

Spatial Optimization of Regional Inclusive Preschool Education Resources in the Context of Low Fertility Rate System Dynamics Research

Huilin Zeng*

Rizhao Polytechnic, Rizhao 276826, China

*Corresponding author email: huilinz127@163.com

Abstract

Against the background of the increasing trend of low fertility rate, the supply and demand structure of regional preschool education resources has undergone profound changes, and the structural imbalance of "excess places and scarcity of high-quality places" coexisting with "difficult to enroll in kindergartens and vacant kindergartens" occurring in some regions. Based on the dynamic feedback characteristics of the education system and the decision-making mechanism of multiple actors, the study constructs a simulation model combining system dynamics and multi-actor modeling, and comprehensively simulates the interactive process of "births-supply-demand-finance-behavior-policy" in order to explore the spatial optimization path of the regional inclusive pre-school education resources. The results show that under different policy scenarios, the key indicators of the system show significant differences; especially under the path of financial subsidy enhancement and quality orientation, the efficiency of resource allocation and the equity of education are significantly improved. Further simulations show that policy tools such as the dynamic regulation mechanism, regional differentiation strategy and parental guidance in choosing schools are effective in alleviating structural conflicts. The results of this study suggest that, in the face of the risk of resource mismatch brought about by demographic changes, it is necessary to achieve the prospective optimal allocation of inclusive education resources through system modeling and feedback regulation.

Keywords

Low fertility rate; preschool education; resource space optimization; system dynamics; multi-subject modeling; policy simulation.

1. Introduction

China is moving into the era of low fertility rate, the birth population continues to be low, and there has been a natural negative population growth in recent years. The country's birth population fell from 17.86 million in 2016 to 9.56 million in 2022, with the birth rate dropping to 6.77 per thousand; in 2023, it further dropped to about 9.02 million.

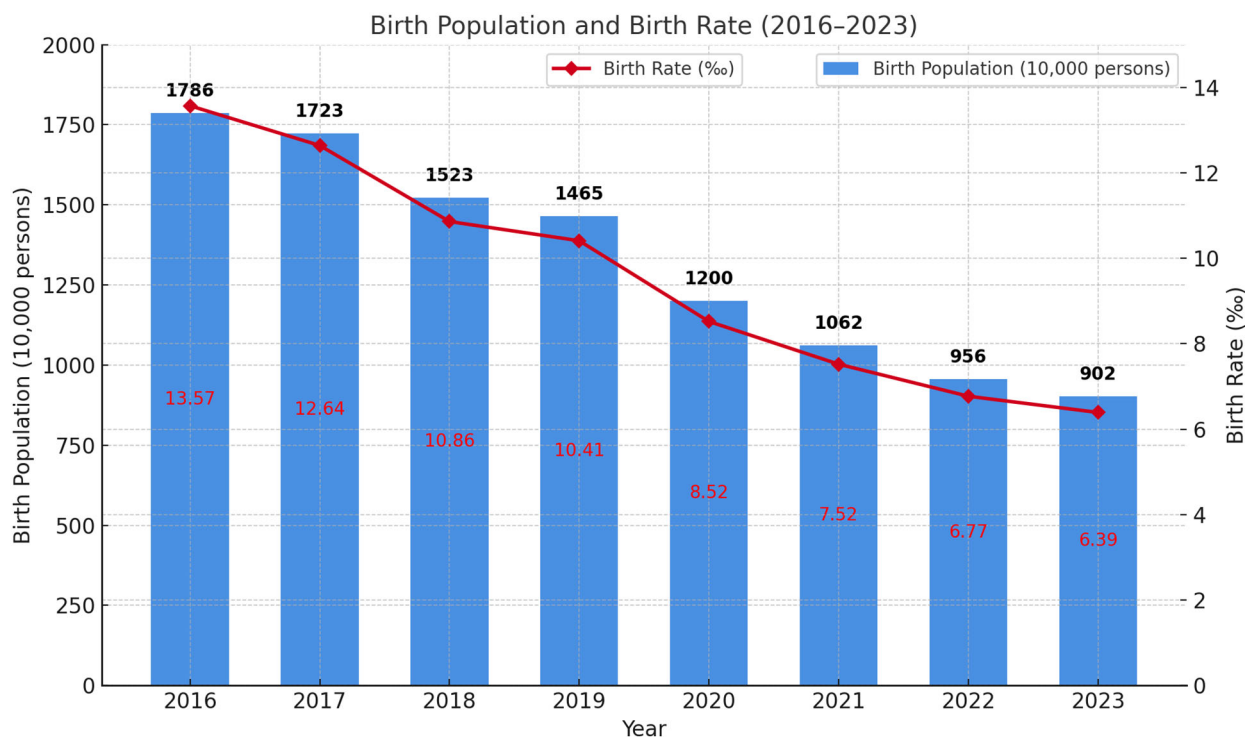


Figure 1. Birth Population and Birth Rate (2016-2023)

Data source: Pi Book Database

With the sharp decline in the preschool-age population, the education system, especially the allocation of resources for preschool education, is facing a profound structural shock. The rapid expansion of preschool education over the past decade or so has ended the growth of the number of children attending kindergartens from 2021 onwards and declined year after year, with the number of kindergartens dropping by 11.6% in 2023 compared with the previous year, and the number of kindergartens dropping by a net 14,800 in tandem. The phenomenon of kindergartens closing down due to insufficient student population has occurred in some regions [1]. The shrinking demand and supply adjustment of preschool education triggered by the low fertility rate has become a major issue that needs to be addressed urgently. To this end, the state issued a series of policies to strengthen planning and guidance. The Several Opinions of the Central Committee of the Communist Party of China and the State Council on Deepening the Reform and Standardizing the Development of Preschool Education (2018) emphasizes expanding the supply of inclusive preschool education resources, and puts forward the development goal of "universalization and universality, safety and high quality", which requires that the gross enrollment rate be 85% by 2020, and the coverage rate of inclusive kindergartens be 80% [2]. After that, the "14th Five-Year Plan" (2021) further specifies that by 2025, the gross enrollment rate will be more than 90%, the coverage rate of universal kindergartens will be more than 85%, and the ratio of public kindergartens will account for more than 50% of the total number of children in kindergartens. The National "14th Five-Year Plan" also calls for the improvement of the guarantee mechanism for inclusive preschool education, the construction of a public service system for preschool education that covers urban and rural areas, has a reasonable layout, and is inclusive of the public welfare, and the long-term plan is for the universalization of three years of preschool education by 2035, so as to realize a more abundant, inclusive, and high-quality preschool education service [3]. The policy direction indicates that the construction of a "universal and inclusive, safe and high-quality, multi-service" preschool education system has become a consensus and direction of reform efforts.

At present, the spatial distribution of universal kindergartens is facing many contradictions: on the one hand, the total amount of resources is relatively excessive and the shortage of high-quality resources coexist. Negative population growth has led to a sharp decline in the number of pre-school students in some areas, and some rural and peripheral urban kindergartens have been left vacant or even closed; however, parents' demand for high-quality kindergartens is still strong, resulting in a mismatch between supply and demand in which "some kindergartens are not enough to recruit students, while others are not able to get in". On the other hand, the imbalance in regional development has led to obvious differences in spatial accessibility: the preschool population in rural areas is declining more rapidly, and many rural kindergartens are shrinking or being abolished, while urban areas with a concentrated inflow of people are still facing pressure to enroll in kindergartens. Pre-school education resources are unevenly allocated between urban and rural areas, and there are gaps in young children's access to inclusive services close to their homes. The structural problem of imbalance and insufficiency remains prominent, and there is an urgent need to restructure and optimize the layout of preschool education resources according to the trend of population change.

Based on the above background, this study adopts a system dynamics model combined with a multi-subject simulation method to simulate the spatial optimization of regional inclusive preschool education resources. The system dynamics model portrays the dynamic feedback process of the education system from a macro perspective, which can be used to track the policy effect and predict the future evolution trend; the multi-subject simulation model simulates the behavioral interactions among the government, schools and families from a micro level, which can reflect the impact of individual decisions on the macro pattern. The integration of the two methods can better respond to the complex dynamic changes in the allocation of preschool education resources, and provide decision-making reference for the scientific formulation of adjustment and optimization strategies. Under the new normal of low fertility rate, it is of great practical significance and theoretical value to introduce the above modeling and simulation tools for dynamic prediction and spatial optimization of preschool education resources.

