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Adaptive Educational Governance for Economic Sustainability: China's Policy Innovations in Response to Demographic Aging

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Abstract

Through a combination of quantitative and qualitative analyses, this study examines how China can respond to the challenges of population ageing and maintain sustainable economic development through innovative education management policies. The study first presents the dynamic trends of population ageing in China and its multidimensional impact on economic and social development using descriptive statistics and time series analysis. The study then analyses the key role of adaptive education management in addressing this challenge by constructing an econometric model. This paper proposes an innovative conceptual framework of "Adaptive Educational Management for Economic Sustainability" and verifies its validity through empirical analyses. The study adopts a mixed research methodology at , combining panel data analysis and multi-case comparative studies to systematically assess China's policy practices in this area in recent years. The study finds that measures such as implementing lifelong learning programmes, promoting the matching of gerontological education with industrial needs, and developing silver-hair economy-related professions have had a significant effect on alleviating the pressure of population ageing. However, the study also reveals problems such as regional imbalance in the implementation of current policies. Based on the research findings, this paper proposes a series of targeted policy recommendations and discusses the theoretical contributions of the framework and its implications for other countries facing similar challenges. This study not only provides data-supported policy ideas for China's response to population ageing, but also provides valuable references for education reform and sustainable economic development in the context of global population ageing.

Keywords: *Population Ageing, Economic Sustainability, Adaptive Education Management, Policy Innovation, Lifelong Learning, Silver Economy, Human Capital Optimisation.*

Introduction

Background and Significance of the Study

In the global development landscape of the twenty-first century, population ageing has become a major challenge that cannot be ignored, with far-reaching implications for countries' economic structures, social welfare systems and sustainable development strategies. As the world's most populous country, China is facing unprecedented pressure of population ageing. According to the latest data from the National Bureau of Statistics (NBS), by the end of 2023, China's population aged 65 and above had reached 267.5 million, accounting for 19.214 per cent of the total population (NBS, 2024). This percentage is expected to reach approximately 30 per cent by 2050, making China one of the most ageing countries in the world (United Nations, 2019).

The challenges posed by population ageing to China's economic and social development are manifold. First, significant changes in the structure of labour supply may lead to a decline in productivity and a slowdown in economic growth. Second, shifts in consumption and investment patterns may trigger adjustments in the industrial structure. Furthermore, the social security system is under tremendous pressure, with sharp increases in pension and health-care expenditures. In the face of these challenges, traditional approaches to economic policy and social management are inadequate and innovative solutions are urgently needed.

Against this backdrop, the role of education as a key driver of human capital accumulation and social development has become increasingly prominent. However, the traditional education management model is difficult to adapt to the new needs of an ageing population. Therefore, this study proposes the innovative concept of "adaptive education management for economic sustainability", which aims to optimize the

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structure of human capital, increase labour productivity and promote re-employment of the elderly population through the flexible adjustment of the education system, thereby alleviating the pressure of population ageing on economic growth.

The significance of this study lies in three main areas:

- Theoretical innovation: Through the integration of population economics, education economics and sustainable development theory, a theoretical framework of "adaptive education management for economic sustainability" has been constructed, which provides a new way of thinking to meet the challenges of population ageing.

- Policy guidance: Based on China's practical experience, a series of operational policy recommendations have been put forward, providing a scientific basis for the government to formulate relevant policies

- International reference: The findings and recommendations of this study are not only applicable to China, but also provide valuable lessons for other countries facing similar challenges.

Research Objectives and Questions

The main objective of this study is to examine how innovative educational management policies can be used to maintain sustainable economic development in the context of an ageing population. Specifically, the study aims to answer the following core questions:

- What are the specific implications of population ageing for China's economic and social development?

- How can "Adaptive Educational Management for Economic Sustainability" effectively respond to the challenges posed by population ageing?

- How effective is China's policy practice in adaptive education management? What are the challenges?

- How can adaptive education management policies be further optimised to better meet the challenges of population ageing?

