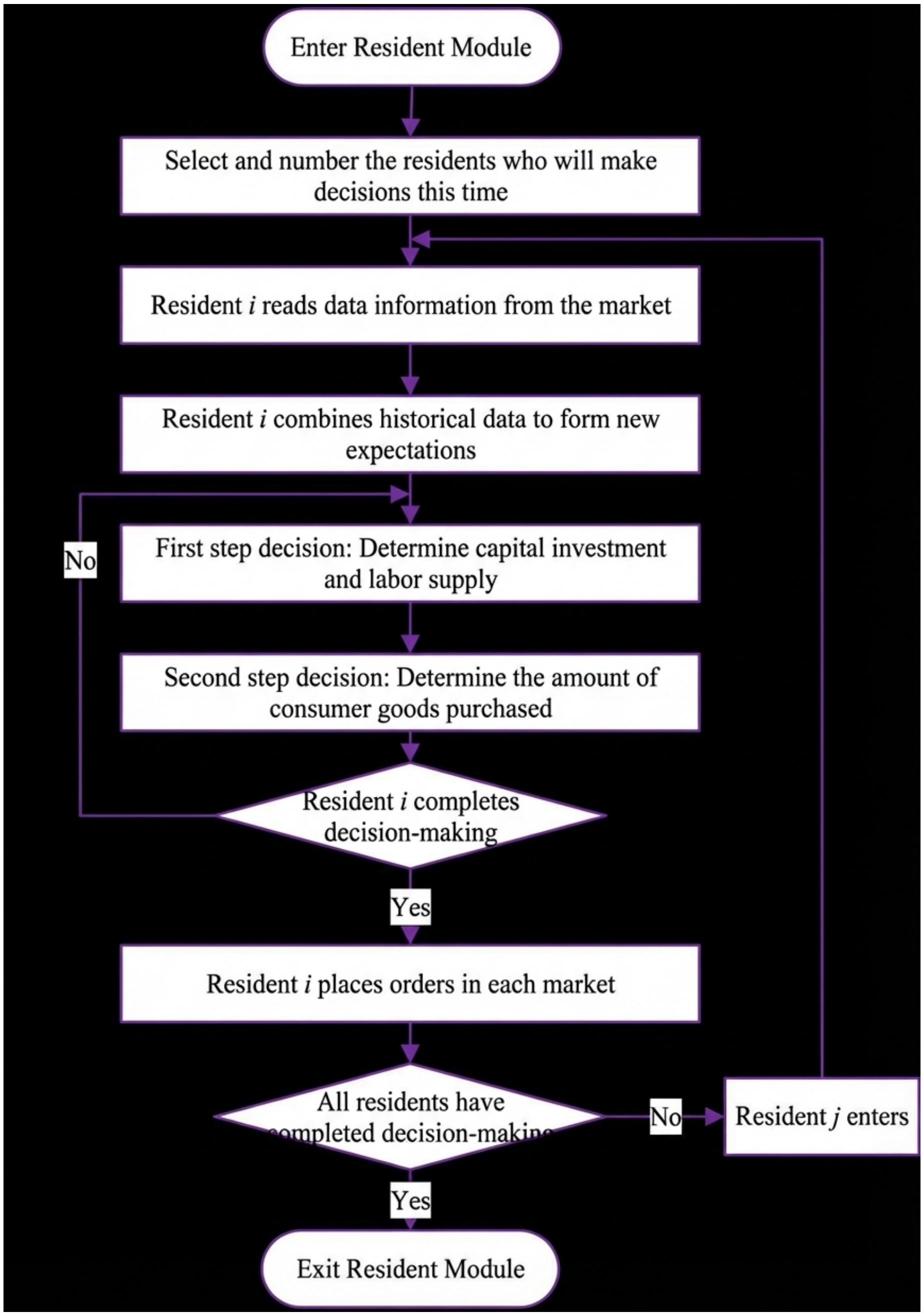

Figure 2: Figure 2

ternal transfers
(b) Assuming already executed consumption cannot be reduced, new consumption amount ≥ 0
(c) Assuming already executed labor contracts cannot be terminated, new labor quantity ≥ 0
(d) Labor quantity provided this quarter ≥ 0, less than individual endowment upper limit

(2) Second Decision: Allocating total consumption across consumption items
Since consumption quantities of various goods are limited by current market prices and the total new consumption amount determined in the first decision, the optimal consumption allocation process is equivalent to maximizing the following utility function:

where u_3 is a function of C , with increasing marginal utility for each component but decreasing marginal increments.

3.1.4 Resident Order Placement Decision

If not entering the market for the first time in period 1 and having transaction demand in the current period, residents must withdraw their remaining order information from the previous match before submitting new orders from this decision to various markets. Each order submission includes: resident ID, price, quantity, transaction product type, buy/sell direction, decision-maker type, and order placement time.

3.2.1 Enterprise Attributes

The enterprise parameter vector for period s includes nine categories: enterprise identity, commodities, materials, labor, machinery, warehouse, capital, R&D, and ratios.

(1) Enterprise Identity Attributes:
`company_{id}, industry, labour_{all}, day, day_{{{line}}_{{num}}}, staff_{id}, patience, s, v, period`
Each component represents: enterprise ID, industry category, employee distribution across production lines, single enterprise sub-period count, single enterprise current period adjustment count, long-term time count, current period remaining days, total production line count, enterprise employee list, enterprise patience value

(2) Commodity Attributes:
`Commodity = {sort, price, price_{volume}, sale_{ceiling}, sale_{{{ceiling}}_{{num}}}}`
Each component represents for each production line: commodity type, current period remaining unit price, next period unit prices under three market conditions, unit commodity volume, current period remaining sales ceiling, next period sales ceiling, commodity inventory

(3) Resource Attributes:

`Resource = {sort, unit_{num}, unit_{price}, unit_{{{price}}_{{volume}}}, num}`

Each component represents for each production line: resource type, material quantity required to produce one unit of commodity in current period, material quantity required in next period, current period material unit price, material unit prices under three market conditions in next period, unit material volume, material inventory

(4) Labor Attributes:

`Labour = {sort, num, price, ceiling, l_{min}, unit_{time}, overtime_{coefficient}}`

Each component represents for each production line: labor type, labor quantity, labor time unit price, daily labor time ceiling, minimum total labor hours, labor time required to produce one unit of commodity, overtime coefficient

(5) Machine Attributes:

`Machine = {num, price, ceiling, unit_{time}, depreciation}`

Each component represents for each production line: machine quantity, machine unit price, daily 机动 time ceiling, 机动 time required to produce one unit of commodity, depreciation

(6) Warehouse Attributes:

`Wareh = {num, price}`

Each component represents: warehouse quantity, warehouse unit price, unit warehouse volume ceiling

(7) Capital Attributes:

`cash, asset, wage, liquid`

Each component represents: current period remaining demand deposit, fixed assets, existing prepaid wages, expected reserved funds

(8) R&D Attributes:

`Research, Develop, re_{{{development}}_{{cost}}}`

Each component represents for each production line: whether to add new R&D, R&D cost, R&D failure probability

(9) Ratio Attributes:

`prob, depreciation_{rate}, discount`

Each component represents: probability of expected next period market condition, unit product depreciation rate, discount rate

3.2.2 Enterprise Model

In real economic environments, enterprises also operate under conditions of information asymmetry. In each decision cycle, enterprises comprehensively evaluate future economic environments and potential risks and returns by combining past performance, market trends, competitor behaviors, and consumer demand.