2. Literature Review

2.1. Spatial allocation of preschool education resources

The spatial allocation of preschool education resources is related to the fairness of education opportunities and the efficiency of resource utilization, and has always been the focus of research attention at home and abroad. In China, the development of high-quality and inclusive preschool education requires rational planning of kindergarten layout in order to narrow the urban-rural and regional gaps, which is a clear orientation at the policy level (the report of the 20th CPC National Congress and the draft law on preschool education emphasize the optimization of educational resources and the promotion of urban-rural integration) [4]. Existing studies have mostly been conducted from the perspectives of resource quantity, distribution pattern and equity efficiency. One study used GIS technology to analyze the supply quantity, service radius, and quality of per-pupil resources of preschool education in a certain province and city, and found that there is an overall phenomenon of "high pressure on kindergarten enrollment and uneven distribution of per-pupil resource quality"; the supply of inclusive kindergartens in new urban districts is better than that of old urban districts, but the internal differences are obvious; and the supply of resources in areas with stable populations is better than that in populated areas in terms of both quantity and quality. The supply of resources in population stabilization areas is better than that in population mobility areas in terms of both quantity and quality [5]. This shows that the current pre-school education resources are still unbalanced among regions, and there is room for optimization. In terms of equity and efficiency, some scholars have revealed through spatial analysis (kernel density,

accessibility measurement, etc.) that the layout of kindergartens in the county needs to be balanced between equity and efficiency. Zheng Chuchu et al. used GIS to visualize and analyze the preschool education resource allocation in 16 districts of Shanghai, pointing out that rational allocation of preschool education resources and balancing equity and efficiency are the key to guaranteeing supply [6]. Internationally, studies on the spatial distribution of preschool education resources have also focused on accessibility and equity. Cobb, in his study of preschool programs in Michigan, USA, pointed out that the effective implementation of preschool interventions requires the efficient distribution of limited resources to the target population, and thus assessing the fairness of the distribution of resources is an important responsibility [7]. They used spatial methods such as geographically weighted regression to evaluate the equity of preschool resource allocation and found that traditional statistical models ignore geographic differences, while spatial models provide deeper insights.

2.2. Adjustment of Educational Resource Allocation in the Context of Low Fertility Rate

As the fertility rate continues to be low, the size of the population of young children of school age is rapidly declining, which has a profound impact on the demand and layout of preschool education resources. Research has pointed out that China's newborn population has been declining by millions per year since 2017, and the birth population fell below 10 million in 2022, and the preschool education industry has entered an "inflection point" after a long period of expansion, and the total demand has begun to change from growth to contraction, which requires timely adjustment of the planning and layout [8]. In this context, the recent research dynamics mainly focus on the following aspects: First, fertility policy and resource demand. Many scholars analyze the comprehensive two-child and three-child policy after the implementation of the preschool-age population trends and the impact on resource allocation, predicting that after the birth of the peak briefly appeared in the demand for kindergarten will continue to decline, so that the layout of educational resources need to look forward to "thinning" and optimization [9]. The second is the change of regional distribution. A study focuses on the uneven distribution of newborns in the region under the low fertility rate, pointing out that the more serious population contraction in the region will appear kindergarten places in excess, while the inflow of population in the region there may still be a structural shortage, so that the allocation of resources more difficult [10]. Third, improve quality and efficiency. While the total amount of decline, how to take the opportunity to improve the quality of preschool education services has become the topic. Some scholars believe that the low fertility background provides an opportunity for the high-quality development of preschool education, and suggest shifting resources from quantitative expansion to quality enhancement, as well as improving the efficiency of resource utilization through layout adjustment [11]. In addition, some studies have drawn on the experiences of foreign low-fertility countries, such as how Japan and Singapore have responded to the challenges of childlessness through financial support and optimization of education services, to provide policy insights for China [12]. Current relevant studies have recognized the impact of low fertility on the allocation of educational resources and called for responses ranging from supply and demand projections to layout adjustments. Lv Yang et al. predict the supply and demand potential of urban and rural preschool education resources based on population cohorts and propose a coordinated strategy [13], and Min Huizu et al. explore the dilemmas and countermeasures of preschool education development under low fertility, all of which are closely related to the topic of this study [14].

2.3. Application of System Dynamics in Education Policy Simulation and Resource Optimization

System Dynamics (SD), as a method to study the feedback structure and long-term behavior of complex systems, has been gradually applied to educational planning and policy simulation research since it was introduced into the field of education in the late 20th century [15]. The system dynamics model can simulate the dynamic evolution of the educational system under different policy or environmental scenarios by establishing a causal feedback loop of variables and a set of differential equations. It has been shown that the scale of development of the education system is influenced by multiple factors, such as demographics, economics, and policies, and traditional static or linear forecasts are difficult to take into account the interaction of these factors. In this regard, researchers have begun to utilize SD models for scenario projection and decision-making evaluation. Wang Mei and Zhang Zeng constructed the SD model of the scale of doctoral education in the United States to simulate the driving effects of faculty and funding on the expansion of doctoral training scale, and to reveal the dynamic relationship between resource inputs and outputs from a system perspective [16]. Ye Maolin constructed a SD model covering compulsory education to postgraduate education, comprehensively considering the effects of demographic structure and economic development on the scale of education, and simulating the development trend of the education system under different scenarios of promotion rates [17]. In the field of preschool education, studies have been conducted to utilize SD to make medium- and long-term forecasts of regional supply and demand for preschool education, providing a basis for layout planning [18]. In the optimization of educational resources, although the pure SD model can reflect the feedback relationship between policy inputs and macro indicators, it lacks a depiction of the decision-making process of micro actors such as families and kindergartens. In this regard, many scholars have proposed the need to combine other methods to make up for the shortcomings of SD, so that the model is closer to the real decision-making situation [19].

2.4. Application of multi-subject modeling in educational behavior simulation

In order to portray individual behaviors and interactions in educational systems, Agent-Based Modeling (ABM) has received increasing attention, which investigates system-level patterns and outcomes by simulating the decision-making rules and interactions of a large number of heterogeneous "agents" (families, students, schools, etc.) [20]. In the field of education, ABM is often used to simulate behavioral scenarios such as school choice, enrollment competition, and teacher markets. In terms of families' school choice (school selection) behavior, Sheridan et al. constructed an intelligentsia-based school district school choice model to simulate the dynamic process of families' shifting from nearby admission to cross-region school choice, and found that even if each family's school choice rules are relatively simple and transparent, the aggregated macro results may be unexpected, such as the emergence of a new concentration of resources or an imbalance in the source of students [21]. Kim et al. investigated the information school choice under asymmetry, and their ABM shows that unequal household access to information about school quality exacerbates competition for quality resources and inequality of access, which provides a rationale for policymakers to reduce information barriers [22]. In addition, ABM is also used to explore scenarios of competition and cooperation for educational resources, such as modeling the strategies of multiple schools in the competition for students, or the interactive game of families' choices of school districts and private gardens [23]. This kind of model can reproduce the phenomenon of "competing for students" and "pinching enrollment" in reality, and evaluate the effects of different policies (e.g., elementary school allocation and subsidies for kindergartens) on alleviating the competition.

2.5. Research Review

Despite the richness of research results on pre-school education resource allocation in recent years, there are still a number of shortcomings that need to be further improved. For one thing, most of the studies adopt a static or flat analytical perspective, lacking consideration of dynamic evolution and systematic feedback mechanisms. For example, many studies on the spatial distribution of kindergartens only make descriptive evaluations of the resource pattern at a certain point in time or make linear projections based on current population data, but lack simulations of how resource supply and demand will be adjusted with feedback over time after continuous population changes and new policy interventions. Against the background of accelerated new urbanization and low fertility rate, it is difficult to answer the question of "how to optimize the layout of resources in the next few years" in this kind of static analysis. Second, the lack of micro-behavioral modeling. Existing literature often focuses on macro supply and demand, but seldom incorporates micro behaviors such as families' choice of kindergarten and kindergarten operation decisions into the model. This leads to research that fails to reveal the mechanism of micro subject behavior on resource allocation outcomes. For example, under the impact of low fertility rate, private kindergartens are facing the dilemma of insufficient student supply, but few studies have been conducted on their adjustment strategies; another example is the lack of quantitative analysis of the impact of parents' preferences for choosing kindergartens (public or private, nearby or prestigious kindergartens) on the balanced allocation of resources in the region. Third, there is a lack of a comprehensive research framework that integrates macro and micro. Currently, there are mostly SD macro-simulations or ABM case simulations, which are conducted separately and have not yet formed a unified systematic model. This makes the evaluation of the effectiveness of education policies often fragmented: macro studies are difficult to take into account individual differences, and micro studies are difficult to reflect the overall direction. As complex systems theory reveals, even with a full understanding of individual behaviors, emergent results at the system level may still be unexpected. Therefore, without connecting the macro feedback with the micro mechanism, the reliability and precision of many strategy suggestions are discounted.