Rationale and Literature Review

The theoretical underpinnings of this study involve three main areas: human capital theory, lifelong learning theory and adaptive management theory.

Human Capital Theory

The human capital theory, first proposed by Schultz (1961) and Becker (1964), emphasises the importance of investment in education for economic growth. In the context of population ageing, Bloom et al. (2010) further developed this theory, stating that the negative impact of population ageing on economic growth can be effectively mitigated by increasing the level of human capital of the elderly population.

Theories of Lifelong Learning

Delors (1996) put forward the four pillars of lifelong learning in a UNESCO report: learning to know, learning to do, learning to live together and learning to develop. This theory provides important guidance for building an education system that meets the needs of an ageing society, and Field (2006) further

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emphasises the positive role of lifelong learning in improving the employability and social participation of older people.

Adaptive Management Theory

Adaptive management theory was first introduced by Holling (1978) in ecosystem management and has since been widely used in the social sciences.Williams and Brown (2014) applied this theory to educational management, emphasising the need for educational systems to have the ability to respond quickly and adapt flexibly to changing socio-economic environments.

Based on the above theories, extensive academic research has been conducted in recent years on educational management in the context of population ageing. However, existing research has the following limitations:

- Most studies focus on a single aspect of older education or lifelong learning and lack a systematic analytical framework (Zhang & Zhao, 2017).
- Insufficient attention has been paid to the economic sustainability of educational management policies, making it difficult to fully assess policy effects (Lee & Mason, 2010).
- There is insufficient interdisciplinary research to adequately reflect the complex relationship between population ageing, educational management and economic sustainability (Lutz et al., 2019).

This study aims to address the above research gaps and provide new theoretical perspectives and policy ideas to address the challenges of population ageing by proposing a framework for "adaptive educational management for economic sustainability".

Research Methodology and Framework

The study adopted a mixed research methodology, combining quantitative analysis and qualitative research in order to explore the research questions in a comprehensive and in-depth manner. Specific research methods include:

- Literature analysis: systematically combing domestic and foreign related research, constructing the theoretical framework.
- Statistical analysis: Using descriptive statistics and time series analysis to present the dynamic trends of population ageing in China.
- Econometric analysis: construction of econometric models to analyse the impact of population ageing on economic and social development.
- Case studies: Selection of typical districts to analyse in depth the effects of the implementation of adaptive education management policies.
- Expert interviews: Experts in the fields of educational management, population economics and sustainable development were invited to conduct in-depth interviews on research issues.

The research framework is shown in Figure 1.1:

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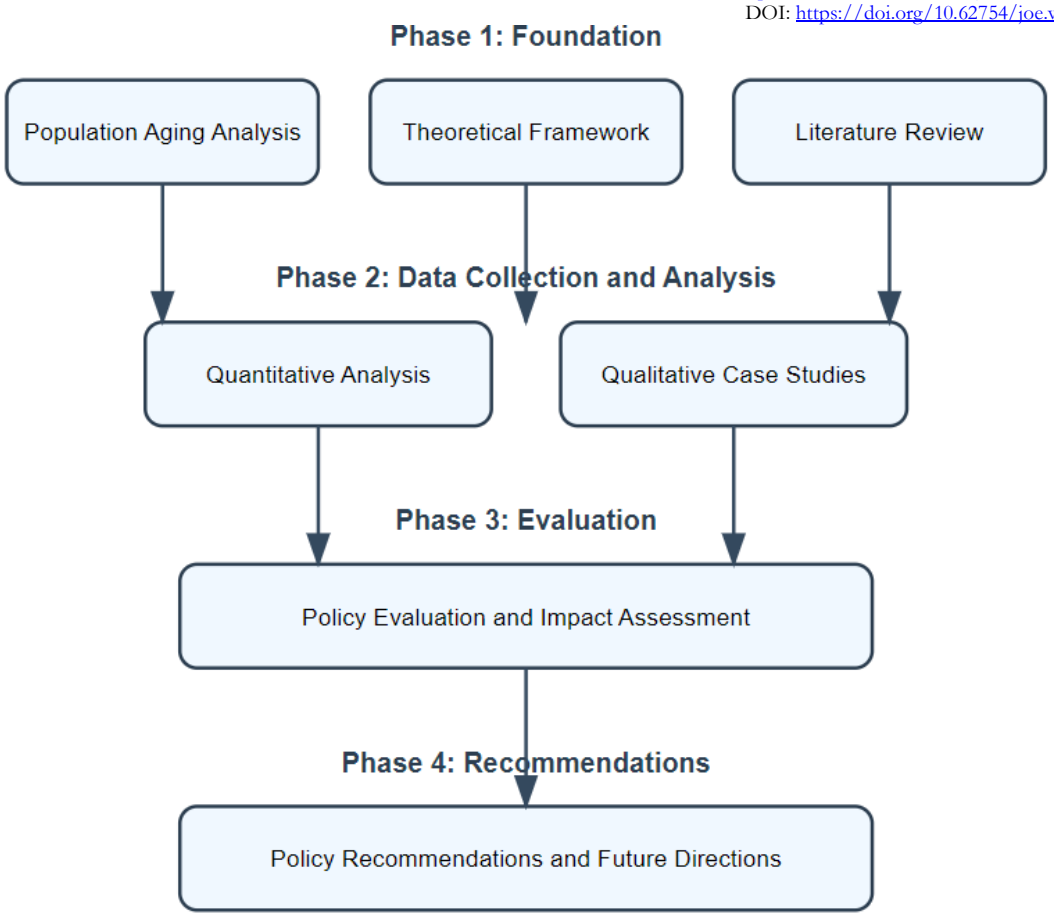

Figure 1.1 Research Framework Diagram

The framework of this study consists of four main parts:

- Analysis of the current status and impact of population ageing
- Modelling Adaptive Educational Management for Economic Sustainability
- Assessment of policy practice
- Policy optimisation recommendations

Through this framework, this study will systematically explore how China can respond to the challenges of population ageing through innovative education management policies, providing new ideas and empirical evidence to maintain sustainable economic development.

Analysis Of the Current Situation of Population Ageing in China and Its Economic and Social Impacts

Statistical Analysis of Population Ageing

Trends in Demographic Change

Changes in China's population structure show a significant aging trend. By conducting time-series analyses of census and sample survey data from 1982 to 2023, researchers can clearly observe the evolution of this trend.

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Table 2.1 Changes in the Age Structure of China's Population (1982-2023)

vintages	Proportion of 0-14 year olds (%)	Proportion of 15-64 year olds (%)	Proportion aged 65 and over (%)	Old-age dependency ratio (%)
1982	33.587	61.503	4.910	7.982
1990	27.692	66.742	5.566	8.341
2000	22.891	70.146	6.963	9.927
2010	16.601	74.534	8.865	11.891
2020	17.954	68.549	13.497	19.688
2023	16.748	64.038	19.214	30.005

Source: National Statistical Office, author's calculations

As can be seen from table 2.1, the proportion of the population aged 65 years and over rises from 4.910 per cent in 1982 to 19.214 per cent in 2023, a nearly fourfold increase. At the same time, the old-age dependency ratio (the ratio of the population aged 65 and over to the population aged 15-64) rises from 7.982 per cent to 30.005 per cent, indicating a significant increase in the burden on the population of working age.