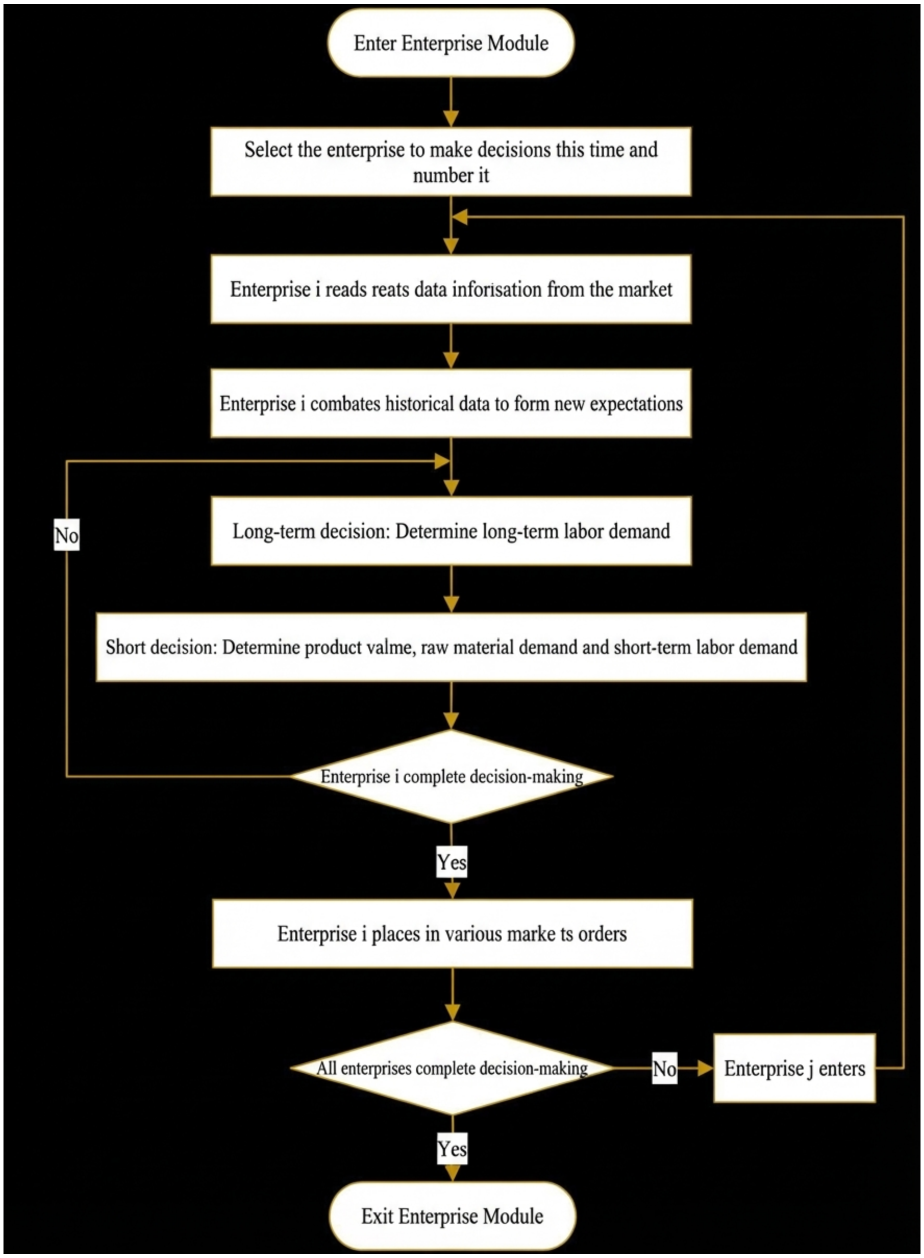

Figure 3: Figure 3

3.2.3 Enterprise Economic Decision-Making

Enterprise economic decisions are divided into long-term and short-term decisions. Long-term decisions primarily involve determining the labor quantity needed for the next ten periods and recruiting based on overall operational requirements, which can be viewed as the sum of ten short-term decisions to optimize final labor demand. After employee recruitment, the short-term decision phase requires adjusting current period production and sales volumes according to market demand and production capacity, forecasting next period's required raw materials, and reasonably arranging employee workloads.

(1) Objective Function

According to microeconomic principles, enterprises pursue profit maximization, thus the decision-making process is assumed to be equivalent to solving the following profit maximization problem. The objective function is the sum of current period profit and discounted expected next period profit. The current period profit function π_1 is calculated by subtracting material, labor, and warehouse storage costs from the sum of current period revenue and material spreads, representing the maximum expected profit value for the current period.

(2) Constraint Conditions:

(a) Production material constraint: The sum of new material quantity and inventory material quantity must satisfy the material quantity required for new commodities to avoid affecting subsequent production

(b) Capital constraint: Enterprises must ensure current expenditures do not exceed budget while maintaining remaining cash $\geq$ reserved funds; `cflow` represents current period remaining cash amount, `gcash` represents remaining funds, `expend` represents total expenditure for this decision

(c) Production line constraint: Total available labor distributed across production lines must be sufficient in the short term

(d) Commodity constraint: Commodity sales ceiling must be $\geq$ sum of new commodity quantity and initial inventory

(e) Warehouse constraint: Maximum warehouse capacity must accommodate the volume occupied by all enterprise commodities and materials

(f) Non-negative constraints: New commodity production/sales quantities and commodity/material inventory quantities must all be ≥ 0

3.2.4 Enterprise Order Placement Decision

If not entering the market for the first time in period 1 and having transaction demand in the current period, enterprises must withdraw their remaining order information from the previous match before submitting new orders from this decision to various markets. Each order submission includes: enterprise ID, price, quantity, transaction product type, buy/sell direction, decision-maker type, and order placement time.

3.3.1 Government Sector Assumptions

The government sector is an important macroeconomic regulation 主体 that pursues social welfare maximization in its decision-making. This objective is achieved by optimizing resource allocation to improve economic efficiency, promote economic growth, and create more employment opportunities. Therefore, the principle for constructing government models is:

$W = \max[U \ + \beta E(U \ _1)] + \text{Control}$

where W represents maximum social welfare value, U represents current period social welfare utility value (such as utility from public services and welfare distribution), U $_1$ represents next period's expected social welfare utility value, and β is the discount factor reflecting the emphasis on future utility. When considering policies, the government must focus not only on current utility but also on future expected utility, optimizing overall social welfare through appropriate policy interventions.

3.3.2 Financial Sector Assumptions

As a core 要素, the financial sector operates based on effective modeling of money supply, interest rates, and financial institution behaviors, optimizing capital allocation and investment decisions through real-time data analysis of market trends and user needs. Taking commercial banks as an example, each bank pursues profit maximization based on its own preferences, resource allocation, and expectations of future information values. The principle for constructing commercial bank models is:

$\max[\text{profit} \ + \beta E(\text{ewealth} \ _1)] + \text{Control}$

where L represents the sum of maximum profit value in period s and discounted expected wealth value for the next period under budget constraints, profit represents the maximum profit obtained by the bank 主体 in the current period, β represents the bank's subjective discount coefficient in the current period, E represents the expected utility value brought by next period's expected wealth value in the current period, and ewealth $_1$ represents the commercial bank's expected wealth value in different expected market conditions for period s+1, including not only the bank's expected profit for the next period but also other non-profit financial wealth values.

4.1 Market Model

A market is a location or place where buyers and sellers exchange goods and services. Buyers and sellers conduct transactions through price mechanisms to achieve resource allocation. This paper constructs a class object to simulate the transaction processes of various sectors in the market, with main processes including market order placement, matching and transaction, order withdrawal, and information feedback. Markets can be primarily divided into commodity markets and labor markets based on transaction types, both following the same process flow as shown below:

4.2 Market System

The labor market is divided into long-term and short-term labor transaction markets. In the model, the employment market (long-term labor market) refers to the transaction process between labor buyers and sellers at the beginning of the period, similar to commodity markets. Both parties adjust their orders based on expectations, market conditions, and current transaction situations until transactions are completed or maximum adjustment counts are reached and orders are withdrawn, with withdrawal indicating unemployment for suppliers. Contracts are set to be valid for multiple periods, requiring suppliers to provide fixed labor output over multiple periods. The short-term labor market refers to situations where, after signing long-term contracts, employers often require workers to work overtime to improve production efficiency and profits, while labor suppliers are also willing to work overtime to earn more wages.

The commodity market is where suppliers and demanders trade goods and services. Residents will purchase six types of goods or services, while enterprises across primary, secondary, and tertiary industries provide different qualities and performances of two goods or services respectively. Residents can meet their needs in these three types of markets, with each industry enterprise having its own target consumer groups. In commodity markets, all order information is aggregated and sorted by posted price, with buyer information sorted in descending order and seller information in ascending order to follow price priority principles, ensuring that buyers with the highest posted prices match with sellers with the lowest posted prices first to achieve optimal transaction outcomes.

4.3 Market Coordination and Feedback Mechanism

In this model construction process, residents and enterprises are often influenced by their respective expected decision periods s and expected adjustment counts v in their decision-making, which largely determines whether they choose to enter the market and when to adjust orders. Residents and enterprises jointly enter the long-term labor market, where enterprises place orders based on production plan needs and residents set order quantity to 1. After successful transactions, residents' orders in the market are permanently withdrawn, with layoffs occurring only when enterprises go bankrupt.

The enterprise bankruptcy mechanism is similarly an indispensable part of market economies. Enterprises may face various challenges during operations, leading to deteriorating financial conditions and eventual bankruptcy. As shown in

, when an enterprise confirms it cannot continue operations, it needs to exit the market and conduct necessary employee dismissal procedures.