3. Research Methods

3.1. System Dynamics Modeling

This study first constructs a System Dynamics (SD) model to portray the macro-dynamic changes in the supply and demand of preschool education resources in the context of low fertility. System Dynamics adopts a top-down aggregation modeling approach, focusing on the causal relationships and feedback loops among the variables within the system, describing the variable interactions in the form of differential equations and solving for the system behavior [24]. The entire preschool education resource system is divided into three interrelated subsystems, namely, population and demand, finance and policy, and resource supply and quality, to analyze the complex system in a hierarchical manner: the causal linkages of the elements are studied within the subsystems and the causal links between the subsystems are established, so as to form a comprehensive model containing multiple feedback loops. At the same time, various model variables and their interrelationships are determined according to the system dynamics modeling specification, and parameter values are set in conjunction with real-world data and policy rationale. The state variable (stock) in the model is used to describe the cumulative quantity in the system (population of school-age children, total number of kindergarten places), and its change is determined by the rate variable (flow) (annual number of births, number of newly built kindergartens); the auxiliary variables are used to characterize the intermediate influencing factors and the basis for decision-making (kindergarten enrollment rate, teacher-to-student ratio, and the proportion of financial subsidies), which are

connected through a functional relationship and influence the dynamic changes of the stock and flow.

This study builds the structure of the SD model according to this method, and uses causal loop diagrams and stock-flow diagrams to clearly demonstrate the feedback structure and dynamic mechanism of the model.

(1) Population and demand subsystem: This subsystem describes the dynamic evolution of the size of the population of school-age children and the demand for schooling. Considering the trend of low fertility rate, the model introduces parameters such as birth rate and population growth rate to simulate the change of the population stock of school-age children. The size of the school-age population determines the potential demand for preschools, and it is assumed that school-age children are generally willing to enroll in preschools, thus the population size directly affects the demand for preschool education. State variables include "population of children of school age", which changes through rate variables such as births and population ageing, and "number of children in school", which depends on changes in enrolment rates (i.e., how many children of school age are actually enrolled in school each year). Auxiliary variables such as "target enrollment rate" and "parental willingness index" are used to connect the relationship between population and actual demand for schooling.

(2) Fiscal and policy subsystem: This subsystem focuses on modeling the government's fiscal input and policy regulation mechanism in the field of preschool education. The state variables include "balance of special financial funds for preschool education", which represents the cumulative funds used for universal preschool education; the rate variables reflect the flow of funds, such as "annual financial allocation" and "annual fund expenditure", which represent the government's annual expenditure on preschool education. Rate variables reflect the flow of funds, such as "annual financial allocation" and "annual fund expenditure", which represent the government's new inputs and expenditures every year. The auxiliary variables include "per capita pre-school education funding", "coverage rate of inclusive kindergartens", "proportion of financial subsidies", etc., which are used to measure the intensity and effectiveness of the policy. In the model, the government's decision-making rules are reflected in this subsystem: when the demand for kindergartens grows and leads to a strain on existing resources, the government increases financial allocations to build new kindergartens or expand kindergartens; when there is a shortage of funds or a waste of resources, the government adjusts the expenditure structure to improve the efficiency of the use of funds.

(3) Resource supply and quality subsystem: This subsystem portrays the scale of pre-school education resource supply and the evolution of education quality. The state variables include "total number of kindergarten places", "number of public kindergartens" and "number of private kindergartens", etc., which are used to represent the stock of different types of preschool education resources; the total number of places can be subdivided into public and private kindergartens, and the number of private kindergartens can be subdivided into public and private kindergartens. The total number of places can be subdivided into public and private places to reflect the composition of inclusive resources. Rate variables describe changes in resource supply, such as "increment of new kindergartens" (number of new places per year), "kindergarten exit rate" (number of kindergartens closed due to insufficient enrollment, etc.), "net increase of teachers", etc., which determine the resource stock. " etc., which determine changes in the resource stock over time. Auxiliary variables are used to measure the efficiency and quality of resource provision, including "average utilization rate of school places", "teacher-student ratio (number of children per teacher)", "teacher qualification level index", "average child care level", "average child care level index", "average child care level index", and so on. "The average quality of teaching and learning index.

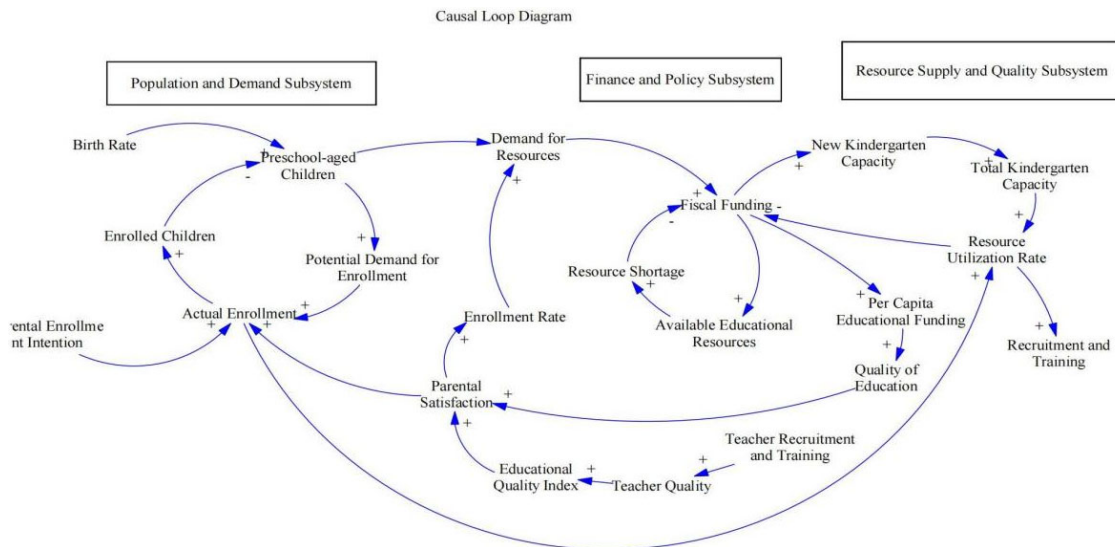


Figure 2. Causal Loop Diagram of the Coupled System for Preschool Education Resource Allocation under Low Fertility

In the model, it is assumed that kindergarten quality indicators (teacher training level, class size, etc.) positively influence parents' choice of kindergarten. Existing research shows that parents place a high value on quality factors such as teacher training and environmental safety when choosing a kindergarten. Therefore, when a region improves the quality of teacher training and infrastructure by increasing investment, it tends to attract more students, thus increasing the utilization rate of school places, forming a positive feedback loop of "quality improvement → increased demand → more fully utilized resources → further promotion of quality investment". On the contrary, if resources are insufficient or quality declines, parents may send fewer children to school, leading to a decline in utilization and idle resources, prompting the government or the market to take action (increasing supply or improving conditions) to rectify the situation, which in turn creates an equilibrium loop of "insufficient supply → decrease in quality → decrease in demand → stimulation of supply expansion". The stock-and-flow diagram formalizes the above relationships and clarifies the logic of causal dependence among the variables, ensuring that the model can correctly reproduce the dynamic equilibrium mechanism between the expansion of resource supply and the evolution of education quality.

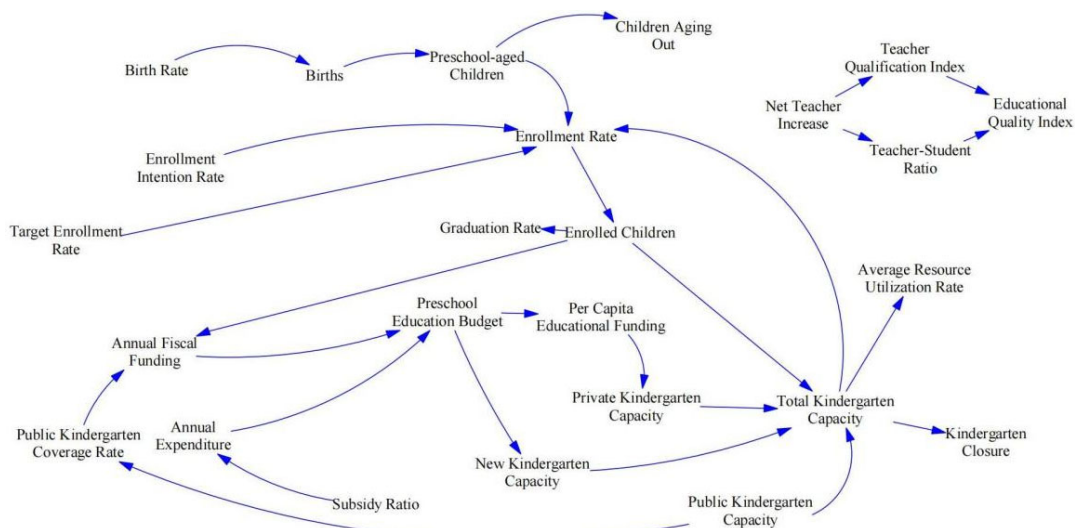


Figure 3. Stock-and-Flow Diagram of the Preschool Education System Dynamics Model