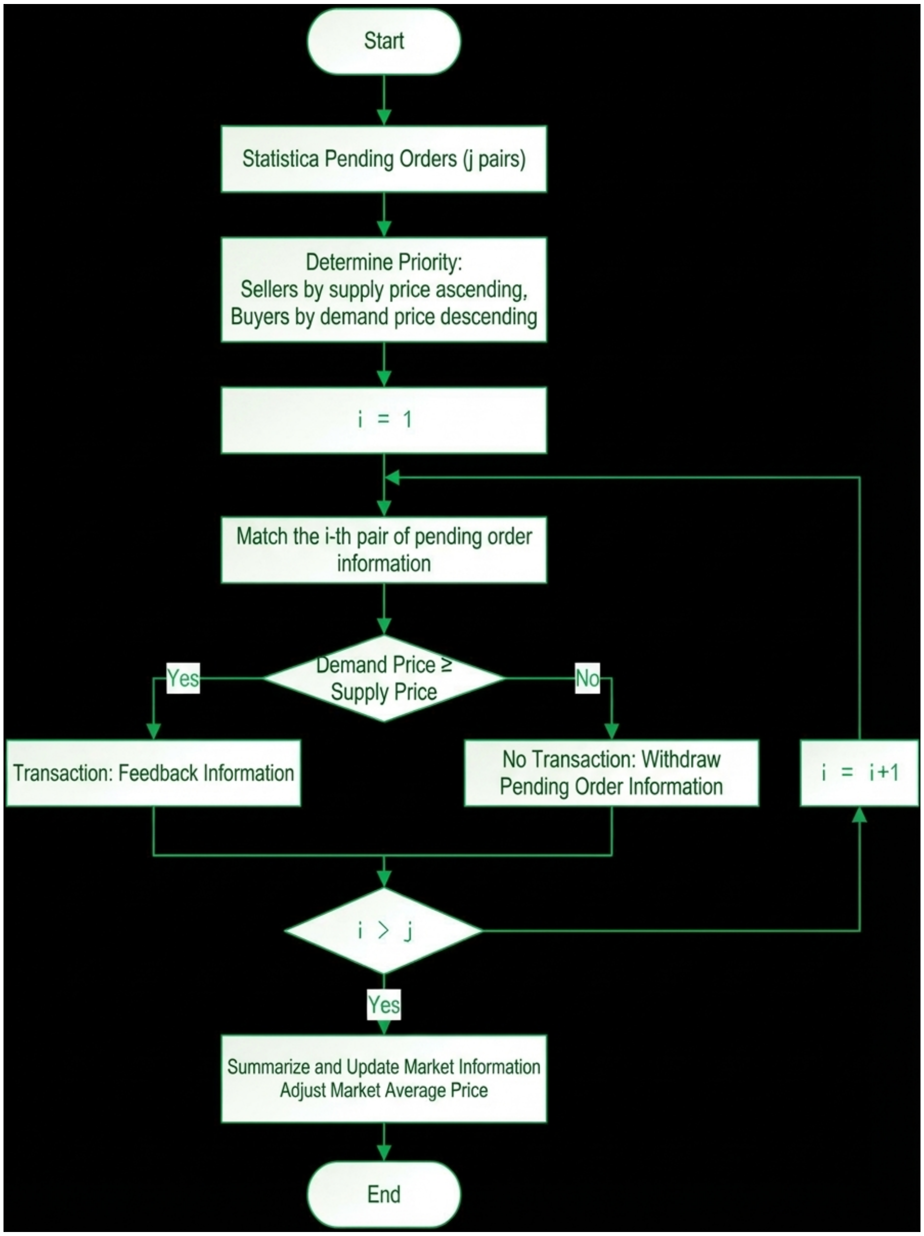

Figure 4: Figure 4

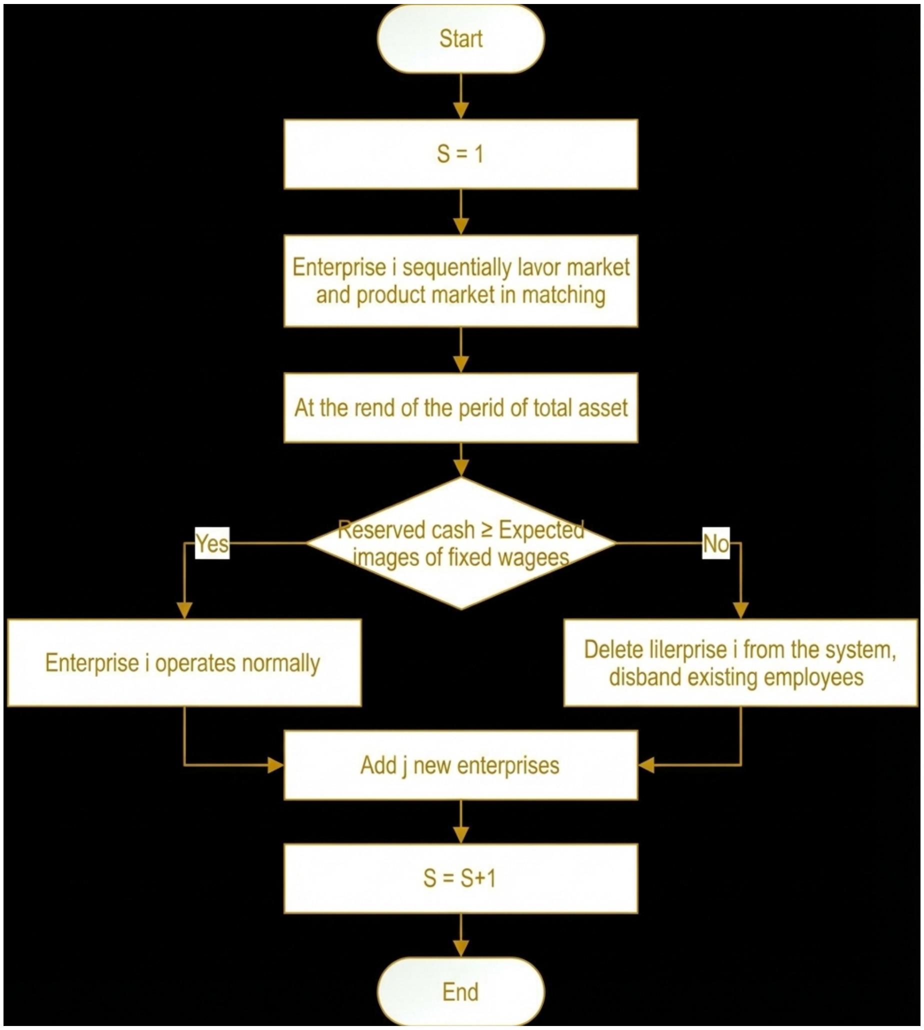

Figure 5: Figure 5

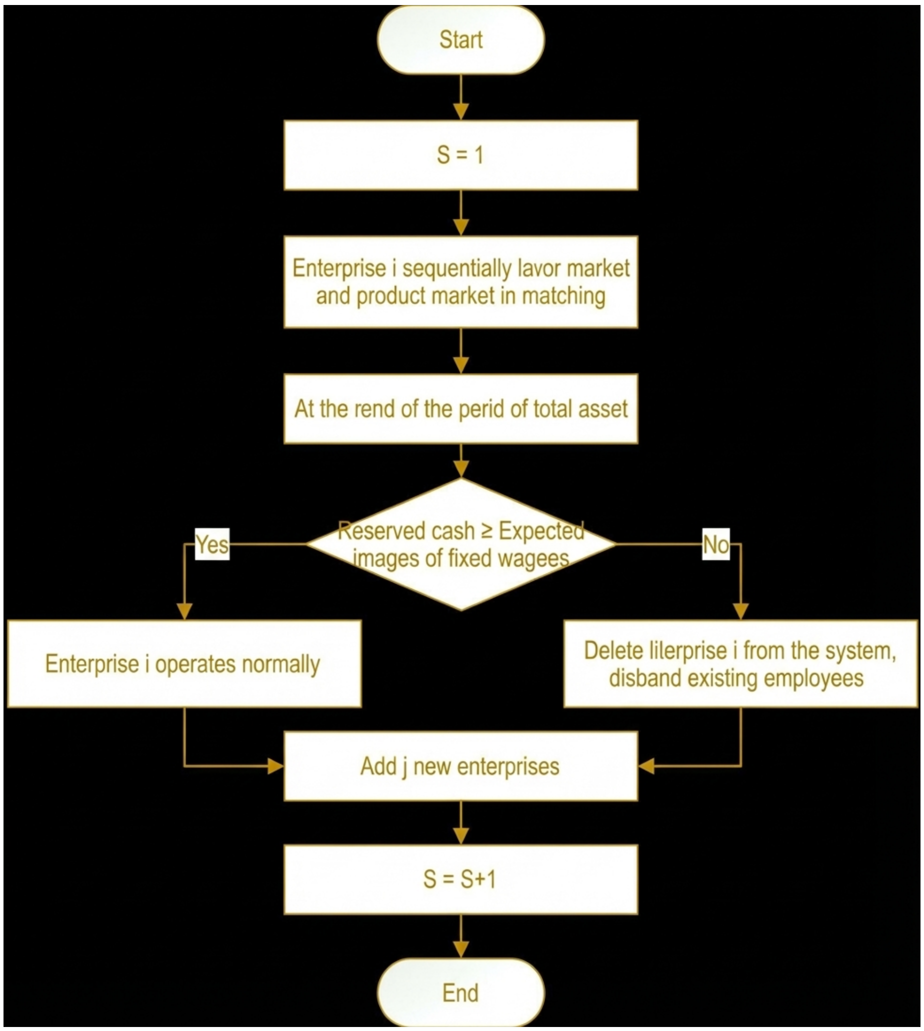

Figure 6: Figure 5

If enterprises fail to recruit sufficient employees, they will continue placing orders in the market to find suitable talent and maintain supply-demand balance. If residents fail to match successfully, they will adjust expectations based on market conditions and decide whether to continue placing orders or enter the industry-changing mechanism. Specifically, the resident industry-changing mechanism refers to individual workers' industry-switching behavior in the long-term labor market based on their matching situation and economic expectations. As shown in [FIGURE:6], when residents cannot find jobs in their current industry with wages matching their expectations or when their original enterprises declare bankruptcy, but their work ability index exceeds 80, they will choose to match within the industry with the current highest market average price to obtain better economic returns and career development prospects.

[FIGURE:6]

Once enterprises successfully recruit employees or residents find positions, enterprises can purchase raw materials for production in commodity markets, then conduct sales, while residents use wages to purchase consumer goods. As sales grow, enterprises typically expand production and require employee overtime, thus entering the short-term labor market to seek overtime work purchases, with employees posting their willing overtime amounts based on personal circumstances.

5.1 Basic Assumptions

(1) Macroeconomic System Initialization
This paper establishes a system containing over 2000 residents and more than 40 enterprises, operating for s periods, where each period allows residents and enterprises v adjustment opportunities. These 40+ enterprises belong to primary industry (6), secondary industry (14), and tertiary industry (24), with enterprises in each industry capable of producing two different levels of products. Residents have demand for six types of goods or services, which correspond exactly to the six products produced by enterprises. Since producing different products requires enterprises to recruit employees with different skills, the entire system can be viewed as having only six major industries.

This paper sets one period as 30 days, with each decision representing order information within one month, and each month allowing 10 adjustment opportunities. Therefore, each adjustment converts order quantity into short-term order quantity for that brief period, though the horizontal axis in the following diagrams uses adjustment count as the scale, with v = 30 representing that economic agents have made decisions and placed orders in the market for three months with a total of 30 adjustments.

(2) Macroeconomic Agent Class Initialization
In this model, initial values are set to truly reflect social phenomena. For residents, attribute initializations include: fixed workload set at 2/3, aiming to leave 1/3 remaining space for optional short-term overtime. Work ability

index, patience values, and other attributes are set using normal distribution, concentrating most residents' attribute values near average levels while 少数 residents' values deviate from this center, forming a "long-tail" effect. Expected prices for six purchasable goods are set and updated based on current market prices, enabling residents to reasonably arrange commodity purchases according to market prices.

For enterprises covering three industry types, due to profit differences across industries, the model sets hierarchical distinctions when establishing initial values for these three categories, such as setting initial funds at 1.5 million for primary industry, 1.7 million for secondary industry, and 1.9 million for tertiary industry. Correspondingly, initial values for expected employee recruitment numbers and machine quantities also differ, with tertiary industry service enterprises requiring significantly higher employee and machine numbers, higher market prices, and relatively larger production ceilings and loan totals.

(3) Market Class Initialization

For the market model, initial market average prices within the system are set as follows, representing magnitudes 100 times the current values, which aligns better with reality:

(1) Long-term labor market average price: [0.85, 0.88, 0.95, 1.00, 1.04, 1.09]

(2) Short-term labor average prices for each industry are set as the product of long-term labor average price and overtime coefficient; commodity market average prices: [0.03, 0.025, 0.06, 0.059, 0.125, 0.14]

(3) Financial commodity market average price: [0.08, 0.10, 0.12]

To better test model feasibility, this paper makes a special setting in the verification section: residents and enterprises preparing to enter the market are divided into odd-numbered and even-numbered groups, with resident order placement counts set as two batches: odd-numbered group [1,3,5,7,9] and even-numbered group [2,4,6,8]. To ensure buy and sell order information exists in the market from the beginning to meet initial transaction conditions, enterprise order information differs slightly from residents: odd-numbered group [0,1,3,5,7,9] and even-numbered group [0,2,4,6,8].

5.2 Dynamic 演绎 of Macroeconomic Agents in Market Mechanisms

The first step is market order placement. At the beginning of each period, each agent places their transaction intentions in the trading market based on their expectations and decisions. Order information mainly includes: order placer ID, quantity, price, time, adjustment count, period number, and order category. The posted price represents the expected transaction price based on market conditions and endowments—maximum acceptable price for buyers and minimum acceptable price for sellers.

The second step is matching and transaction. In the market, transactions occur in two stages: initial matching using call auction rules, followed by continuous auction. After market conditions are determined, traders buy and sell at current market prices. Unmatched buyers and sellers decide whether to adjust prices and quantities based on patience values. High patience means traders prefer waiting for favorable prices, suppressing market price fluctuations; low patience indicates urgency to trade, potentially increasing price volatility. Patience values reflect trader psychology and affect market supply-demand relationships and price formation.

For agents choosing to continue placing orders without adjustment, they remain as current market status. Agents choosing readjustment modify posted prices according to readjustment price strategies and optimize readjusted order quantities before continuing to place orders and rematch based on current market conditions. The readjustment price strategy is:

f(u,v) = current_{{{market}}{{average}}}{price} $\times$ (1 + patience^{-1} $\times$ 2arctan(log(v))) $\times$ random(0.9,1.1)

The third step is order withdrawal. For various trading agents who fail to match successfully in the short term, they may rely on experience or current market information to timely adjust expectations and make more accurate and rational decisions. Based on this, this model also provides multiple adjustment opportunities for each agent until the market reaches a state where one side is cleared. The adjustment count also has a maximum threshold maxv; when all parties reach the maximum adjustment count, they stop adjusting, and agents still without successful transactions after stopping adjustment have their information withdrawn from the market.

The fourth step is information feedback. Before each readjustment, transaction information from the previous step must be fed back to update each agent's status attributes. Updated resident attributes include: each consumer good stock c, labor quantity n, asset product quantity k, remaining spendable cash cashc, patience level with market matching, expected prices epc, epk, en. Updated enterprise attributes include: existing prepaid wages wage, current remaining days day, demand deposit cash, sales ceiling sale_{ceiling}. After this adjustment, v is updated.

After completing the commodity market transaction process within one period, end-of-period summary updates are required. Resident updates include: consumer goods stock c, asset product quantity k, long-term labor n. Enterprise updates include: current remaining days day, existing wages wage, sales ceiling sale_{ceiling}, current remaining demand deposit cash, inventory num. After period completion, s is updated.