3.2. ABM (All-Body Modeling)

Macro-SD models are capable of portraying the overall evolutionary trend, but it is difficult to reflect the influence of individual differences and spatial factors on the system. This study therefore introduces Agent-Based Modeling (ABM) to simulate the attributes and behaviors of the three types of micro-agents, namely parents, government, and kindergartens, as well as the interaction processes among them. ABM is a bottom-up modeling approach that treats the system as consisting of a number of agents with autonomous behavioral rules, and simulates the decision-making and interactions among the agents to observe how macro phenomena emerge from micro behaviors [25]. In contrast to SD, which focuses on aggregating variable relationships, ABM allows the complexity of the decision-making process to be described at a fine-grained level. For decision-making scenarios involving multiple factors, ABM often allows the subject to make choices based on the environment by setting conditional rules or utility functions, and can also introduce optimization algorithms to solve the optimal decision under the given constraints.

(1) Parent Agent (Parent Agent): Parents are the executors of the decision of early childhood enrollment, and their behavior directly determines the utilization of preschool education resources. In the model, each school-age child corresponds to a Parent Agent, whose main attributes include: the geographic location of the family (related to the distance to the kindergarten), the level of affordable costs (family economic status), the preference for the quality of their children's education (the degree of importance attached to teachers and the environment), as well as possible constraints on the time of work and childcare (which affects the sensitivity to the distance of the pick-up and drop-off), and so on. The core behavior of parent agents is the decision to choose a kindergarten. Parent agents obtain information about the attributes of neighboring kindergartens (fees, teacher quality ratings, distance), then calculate the overall "attractiveness" score of each kindergarten (quality positively, cost and distance negatively), and select the kindergarten with the highest score as the target [26]. In the case of families with multiple children, the decision to choose a kindergarten can be made separately for each child, but the present study focuses on the case of a single child. It is worth noting that if there are no nearby kindergartens that meet parents' basic expectations (e.g., all accessible kindergartens are over-budget or too far away), parents may choose not to send their children to kindergartens or seek alternative care.

(2) Government Agent: The government is the macro-regulator of pre-school education provision and acts as a special agent with decision-making functions in the model. The attributes of the government agent include: the amount of annual budget, planning objectives (e.g., the target of the gross enrollment rate of the first three years of preschool, the indicator of the coverage rate of universal kindergartens), and the parameters of policy tools (e.g., the construction plan of public kindergartens, the subsidy standard of universal private kindergartens), and so on. The behavior of the government agent is embodied in its policy decisions per cycle based on the system state. The specific rules are: at the beginning or end of each simulation cycle, the government assesses key indicators of the current preschool system, including the overall enrollment rate, the gap between supply and demand of school places in each region, the average distance of parents to school, the average class size of kindergartens, and the status of teachers. If it is found that the demand for kindergarten places in certain regions has remained unmet for a long period of time (e.g. a large number of school-age children but insufficient local kindergarten places, low kindergarten enrolment rate), the government will take measures to increase supply in the next cycle: including building new public kindergartens or expanding existing kindergartens, and increasing the supply of kindergarten places in the areas with shortfalls. If it is found that the high cost of schooling makes it difficult for some families to afford it (e.g., private school fees far exceed the affordability level of families), the government may increase the level of inclusive subsidies, such as providing

operating subsidies to private schools in exchange for lower fees, or directly providing subsidies to children attending schools to reduce the actual burden on parents. If there are problems with the quality of education (e.g., high teacher-student ratios, unqualified teachers), the government will make targeted investments in teacher training, improve teacher salaries, or introduce policies to lower the maximum class size to ensure quality. The goal of the government's decision-making is to strike a balance between universality (the highest possible enrollment rate) and equity (different regions and different families have close access to education).

(3) Kindergarten Agent: The kindergarten is the basic unit of pre-school education resource provision, and each kindergarten (or each garden node) is set as an agent in the model. The attributes of the kindergarten agent include: type (public, universal private, non-universal private, etc.), geographic location (coordinates mapped to parent distribution for distance calculation), capacity (maximum number of classes or students that can be accommodated), level of teachers and facilities (which can be used for calculating quality indicators such as teacher-student ratios), and fee (tuition). The behavioral rules of kindergarten agents are mainly reflected in their response to changes in supply and demand and their own operational decisions: when there is a shortage of students (under-enrollment), especially for for-profit private kindergartens, they may take measures to reduce fees and increase special programs to attract students; if they continue to fail to recruit students, they may choose to exit the market (close down the kindergarten agent). On the contrary, when demand is too high (enrollment far exceeds capacity), kindergartens will react differently depending on their attributes: public kindergartens are usually constrained by their establishment and finances, and are not easily able to expand enrollment arbitrarily, but rather the government decides to solve the problem by adding a new kindergarten; private kindergartens, on the other hand, may try to control the match between demand and their own capacity by either expanding enrollment (adding more classes and teachers) or raising fees. From a quality perspective, kindergarten expansion requires sufficient teachers, otherwise too large class sizes will reduce the quality of teaching and learning; the model monitors this through indicators such as teacher-student ratios and assumes that if a private kindergarten's class size exceeds the limit for a long period of time, it will lower its quality rating in the eyes of parents and thus lose a portion of its student population in the next cycle (a spontaneous equilibrium in the market). In addition, kindergarten agents also follow the government's regulatory policies, for example, agents recognized as "inclusive private kindergartens" must limit their fees to the government's guideline price and meet certain teacher staffing requirements, or else they may lose their subsidy status.

4. Model Construction and Simulation Analysis

4.1. Model parameter initialization and baseline scenario setting

This study adopts the statistics from 2010 to 2019 as the initial parameters of the model, including the birth rate, the proportion of preschool-age population, the level of financial investment, and the supply of kindergarten places. As of 2019, the number of preschool children in kindergartens nationwide is about 47.14 million, and the gross enrollment rate of three years of preschool reaches 83.4%. On this basis, the simulation time span is set from 2010 to 2035, and the initial values of the indicators in 2010 are used as the starting point of the model. The baseline scenario assumes no additional policy intervention, i.e., maintaining the current development trend: through three consecutive pre-primary education action plans in 2010, the supply of school places has increased significantly, and the gross enrollment rate has risen from 56.6% in 2010 to about 85% in 2020. The "comprehensive two-child" policy generates some expansion in demand for kindergartens around 2016, but according to the

National Bureau of Statistics (NBS), the number of births declined consecutively from 2016-2019, and the trend of low fertility rate is obvious. As a result, the number of children enrolled in preschools in the baseline scenario peaks around 2021 (around 48 million) and then begins to gradually decrease. In the baseline scenario, the government extends the universal kindergarten expansion initiative established at the end of the 13th Five-Year Plan, with the coverage rate of universal kindergartens reaching more than 80% by 2020; thereafter, it is assumed that the investment in preschool education and the supply of preschool places are routinely adjusted in line with the changes in the school-age population, but there are no new special policies. The simulation will portray the natural evolution trend of the preschool education system in the absence of new policies.

4.2. Scenario Setting

Three contrasting scenarios are designed to explore the impact of different policy paths:

(1) Continuing Low Fertility Decline Scenario: It is assumed that the total fertility rate (TFR) and the number of births will decline further than in the baseline scenario and remain at a low level. The preschool-age population will shrink even faster than in the baseline, and demand for kindergarten places tightens considerably. However, the government does not take additional countermeasures, and the supply of pre-primary education adjusts passively with the market mechanism. Some private kindergartens close due to insufficient student enrollment, and the incremental increase in public school places stops, causing the gross pre-primary enrollment rate to naturally rise to about 93% by 2025 before saturating. The scenario simulates a more severe population decline shock by lowering the birth rate parameter.

(2) Enhanced Fiscal Subsidies and High Quality Orientation Scenario: This scenario assumes that the government actively intervenes in response to low fertility by increasing fiscal investment and shifting to a development strategy that improves the quality of pre-primary education. Specific measures include: continuing to increase operating subsidies for public and privately-run kindergartens and raising the per-pupil financial allocation standard to compensate for the funding gap caused by the decline in the number of students; shifting from "increasing the number of school places" to "improving the quality and stabilizing the number of school places," and strengthening investment in equipment and teacher training in schools in weak areas; and increasing the number of kindergartens with a high quality orientation. The focus of work will be shifted from "increasing the number of places" to "improving the quality and stabilizing the number of places", and the investment in equipment and teacher training will be strengthened for weak kindergartens in the districts so as to improve the quality of teaching and learning. At the same time, kindergartens with the necessary conditions are encouraged to extend their services to 0-3 year olds, realizing the integration of childcare to make full use of surplus premises and meet the needs of families. This scenario simulates the effect of the policy by increasing the fiscal input parameters (e.g., annual budget growth rate, subsidy rate, etc.) and improving quality-related parameters (e.g., teacher-child ratio, curriculum quality index, etc.).

(3) Fiscal Contraction and Resource Integration Scenario: It is assumed that the government tightens its fiscal expenditure on preschool education in the context of childlessness, with resource optimization as the main strategy. Specifically, the local government gradually reduces investment in new kindergartens and merges kindergartens with too few students, and reduces unit costs by compressing unused places through layout adjustment. In principle, no new kindergartens will be built in rural areas, and township central kindergartens will be encouraged to consolidate surrounding resources by organizing sub-teaching points or cooperating in running schools. Some small-scale private kindergartens have withdrawn from the market due to a sudden drop (>25%) in the number of students, making them untenable. At the same time, we are encouraging qualified schools to transform themselves into 2- to 3-

year-old nursery classes, so as to fill preschool vacancies and increase the utilization rate of their facilities in a "sinking" manner. This scenario is modeled by lowering the growth rate of fiscal inputs, reducing the incremental supply of school places, and introducing a feedback mechanism for integrating school places. The policy path focuses on controlling the scale of supply and expenditure, so that public pre-school education services can be as cost-effective as possible while ensuring basic coverage. It should be emphasized that some studies have pointed out that a decline in the number of students does not mean that funding for pre-primary education can be cut in the same proportion, and that the government still needs to adjust its investment in order to steadily improve the level of service. Therefore, in this scenario, while reducing the total number of preschools, the government maintains the subsidies for basic preschools in remote areas, so as to avoid the problems of "far-away" and "loss of teachers" due to over-expansion of preschools.

4.3. Simulation results

The model is calibrated to be able to reproduce the trend of the main indicators of preschool education during the period of 2010-2020, and on the basis of which three scenarios are simulated for the period of 2021-2035. The results show that the key indicators of the system under different scenarios show significantly different dynamic evolution trends. The changes in degree utilization, financial pressure, parental satisfaction and education equity index are described below in conjunction with the figures.

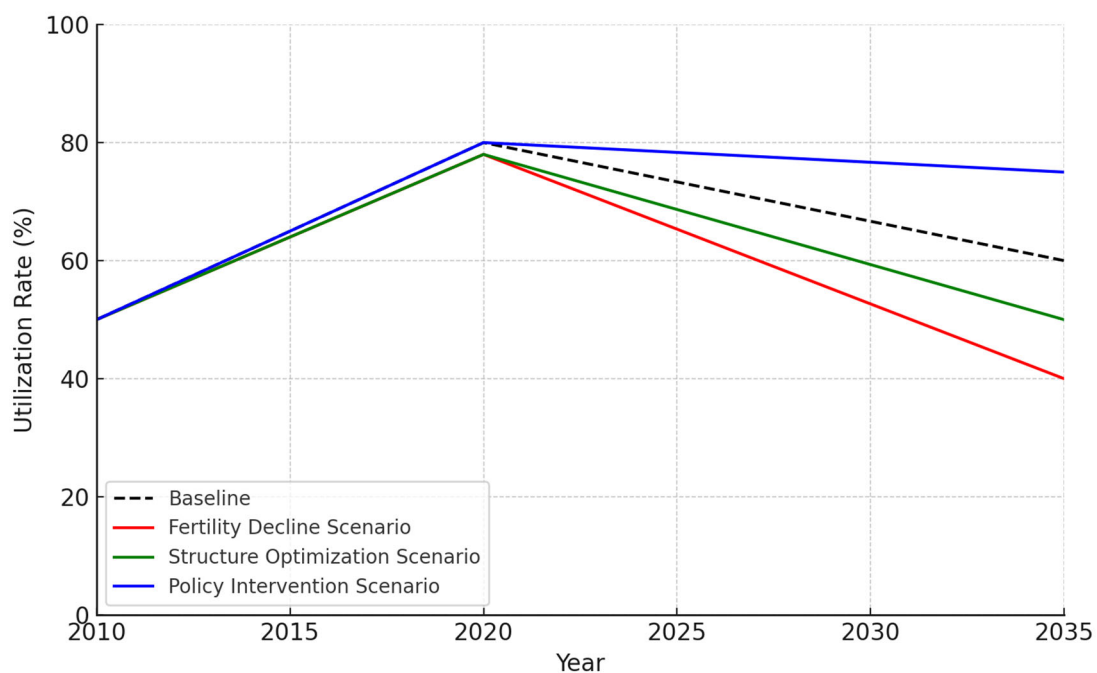


Figure 4. Dynamic Changes in Kindergarten Utilization Rate under Different Scenarios (%)

Figure 4 illustrates the dynamic changes in Kindergarten Utilization Rate under Different Scenarios (%). The baseline scenario (black dashed line) shows utilization of kindergarten places rising first and then falling: from about 50 percent in 2010 to about 80 percent by 2020 as enrollment increases, and then falling back to about 60 percent by 2035 as the school-age population declines. In the scenario of continued low fertility decline (red line), the number of children falls sharply while the adjustment in the supply of kindergartens lags behind, with the utilization rate falling sharply from nearly 78 per cent in 2020 to about 40 per cent in 2035, resulting in a significant degree of idleness of school places. This implies a large number of surplus places and wasted resources in the absence of policy intervention in the event of a

lower fertility shock. Under the Fiscal Subsidy Enhancement Scenario (Green Line), the trend in utilization rates is relatively flat: around 80 percent in 2020, and slowly declining and stabilizing at around 50 percent thereafter.

As the government proactively controls the pace of supply and diverts some places through childcare integration, and moderately retains surplus places to reduce class sizes and improve quality, the utilization rate is slightly lower than the baseline but does not fall out of control. Under the Fiscal Contraction Scenario (Blue Line), the utilization rate remains consistently high: around 80 percent in 2020 and stabilizing at over 75 percent thereafter. This reflects the fact that the scenario effectively avoids wasted places by consolidating unused premises and pooling resources for supply. Yet too high a utilization rate also implies large class sizes and insufficient flexibility, which may put pressure on the quality of care. Taken together, the population decline leads to a naturally lower utilization rate in the baseline scenario; the positive intervention scenario moderately tolerates a lower utilization rate in exchange for smaller class sizes; and the austerity scenario seeks an efficient allocation with a tight balance between supply and demand.