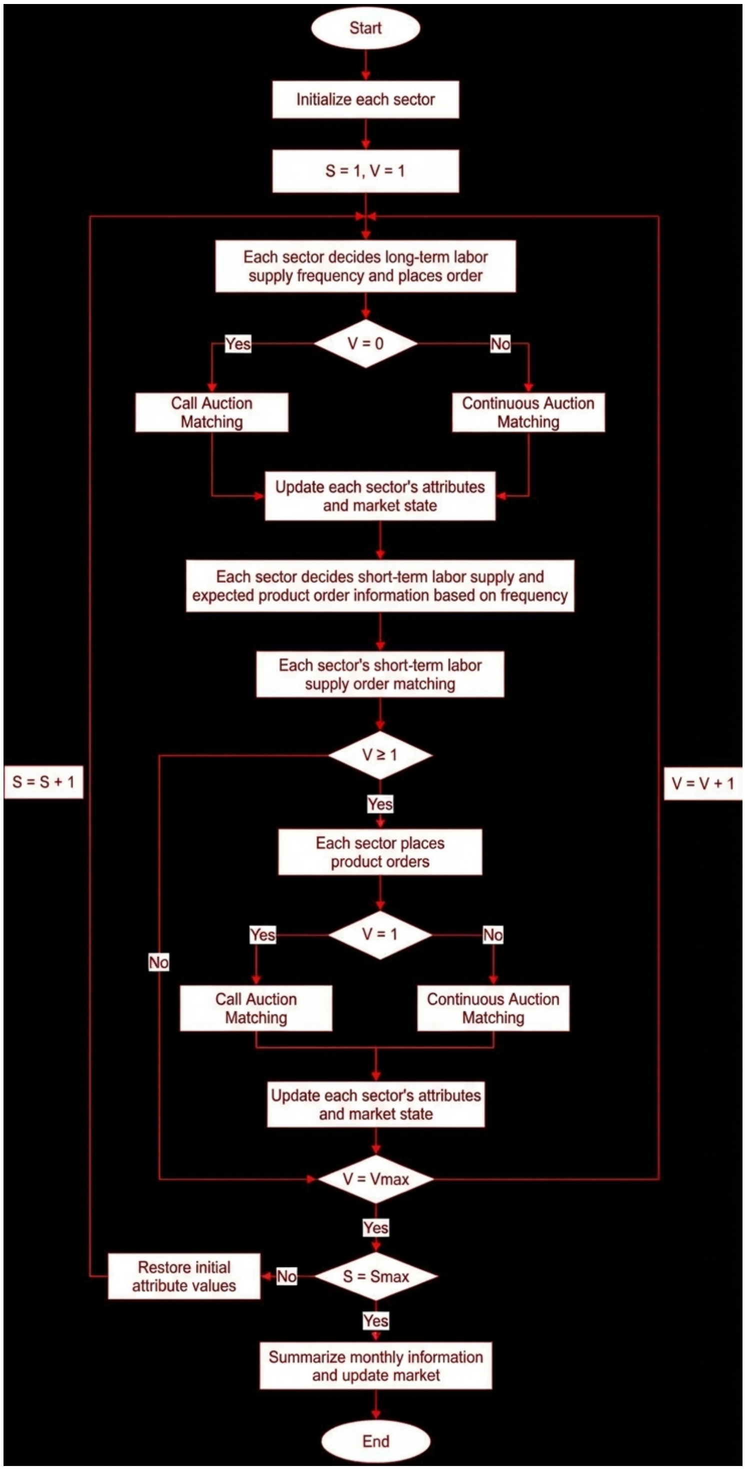

Figure 7: Figure 7

5.3.1 Employment Market Transaction Model

Long-term labor matching order quantity represents recruitment numbers, where each resident represents themselves (quantity = 1), and enterprise order quantity represents needed workers (integer). Residents' order quantities in odd and even batches decrease with adjustment count increases. Unemployed residents and enterprises needing recruitment in the system gradually decrease. At v = 0, all residents have been matched to employment positions. As shown in

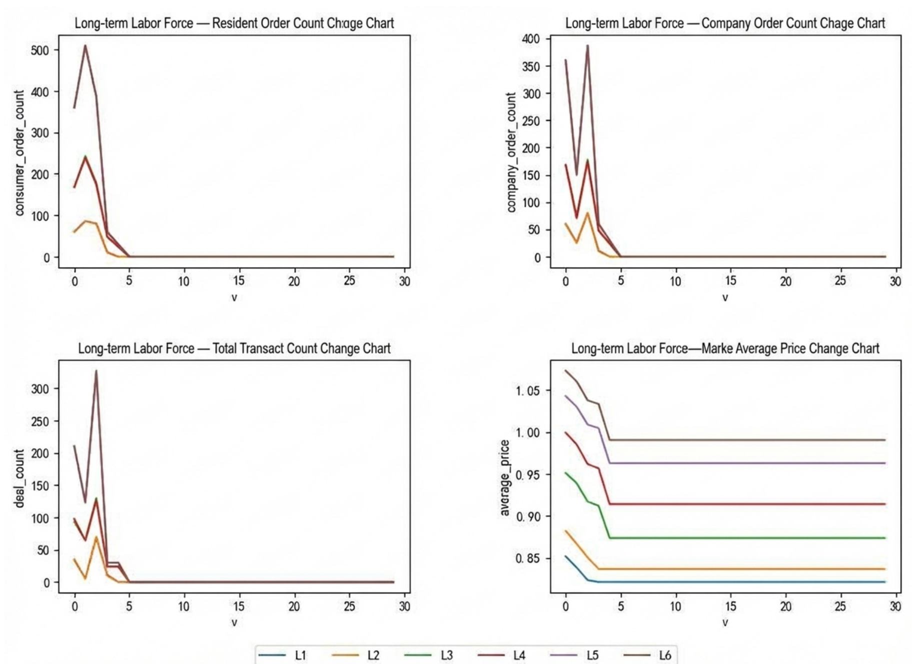

Figure 8: Figure 8

, because the number of residents placing orders at the same time is always smaller than enterprises, the market condition is oversupplied, causing long-term labor market average price to decrease with adjustment count increases. Market average price changes with transaction conditions, with no transactions occurring at v = 5, thus market average price remains stable at v = 4.

The first and second industries represent worker recruitment, third and fourth industries represent service personnel, and fifth and sixth industries correspond to high-tech talent. With industrial advancement, the latter has relatively higher technical content and wage levels, with market average prices showing stepwise increases. The model requires residents to successfully complete long-term recruitment before short-term overtime, and enterprises must recruit suitable employees to maintain production. Therefore, in model verification, total supply and demand are set equal. Across the three industries involved, enterprise recruitment numbers equal resident numbers for two industry types, resulting in minimal differences in order placement numbers, though not absolutely identical.

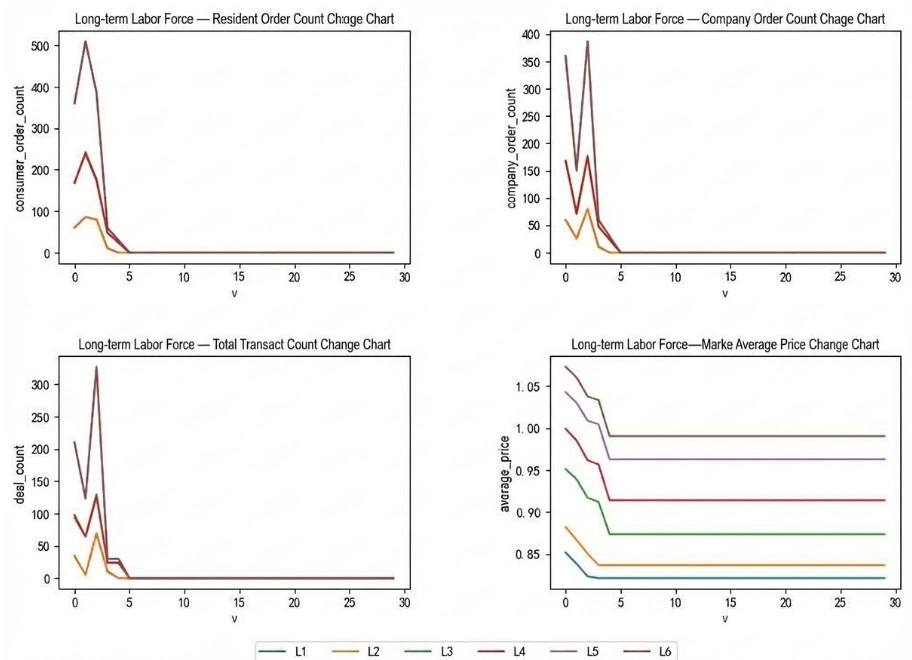

Figure 9: Figure 8

5.3.2 Labor Quantity Transaction Model

As shown in

, residents' total supply and enterprises' total demand represent actual working hours needed by enterprises, while residents' order quantities reflect their expected total workload, including regular and overtime hours. Overtime is limited to matching within the same enterprise. Total matched labor quantity differs from labor matching, with tertiary industry showing higher demand than secondary industry due to higher profits, longer production deadlines, and higher overtime wage rates. Simultaneously, secondary industry labor order quantities exceed primary industry.