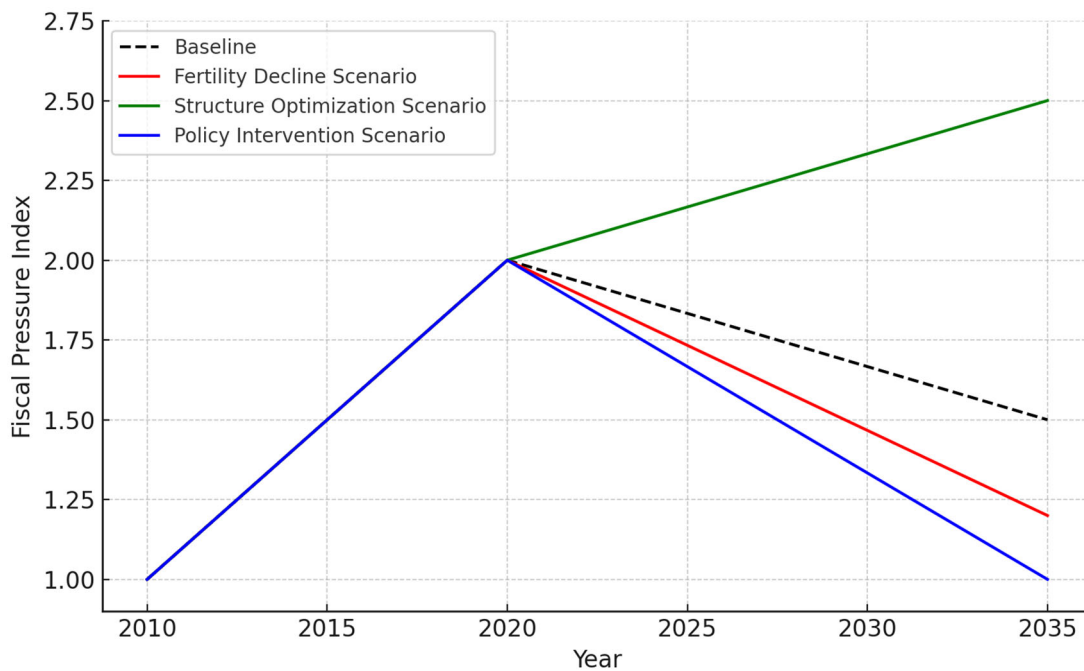


Figure 5. Changes in Fiscal Pressure Index under Different Scenarios

Figure 5 shows the changes in Fiscal Pressure Index under Different Scenarios. Fiscal pressure is expressed as a relative index of annual government spending on preschool education, initially set at 1.0 in 2010. The baseline scenario (black dashed line) shows fiscal investment roughly doubling with the expansion of school places from 2010 to 2020 (to an index of 2.0), after which total government spending tends to slow down as fewer children are of school-going age and then declines slightly, to about 1.5 by 2035. 1.5. In the low fertility scenario (red line), the decline in total required expenditures is even more pronounced due to the rapid decline in children, with a fiscal index of about 1.2 in 2035, 20 percent lower than the baseline. The fiscal subsidy enhancement scenario (green line) is the opposite: the government significantly raises per-child inputs to improve the quality and coverage of childcare, and total inputs continue to rise despite the decline in children in school, reaching an index of 2.5 in 2035, about 67 percent higher than the baseline.

This suggests that governments in this scenario take on a greater fiscal burden in exchange for higher quality and coverage of services. The fiscal contraction scenario (blue line), in which government spending compresses sharply in line with the decline in student enrollment, has an index of about 1.0 in 2035, falling back to the 2010 level. It can be seen that the fiscal pressure on pre-primary education under different policy orientations diverges significantly: the enhanced input scenario requires the government to invest far more than the baseline to support the goal of high-quality universal coverage; while the contraction scenario eases the fiscal pressure, but it may lay a hidden worry about the quality of service due to insufficient investment. The trade-off between lowering total inputs and safeguarding service quality is a key decision for the system.

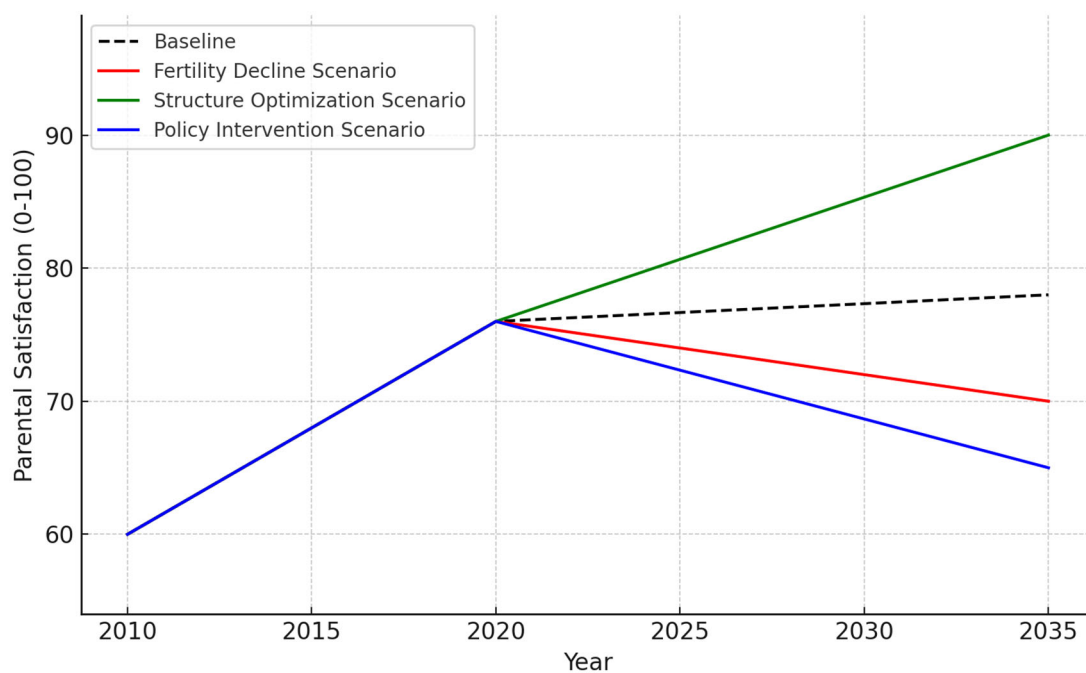


Figure 6. Simulated Changes in Parental Satisfaction (Index 0-100) under Different Scenarios

Figure 6 shows the simulated changes in Parental Satisfaction (Index 0-100) under Different Scenarios. Parental satisfaction is influenced by the quality of preschool education, cost burden, and service accessibility. In the baseline scenario (black dotted line), satisfaction rises gradually from 60 in 2010 to about 75 in 2020, reflecting that measures such as the Three-Year Action Plan for Pre-primary Education increase enrollment while improving the quality of services to a certain extent, and that after 2020, satisfaction in the baseline scenario rises slowly to close to 80 in 2035, due to a decrease in per capita resources resulting from a decrease in student enrollment. This is due to an increase in per capita resource availability due to a reduction in the number of students, but the improvement is limited because no new quality projects are implemented. In the Low Fertility Scenario (Red Line), satisfaction declines after 2020 to around 70 in 2035, with continued low births causing some kindergartens to fall behind, teacher turnover and closures increasing, and parental confidence in the proximity of kindergartens and the stability of services declining. Satisfaction in the financial subsidy enhancement scenario (green line) climbs significantly, jumping from 75 in 2020 to a high level of around 90 in 2035. Increased government investment leads to improved quality of education and lower fees, and parents' recognition of services increases as the problem of "difficult and expensive schooling" is basically solved. In addition, high-quality universal services ease the pressure on families to raise children to a certain extent, and are thought to help increase the fertility intentions of families of childbearing age. The fiscal contraction scenario (Blue Line),

on the other hand, leads to a decline in satisfaction, which falls below the benchmark level to about 65 by 2035. As a result of the financial constraints and the consolidation of kindergartens, parents are likely to face difficulties such as "far away from kindergartens" and "large class sizes", and the decline in the quality and accessibility of services triggers a decline in satisfaction. It can be seen that policy choices have a great impact on people's satisfaction: strengthening investment and improving quality can lead to higher satisfaction and social trust, while simply compressing investment may jeopardize the service experience and lead to parents' dissatisfaction.

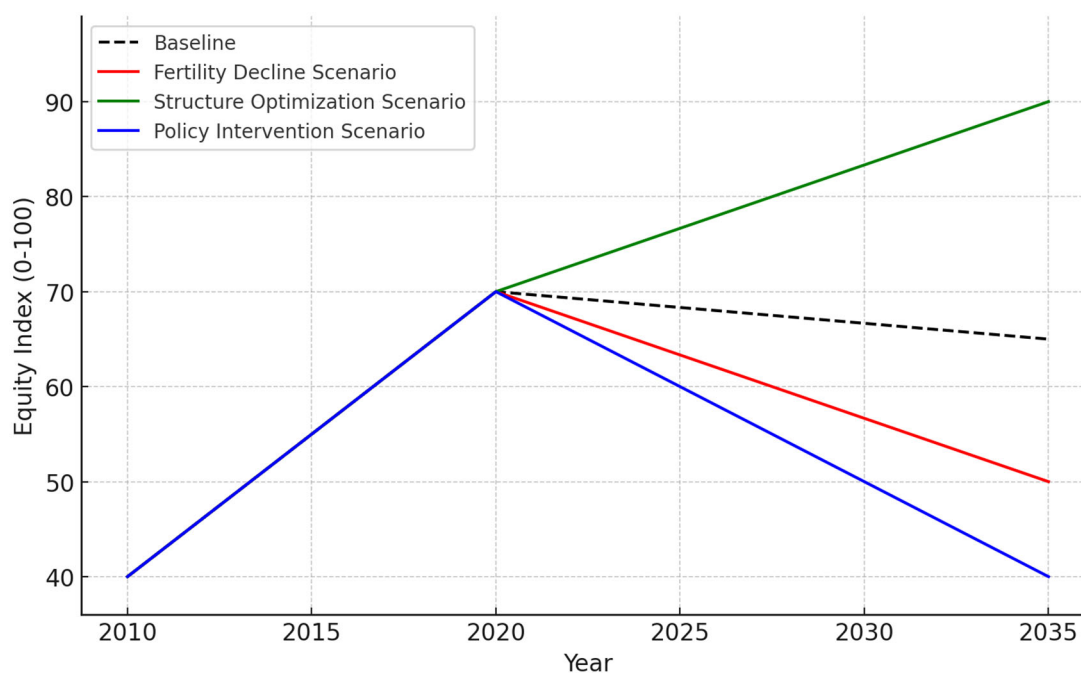


Figure 7. Simulated Changes in Education Equity Index (0-100) under Different Scenarios

Figure 7 shows simulated changes in Education Equity Index (0-100) under Different Scenarios. The Education Equity Index is used to measure the degree of equality in access to preschool resources between urban and rural areas and between groups, with higher values representing better equity. Under the baseline scenario (black dotted line), the index increases from 40 in 2010 to about 70 in 2020, showing that the "level of public welfare and inclusion in preschool education" has increased significantly over the past decade, with the coverage rate of national inclusive resources increasing from 66% in 2012 to 90.8% in 2021. However, after 2020, with population mobility and regional polarization, the equity index declines slightly, to about 65 in 2035, which may be due to a faster decline in school-age children in rural areas, the shrinkage or even closure of some rural preschools, and some pressure for enrollment in urban areas, which leads to a small reduction in equity due to the imbalance of supply and demand between regions. Educational equity is more prominent in the low fertility scenario (red line), with the index declining from 70 in 2020 to around 50 in 2035. Less developed regions and private gardens bear the brunt of the impact of the decline in student numbers, and access to gardens is limited for some disadvantaged groups. The financial subsidy enhancement scenario (green line) realizes a significant increase in the education equity index, approaching 90 in 2035. the government narrows the gap between gardens of different regions and natures by increasing support for central and western and rural pre-school education, and by sounding the mechanism of multi-level financial sharing. The expansion and balanced layout of universal resources has enabled more families to enjoy access to quality kindergartens close to their homes, and equity has improved significantly. The fiscal contraction scenario (Blue Line), on

the other hand, has brought the equity index down to a low of about 40, indicating that the gap in the distribution of education resources has further widened. Many rural and impoverished areas "lose" preschool services due to insufficient funding and the abolition of kindergartens, and disadvantaged groups are not guaranteed access to kindergartens, exacerbating the urban-rural divide and class disparities. This result sends a warning: in a period of demographic downturn, if the Government simply reduces inputs according to the population ratio, educational inequity may deteriorate rapidly; only through policy interventions to support the bottom line can the phenomenon of polarization, in which "no one cares" and "no school" coexist, be avoided.

5. Analysis and Discussion

5.1. Problem Analysis

The trend of low birth rate is profoundly affecting the pattern of supply and demand of preschool education resources. Simulation results show that, against the background of the continuous decline in the birth population, the contradiction between supply and demand in different regions is obviously differentiated: urban densely populated areas still have strong demand for kindergartens due to their large population base and concentrated inflow, while some rural areas have redundant resources due to the continuous outflow of population. Educational resources are shifting from a "shortage" to a "surplus", which will have a far-reaching impact on the supply of education. The current allocation of preschool education resources is facing two major problems: first, uneven spatial distribution, mismatch between supply and demand in different regions, resulting in some areas being "difficult to enroll in a school" and others being "empty and unused"; and second, lagging control mechanisms and a lack of dynamic monitoring and timely response, which can easily lead to a waste of financial resources or a waste of service provision. Secondly, the regulatory mechanism is lagging behind, lacking dynamic monitoring and timely response, which easily leads to the waste of financial resources or insufficient supply of services. In the face of this series of challenges, it is necessary to analyze the root causes of the problems based on the simulation conclusions of the System Dynamics-Antibody Model (SD-ABM), propose differentiated optimization strategies for different regional characteristics, and design dynamic regulation mechanisms and policy tools to achieve efficient matching and fair allocation of supply and demand for preschool education resources.

(1) In terms of regional layout, simulation analysis reveals the current imbalance in the supply of inclusive preschool education resources. Some new towns and areas with population inflow have a tight supply of preschool education resources due to lagging planning, and the pressure to enroll in kindergartens is great; in contrast, some rural areas, especially remote villages, have a low utilization rate of kindergartens or even idle kindergartens due to a sharp decline in student population. This problem of "structural tension" and "structural surplus" shows that a single policy of equalization is difficult to take into account varying regional needs.

(2) In terms of resource allocation mechanisms, the traditional static planning approach makes it difficult to respond to fluctuations in the school-age population in a timely manner. If too many new kindergartens are built at the peak of the birth cycle, resources will be left unused after the peak; on the other hand, if the supply is only maintained according to the current number of students, there may be a shortage of supply when there is a localized peak in the number of students enrolled in kindergartens. Therefore, it is necessary to establish a sensitive dynamic monitoring and adjustment mechanism to track in real time the chain of changes in the "fertility rate, school-age population, demand for kindergartens, and supply of resources," so as to realize early warning and proactive intervention.

(3) In terms of policy support, the current financial input mechanism and quality supervision of preschool education are still inadequate. The government's investment in preschool education is on the low side, with financial investment in preschool education accounting for only 5.9% of education expenditure in 2021, far lower than the average of about 11% in countries at the same level of development. The per-pupil financial subsidy standard for inclusive kindergartens is not uniform and is generally low (in some provinces, it is less than 500 yuan per pupil per year), which has led to difficulties in the operation of public kindergartens and insufficient incentives for privately-run inclusive kindergartens. At the same time, the phenomenon of parents "choosing kindergartens" has, to a certain extent, exacerbated the imbalance between the supply of and demand for high-quality resources, with some high-quality kindergartens in short supply and some general kindergartens left vacant.

5.2. Design of Dynamic Adjustment Mechanism

In order to cope with the fluctuations in demand for preschool education brought about by demographic changes, it is necessary to establish a dynamic monitoring and linkage adjustment mechanism. Based on the results of SD-ABM simulation model, we can design a "fertility rate - resource redundancy - financial early warning" three-in-one regulation framework to achieve real-time optimization of resource allocation. The core idea is: advance monitoring, timely warning, linkage regulation.

(1) Establish a regularized monitoring system for population and demand for kindergartens. At the macro level, the education department should work with the health and statistics departments to closely track changes in the birth rate, household registration and the size of the floating population, and regularly predict the future trend of the number of school-age children, so as to form high-precision forecasts of demand for kindergartens. At the micro level, a database on the supply and demand of pre-school education places (places i.e. admission quotas) should be established, with precise information on the enrollment capacity, number of children enrolled, and vacant places in each kindergarten, and updated annually. Information technology is used to realize the dynamic collection and visualization of data, so that the supply and demand situation in each region and each kindergarten is well known.

(2) Setting up an early warning trigger mechanism based on monitoring data. When it is found that there is resource redundancy (e.g., the number of school-age children is consistently below a certain percentage of the capacity of the school) or resource shortage (e.g., the enrollment is full and a large number of school-age children have not yet been admitted to the school) in a certain region, the system should issue an early warning signal. For example, red line thresholds can be set: a "surplus warning" is triggered when the regional average enrollment rate is below a certain percentage, and a "shortage warning" is triggered when it is above a certain percentage. The early warning should be transmitted to the education administration and the finance department at the same time, forming a financial early warning linkage. For the "surplus warning", the financial sector needs to assess the effectiveness of the use of public school funds, and timely adjust the investment plan for the next cycle, to avoid the waste of financial funds in the extremely insufficient number of students in the area of idleness. For the "shortage warning", emergency reinforcement mechanisms should be activated, such as special allocations to support the establishment of additional classes or temporary gardens, to alleviate the urgent needs.

(3) Build a flexible decision-making mechanism for resource adjustment. Linkage adjustment should include two aspects of adjustment: first, quantity adjustment, i.e., timely increase or decrease in the supply of gardens and school places according to the early warning signal. In the case of areas where there is an obvious decline in the number of students, measures such as the integration of small-scale schools and kindergartens and the reduction of classes can be initiated; in the case of areas where there is a small peak in the number of births, the supply of

school places will be rapidly increased or the upper limit of class size will be expanded. The second is standard adjustment, that is, dynamically adjusting the standard of schooling conditions to absorb fluctuations. As experts have pointed out, a moderate degree of redundancy in supply can be maintained through the regulation of class sizes and other means, so as to smooth out the peak without overbuilding schools. For example, in the face of a short-term peak in enrolment, the upper limit of class size can be temporarily raised or classrooms can be utilized for multi-functional purposes to expand capacity; during a period of declining student numbers, the class size standard can be adjusted downward and small-class teaching can be implemented to improve the quality of education while absorbing surplus school places. Through the dual regulation of quantity and standard, it ensures that supply and demand are always in a state of dynamic equilibrium.