In actual average transaction price diagrams, the curve shows a sharp increase at v = 0 because both odd and even batches enter the market for matching for the first time, greatly increasing successful matching probability. However, at v = 1, the number of residents and enterprises remaining in the labor market is smaller, resulting in declining transaction quantities. The changing trend shows

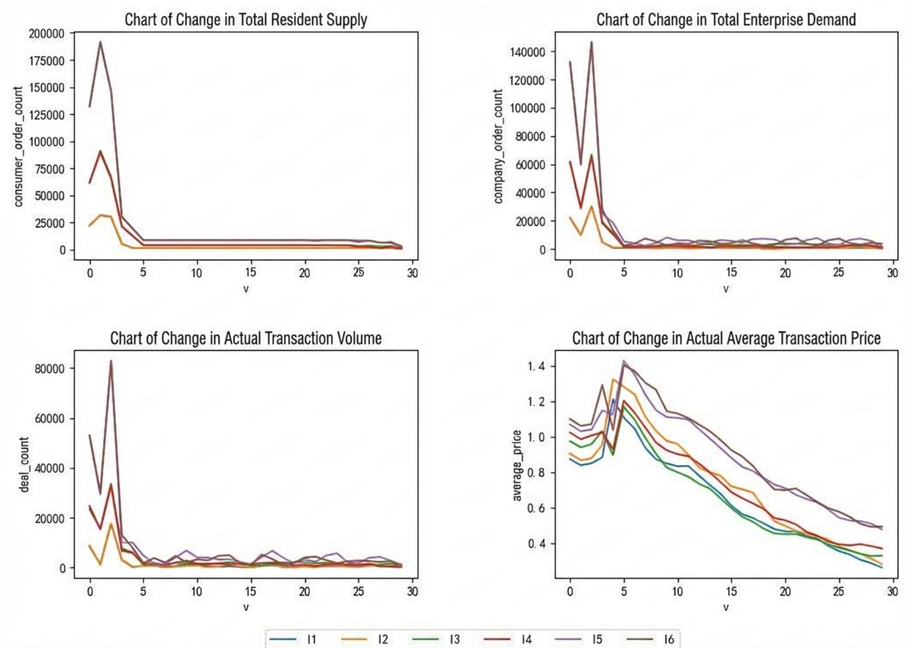

Figure 10: Figure 9

decline and slight increase from v = 1-3, as matched residents and enterprises constitute a large proportion of the employment market, and long-term labor market average price does not show a downward trend. Increasing numbers of residents and enterprises can conduct short-term overtime labor matching, with short-term overtime wage rates exceeding regular wage rates, causing actual average transaction prices to rise during v = 2-3. At v = 4-5, very few residents and enterprises remain for matching, and long-term labor market prices show significant declines. Although short-term overtime labor matching occurs, long-term labor orders constitute a large proportion compared to short-term overtime orders, resulting in declining overall average prices for total labor quantity transactions. After v = 5, all employees are matched, so long-term labor transaction volume is 0, and short-term labor quantity dominates, causing average prices to rise. In subsequent matching after v = 5, residents' overtime quantities always exceed enterprise demand, causing transaction average prices to continuously decline.

5.3.3 Commodity Transaction Model

As adjustment counts increase, after residents enter the employment market and match with their enterprises, they can stably supply labor quantities and purchase needed goods. Similarly, after enterprises match with needed long-term labor, they can stably maintain production and sales quantities. Therefore,

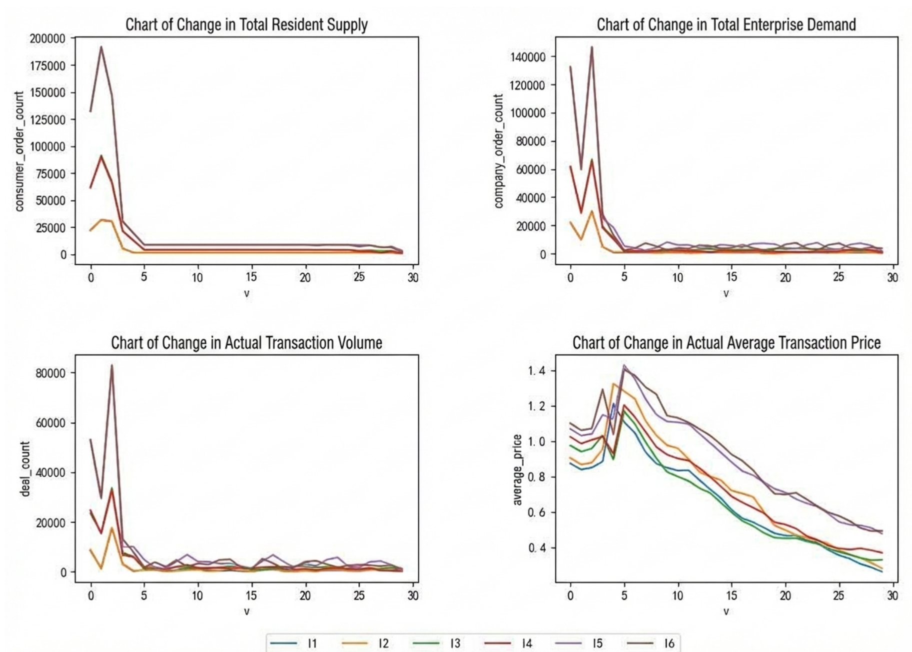

Figure 11: Figure 9

their order quantities stabilize after v = 5. Since enterprise supply quantities always exceed resident demand quantities, commodity market average prices show a downward trend. For commodities that enterprises cannot completely sell, the model verification section includes a commodity export setting to prevent enterprise bankruptcy due to low sales volumes.

6.1 Tax Policy

Personal income tax and corporate income tax implementation provides government fiscal revenue and promotes economic stability. All residents in this system are employed workers with average wage rates in [0.1, 0.9], so a uniform 10% personal income tax rate is set for residents with wage rates > 0.4, and corporate income tax rate is set at 25%. Based on this, assuming a 20% tax rate reduction (personal income tax range [10%, 8%], corporate income tax range [25%, 20%]), a series of comparison diagrams are produced.

6.1.1 Tax Changes Under Different Tax Rates As adjustment counts increase, more residents successfully match with long-term labor and pay personal income tax. As shown in

, after all residents in the system are matched, personal income tax stabilizes among residents with wage rates > 0.3. Sawtooth fluctuations arise from resi-

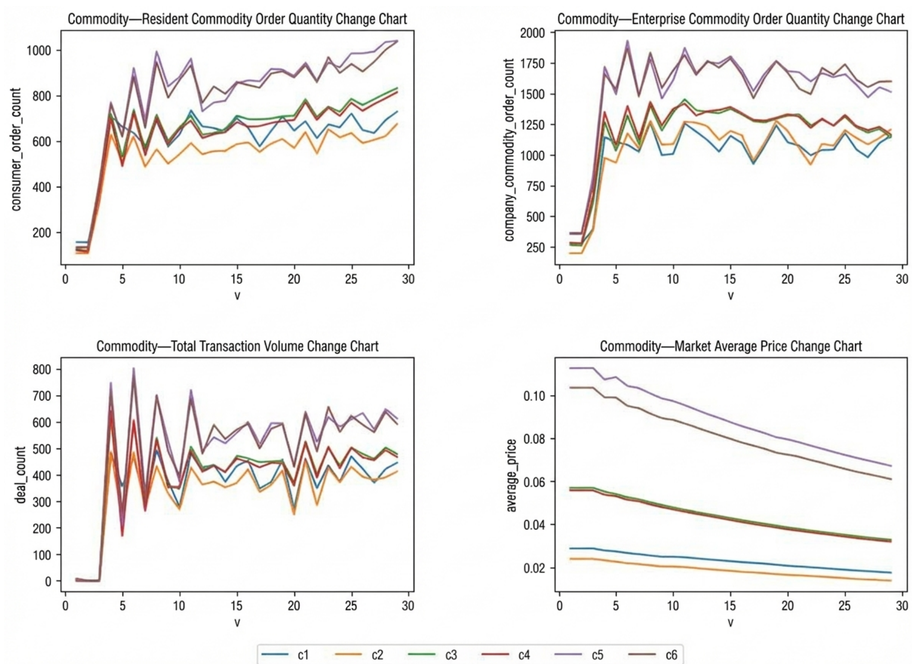

Figure 12: Figure 10

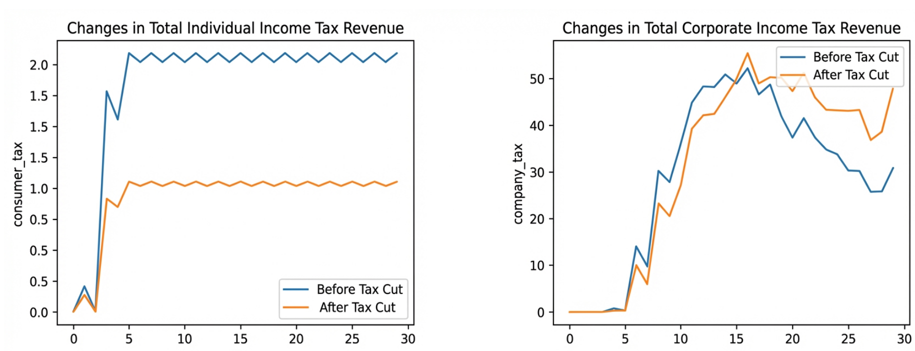

Figure 13: Figure 11

dents and enterprises entering the market in odd and even batches. In comparisons between 10% and 8% personal income tax rates, tax change amplitudes are smaller initially because only 少数 residents have signed contracts. Enterprises in early recruitment stages have small production scales and low profits, so tax changes are minimal. However, as enterprises resume normal operations and profits increase, total corporate income tax gradually rises. When corporate income tax rate is 25%, eventual profit growth makes post-tax-reduction total tax exceed pre-reduction total tax.

6.1.2 Income Changes Under Different Tax Rates As shown in [FIGURE:12], under 25% and 20% personal income tax rates, residents' actual total income in the system gradually rises and eventually stabilizes. The fluctuation at v = 1 occurs because residents entering the market at v = 1 and v = 0 are not the same batch, with v = 1 having more residents than v = 0, resulting in larger matching success at v = 1 than v = 0. Enterprises' total net profit is 0 during v = 0-1 as they are in production preparation stages. Subsequently entering formal production and operation stages, net profits gradually increase until enterprises can enjoy benefits from corporate income tax rate reductions, i.e., increased net profits and capital accumulation lead to expanded production scales, with more sales orders placed under low tax rates than high tax rates. Therefore, enterprises' total net profits under low tax rates exceed those under high tax rates, with the gap becoming increasingly obvious as adjustment count v increases.

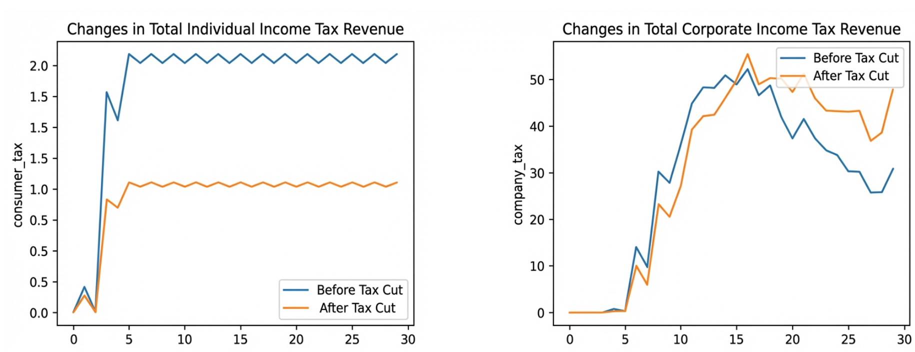

Figure 14: Figure 11

[FIGURE:12]

6.1.3 Market Transaction Changes Under Different Tax Rates (1) Residents' Commodity Order Decisions Under Different Tax Rates This system sets each resident to conduct transaction matching behaviors for only 6 types of commodities, with initial commodity stock of 0 for all types. As residents' disposable income and total consumption increase, demand for goods and services across the three major industries grows. At low consumption levels, residents mainly purchase primary and secondary industry goods. As income rises, residents gradually prefer secondary industry goods. When disposable income reaches certain levels, residents begin prioritizing tertiary industry goods and services, indicating increasing emphasis on quality of life improvement.

As shown in

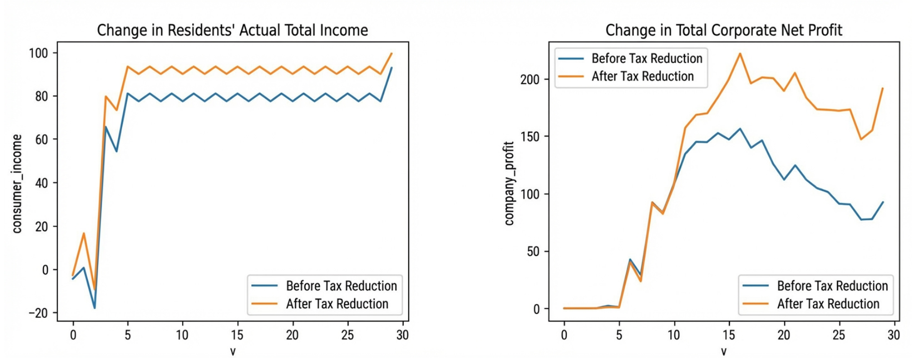

Figure 15: Figure 13

, as residents' disposable income increases and stabilizes after all residents are matched with long-term labor contracts, demand for the 6 commodity types gradually increases but with varying growth rates. At small adjustment counts v, because residents' incomes are unstable and relatively low, order quantities for primary industry goods (c_1 and c_2) exceed those for secondary and tertiary industries, with similar order volumes for c_1 and c_2. As residents' income increases, order quantities for secondary industry goods (c_3 and c_4) exceed those for c_1 and c_2. When residents' wage income stabilizes after all are matched with long-term labor, order quantities for tertiary industry goods (c_5 and c_6) significantly exceed those for c_3 and c_4. Additionally, reduced personal income tax rates increase residents' disposable income, enabling purchase of more consumer goods and services, so under the 5% low tax rate scenario, residents' order quantities for the 6 goods and services continuously increase and exceed those under the 10% high tax rate scenario as adjustment counts increase.

(2) Enterprises' Commodity Order Decisions Under Different Tax Rates

As enterprises enter stable production and operation stages, order quantities for various commodities across industry types stabilize. Due to higher prices and larger profit margins for tertiary industry goods/services, enterprises' production and sales quantities for these exceed those for the first two industries. When corporate income tax rate decreases to 20%, increased net profits allow more capital for production and operation, so enterprises' order quantities for the 6 commodities under low tax rates exceed those under the 25% high tax rate scenario.

(3) Commodity Transaction Changes Under Different Tax Rates When both personal income tax and corporate income tax rates decrease, residents' disposable income and enterprises' net profits and capital increase. This enables residents to have more funds for purchasing consumer goods, and enterprises to have more capital for larger-scale production and operation. Consequently, order quantities for the 6 goods and services by both residents and enterprises increase, ultimately leading to higher total transaction volumes in the market compared to high tax rate scenarios.

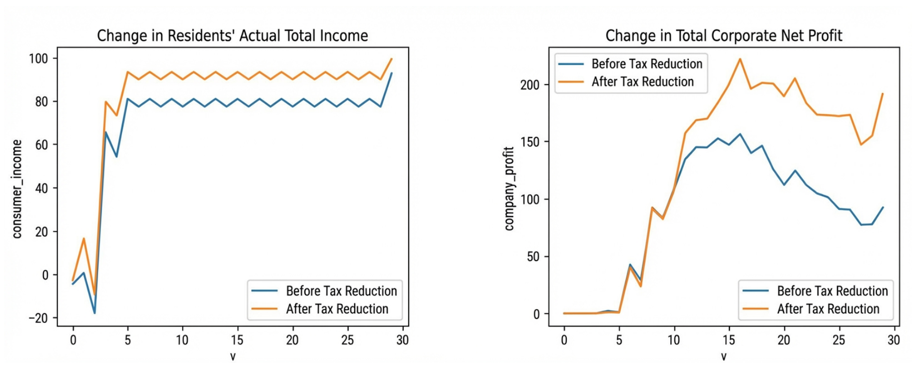

Figure 16: Figure 13

[FIGURE:14]
[FIGURE:15]
[FIGURE:16]

6.2 Employment Policy

The state implements employment subsidies to promote employment and reduce enterprise labor costs. This paper assumes a 15% wage subsidy for low-income groups (wage rate < 0.4) and a 15% social security subsidy for enterprises with new R&D projects, achieving income level improvements and virtuous cycles within the system.

6.2.1 Employment Subsidies for Low-Income Resident Groups As shown in [FIGURE:17], residents' actual income entirely comes from fixed labor quantity and overtime work expenditure. Therefore, when adjustment count v reaches the point where all residents find their long-term stable jobs, actual income in the system stabilizes, showing a sawtooth pattern because the diagram only records resident information entering the market at each adjustment count v, causing 交错排列 of actual incomes between odd and even batches. When the employment subsidy ratio for low-income residents is 15%, actual income in the system is significantly higher than when no subsidy is provided (0% subsidy ratio).

As shown in

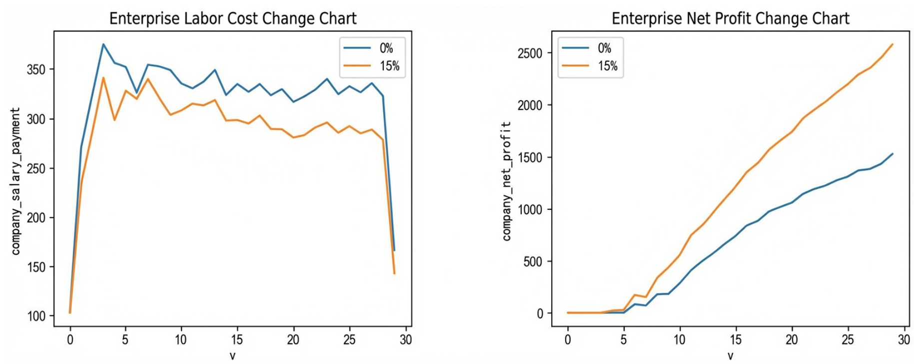

Figure 17: Figure 18

, as residents' actual income stabilizes, the quantity of disposable income used to purchase consumer goods also gradually increases. After reaching certain economic levels, residents' order quantities for tertiary industry goods and services are highest in the same period. With a 15% government employment subsidy ratio, residents' demand for various consumer goods significantly exceeds demand when no subsidy is provided. Since government employment subsidies target low-income groups to maintain basic living standards, when implementing 15% employment subsidies, the increment in demand for primary industry goods among residents entering the market exceeds demand increments for the other two industries.