6. Conclusion and Outlook

6.1. Conclusion

Under the background of low fertility rate and taking Shandong Province as a typical case, this study comprehensively applies various methods such as GIS spatial analysis, system dynamics (SD) and multi-subject modeling (ABM) coupled simulation, and takes the "population-policy-resource-behavior" multi-dimensional perspective. "The dynamic optimization model of regional inclusive preschool education resource allocation is constructed from the multidimensional perspective. Through empirical data analysis and simulation, this paper draws the following main conclusions:

- (1) There are significant spatial differences and structural mismatches in the supply and demand of regional inclusive preschool resources. Under the trend of low fertility rate, resource tension and redundancy problems coexist in urban and rural areas, as well as in new urbanized areas, and the phenomena of service blind zones, hotspot kindergartens overloaded, and coldspot kindergartens vacant are obvious.
- (2) The system dynamics model reveals the dynamic feedback relationship between "fertility - school-age children - demand for kindergartens - financial supply - regulation of kindergartens". In a scenario of declining fertility, without timely intervention, universal resources will fall into a vicious cycle of "misalignment of supply and demand, financial waste, and quality slippage".
- (3) The ABM simulation with the introduction of parents shows that parents' choice of schools has a key influence on the balance of the system. Excessive centralization of high-quality garden selection will exacerbate the structural contradiction between supply and demand, leading to the coexistence of overloaded high-quality gardens and vacant gardens.
- (4) The two-way coupled SD-ABM model can effectively simulate the system response under different policy and behavioral scenarios and provide prospective predictions for policy design. The simulation results show that the establishment of a dynamic regulation mechanism based on real-time monitoring and feedback adjustment, the implementation of differentiated regional strategies and the optimization of the financial subsidy structure can help to improve the efficiency of resource allocation and educational equity.

6.2. Theoretical and Practical Contributions

This study has made innovative explorations in both theory and practice:

- (1) Breakthrough in method integration: For the first time, GIS spatial analysis, SD system dynamics modeling and ABM multi-subject simulation are organically integrated, realizing a unified coupled modeling of macro-structure and micro-behavior. The model not only portrays the long-term evolution trend of the education system, but also simulates the cumulative effect of nonlinear individual decisions such as parents' choice of school, expanding the application boundary of complex system modeling in the field of education resource allocation.

(2) Deepening of research perspective: Breaking through the traditional research framework of "static assessment and point optimization", we construct a new paradigm of education resource layout adapted to the trend of low fertility rate from the perspective of "dynamic regulation and system feedback", emphasizing the importance of the new paradigm of education resource layout. A new paradigm of education resources layout is constructed to adapt to the trend of low fertility rate from the perspective of "dynamic regulation and system feedback", emphasizing the strategic thinking of combining prediction, adaptation and adjustment.

(3) Practical support of policy tools: The study proposes operational strategies for regional differences, a financial early warning mechanism, a path for improving the quality of kindergartens, and measures for guiding parents in choosing kindergartens, which provide theoretical support and data validation for the optimization of current preschool education resources, and help to improve the level of the government's scientific decision-making in the provision of public services in education.

6.3. Research Shortcomings and Future Prospects

Despite the efforts of this study in theoretical modeling and empirical simulation, the following limitations still exist, and future research can be further expanded in the following areas:

(1) Data accessibility limitations: some model parameters rely on statistical yearbooks, questionnaire surveys and local policy texts, and the simulation accuracy of the model at the prefecture and city levels and in more refined regions still needs to be improved due to the spatial granularity and temporal accuracy of the data.

(2) Complexity of parental behavior modeling: The parental choice rules in ABM are based on sample surveys, and it is difficult to fully simulate the complex psychological factors such as information asymmetry, social network influences, and cultural preferences, etc. A model mechanism based on behavioral economics or social networks can be introduced in the future.

(3) The interference of external variables has not been fully incorporated: for example, the impact of the new crown epidemic on kindergarten enrollment behavior, the constraints of the economic cycle changes on the ability of financial input, and the lag of the adjustment of education policies, etc. These factors are only trend assumptions in the model, and fail to be dynamically integrated.

Based on the above limitations, future research can be carried out in the following directions:

(1) Refined spatial modeling: combining POI data with population raster data with higher precision of residence to improve the realism of spatial simulation and the pertinence of policy evaluation.

(2) Cross-field integration: Introduce artificial intelligence, machine learning and other means to realize parameter learning and adaptive adjustment of prediction models, and improve the model's autonomous evolution capability.

(3) Multi-policy linkage simulation: build a cross-sectoral linkage policy scenario library to simulate the system behavior under multi-policy combinations such as finance, education, health, etc., in order to support a more comprehensive policy pre-assessment.

(4) Multi-region comparative study: Expand the model to other provinces or countries, and summarize the optimization path of resource allocation under different demographic structures and policy regimes through comparative study, so as to enhance the universality and theoretical outreach of the model.

In conclusion, low fertility is both a challenge and an opportunity. Through the in-depth integration of simulation and regulation mechanism, this study hopes to provide guidance for the scientific allocation of preschool education resources in China in the new era, and to

promote preschool education from "universal access" to "high quality and accessibility", so as to realize the grand goal of education modernization.

References

- [1] H. He, J. Gao and F. Wang: *Journal of Educational Studies*, (2025) No.4, p.41-47.
- [2] Z. Chu and Q. Liu: *Educational Science Research*, (2025) No.1, p.27-33.
- [3] W. Feng, Y. Yuan and J. Wu: *Preschool Education Research*, (2024) No.5, p.45-57.
- [4] Y. Xu, C. Lan and W. Feng: *Journal of Xinjiang Normal University (Philosophy and Social Sciences Edition)*, Vol. 45 (2024) No.6, p.145-153.
- [5] Y. Cai, C. Cui, M. Zi et al.: *Preschool Education Research*, (2024) No.1, p.24-37.
- [6] C. Zheng, Y. Jiang, J. Wang et al.: *Preschool Education Research*, (2017) No.2, p.17-26.
- [7] C.D. Cobb: *Review of Research in Education*, Vol. 44 (2020) No.1, p.97-129.
- [8] S. Wang: *Wuhan University (Master's Thesis)*, (2023).
- [9] C. Huang and L. Li: *Journal of East China Normal University (Education Science Edition)*, Vol. 41 (2023) No.12, p.113-126.
- [10] J. Zhang and N. Jiang: *Journal of Chongqing Second Normal University*, Vol. 37 (2024) No.3, p.67-73,128.
- [11] Y. Li, X. Yang, Y. Fan et al.: *Preschool Education Research*, (2025) No.5, p.50-63.
- [12] S. Zuo and X. Yao: *Advances in Education*, Vol. 14 (2024), p.619.
- [13] Y. Lyu and B. Hao: *Journal of Sichuan University of Light Industry (Social Sciences Edition)*, Vol. 40 (2025) No.1, p.115-128.
- [14] H. Min, H. Wang and T. Yang: *Research on Educational Development*, Vol. 43 (2023) No.12, p.25-32.
- [15] C. Wang, L.J. Gu, F. Li et al.: *Chinese Journal of Educational Technology*, (2021) No.5, p.39-48.
- [16] M. Wang and Z. Zhang: *Research on Graduate Education*, (2020) No.5, p.81-90.
- [17] M. Ye: *Journal of Quantitative Economics and Technical Economics*, (2002) No.9, p.11-14.
- [18] Z. Zhou, N. Tian and Y. Zhao: *Journal of Southwest Normal University (Natural Science Edition)*, Vol. 42 (2017) No.3, p.49-55.
- [19] S. Maroulis, E. Bakshy, L. Gomez and U. Wilensky: *Journal of Artificial Societies and Social Simulation*, Vol. 17 (2014) No.2, p.3.
- [20] J. Zhang and B. Yu: *Chinese Distance Education*, Vol. 44 (2024) No.2, p.47-61.
- [21] S.M. Sheridan, N. Koziol, A.L. Witte et al.: *Early Childhood Education Journal*, Vol. 48 (2020) No.3, p.365-377.
- [22] E.H. Kim, C.B. Flack, K. Parham et al.: *Review of Educational Research*, Vol. 91 (2021) No.3, p.356-396.
- [23] M. Mosharraf and F. Taghiyareh: *IEEE Transactions on Learning Technologies*, Vol. 13 (2019) No.2, p.297-311.
- [24] M.A. Achachlouei and L.M. Hilty: *Environmental Modelling Software*, (2015), p.1-25.
- [25] A. Brugière, D. Nguyen-Ngoc and A. Drogoul: *Frontiers in Applied Mathematics and Statistics*, Vol. 8 (2022), p.1020353.
- [26] T. Jiang: *Journal of Finance and Economics*, Vol. 47 (2021) No.8, p.94-108.