As shown in

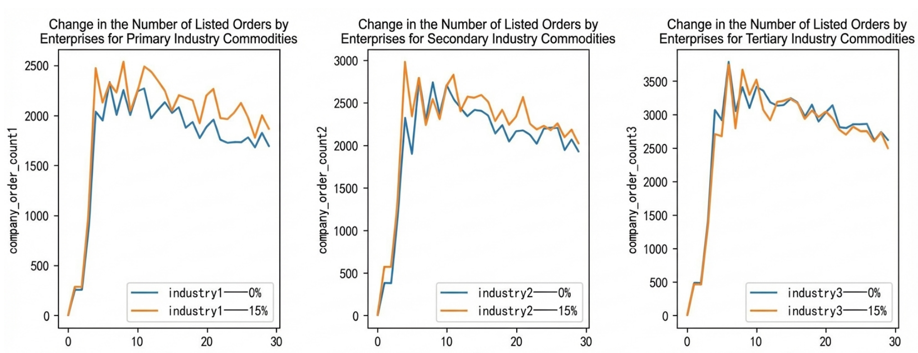

Figure 18: Figure 19

, residents' expected consumption quantities for various goods are determined by total consumption amount. Residents' expected total consumption for the three industry types shows a declining trend because the market's supply-exceeds-demand situation causes commodity unit prices to decline, as shown in [FIGURE:20] for market average prices under 15% employment subsidy ratio and in commodity market

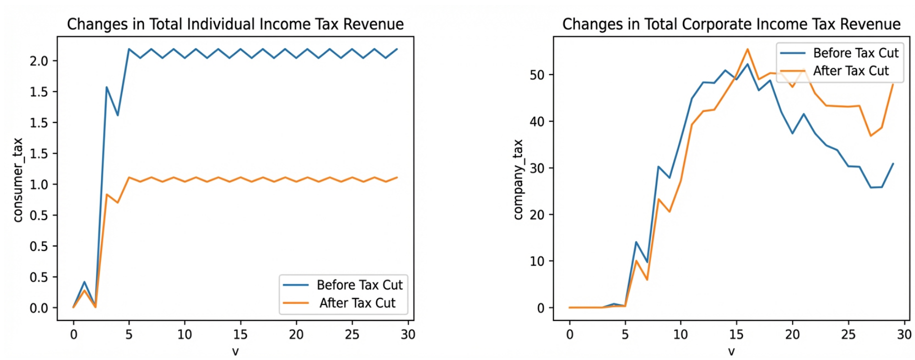

Figure 19: Figure 11

under 0% employment subsidy ratio. Tertiary industry prices decline most significantly, followed by secondary industry, with primary industry commodity prices declining least. Therefore, although residents' expected purchase quantities for the 6 commodities gradually increase, the expected total consumption amount shows a declining trend.

[FIGURE:17]

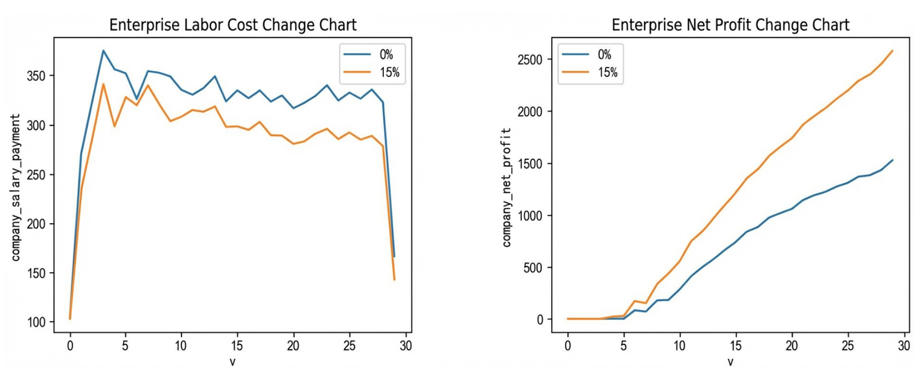

Figure 20: Figure 18

[FIGURE:20]

6.2.2 Employment Subsidies for Emerging R&D Enterprises Since all enterprises in the system conduct R&D, the government provides a 15% social security employment subsidy to all enterprises. During the recruitment phase, labor costs increase dramatically, but after recruitment completion, enterprises

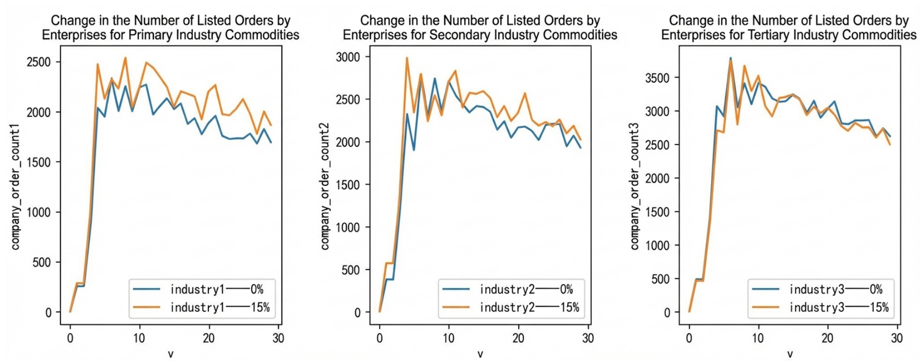

Figure 21: Figure 19

only pay fixed wages and short-term overtime wages, causing slight declines in short-term labor unit prices and labor costs during intermediate phases. Employment subsidies reduce enterprise labor costs by 15%, thereby increasing net profits. Compared to 0% subsidy ratio, total labor costs under 15% subsidy ratio are significantly reduced.

To maintain normal enterprise operations without bankruptcy, this system sets relatively large enterprise capital amounts, so enterprises will not cease production and sales due to reduced government subsidies, as initial enterprise values are set based on scenarios without additional government subsidies. As shown in [FIGURE:22], when the government provides employment subsidies to all enterprises, only primary and secondary industry enterprises show increased commodity order quantities, while tertiary industry enterprises with the highest profit margins show no obvious growth trend.

[FIGURE:21]
[FIGURE:22]

6.2.3 Market Transaction Changes Under Different Employment Subsidy Ratios The government's 15% employment subsidies for low-income residents and new R&D enterprises increase total commodity transaction volumes in the market, demonstrating positive policy effects. Low-income residents increase living expenditures and consumption willingness through subsidies, while R&D enterprise subsidies reduce operational costs, promoting short-term economic activity and market demand, laying foundations for long-term sustainable development.

[FIGURE:23]

7 Innovations, Limitations, and Future Prospects

The innovation of this paper lies in constructing intelligent micro-entity models to deeply explore decision-making processes for investment, consumption, and labor supply, where investment involves capital allocation and portfolio selection, consumption focuses on individual goods and services demand, and labor supply represents individual market participation decisions. Simultaneously, through production functions, it studies enterprise decisions on capital and labor allocation and output maximization under market competition, thereby predicting overall economic system development trends and providing theoretical support for policy formulation.

Since macroeconomic systems are complex adaptive systems composed of numerous individuals, traditional economic models have limitations in handling individual interactions and adaptability. Therefore, intelligent micro-entity models based on agent-based thinking can better simulate individual decision-making and interactions in economic systems, reflecting their complexity and non-linear characteristics to effectively understand and predict economic behaviors.

The macroeconomic system constructed in this paper faces multiple challenges, including model complexity, computational resource requirements, model matching, and micro-data acquisition. First, because macroeconomic models involve interactions among multiple factors, researchers need model construction and analysis capabilities to ensure model rationality and stability. Second, model complexity and large data volumes require researchers to possess sufficient computer technology and resources to support simulation research. Additionally, during dynamic simulation, matching among resident, enterprise, financial, and government systems becomes a major challenge, as these systems are typically extremely complex, containing numerous participants, rules, and interaction relationships that are difficult to simulate completely. Finally, in dynamic models, real data application is limited, with research often relying on parameters and assumptions. While evaluating model reliability and adaptability through assessing responses to data changes and uncertainties, this method still cannot completely replace real data verification.

Therefore, subsequent research will focus on optimizing macroeconomic policies and upgrading economic structures, providing solid theoretical foundations and rich empirical support. Through systematic theoretical analysis and empirical research, it aims to provide data support for more effective economic policy formulation. Additionally, it will explore deep integration between statistics and economics, developing new theoretical frameworks and research methods to overcome limitations in model generalizability.

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