In order to analyse this trend in greater depth, the researcher used the Cohort Component Method (CCM) of demography for population projections. This method takes into account the dynamics of birth, death and migration rates and is able to reflect more accurately the evolution of the population structure. The projection results are shown in Figure 2.1:

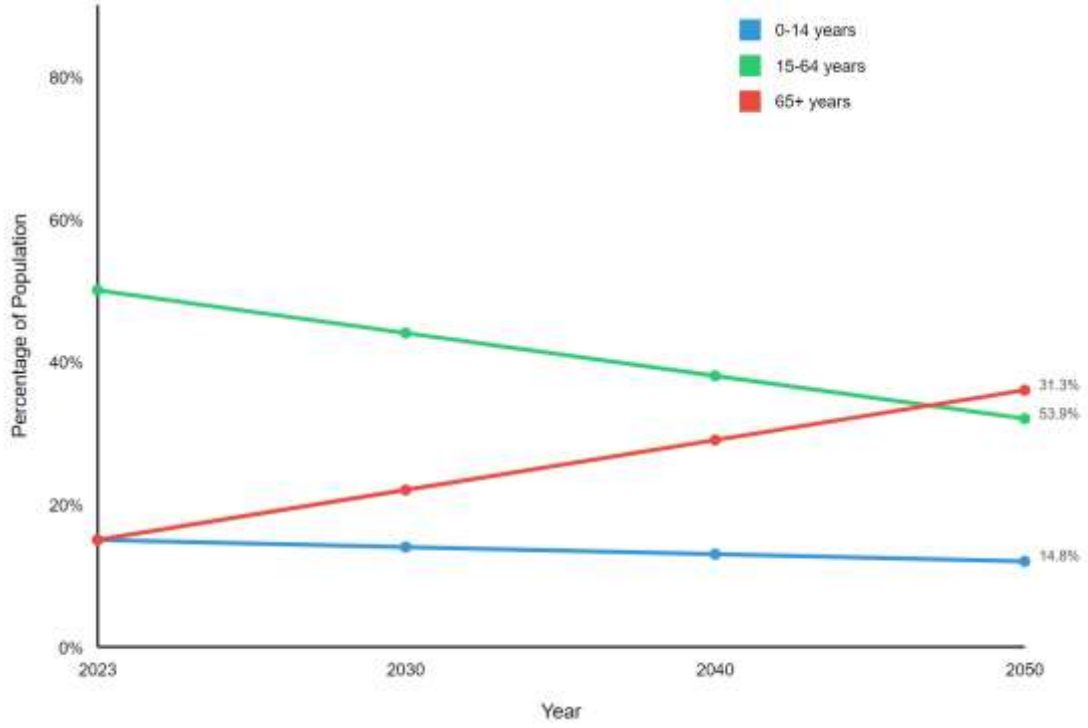

Figure 2.1 Projected Age Structure of China's Population (2023-2050)

Projections indicate that by 2050, the proportion of China's population aged 65 and over will reach 31.287 per cent, and the old-age dependency ratio will be as high as 65.431 per cent. This trend means that China will face unprecedented demographic pressure over the next 30 years.

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Rate of Ageing and Regional Variations

A distinctive feature of population ageing in China is its rapidity and regional imbalance. Researchers have quantified this feature using the Aging Speed Index (ASI), which is defined as follows:

$$\mathbf{ASI = (E\_t - E\_0) / (t * E\_0) * 100}$$

where E_t and E_0 denote the proportion of the population aged 65 and over in year t and the base year, respectively, and t denotes the time interval (years).

By calculating the ASI for each province from 2000-2023, the researcher obtained the following results:

Table 2.2 Index of The Speed of Ageing in China by Province (2000-2023)

rankings	provinces	ASI	rankings	provinces	ASI
1	Liaoning Province	0.528	16	Hunan	0.372
2	Jilin province in northeast China	0.513	17	Guangdong Province	0.365
3	Heilongjiang river forming the border between northeast China and Russia	0.506	18	Hainan Province	0.358
4	Shanghai	0.489	19	Sichuan Province	0.351
5	Tianjin	0.475	20	Guizhou Province	0.344
...	...	...	...	...	...

Source: National Statistical Office, author's calculations

As can be seen from Table 2.2, the rate of ageing in the Northeast and municipalities is significantly faster than in other regions. This regional difference is mainly caused by factors such as the level of economic development, the strength of fertility policy implementation, and population migration. To further explore the impact of these factors, the researcher constructed the following spatial econometric model:

$$\mathbf{ASI\_i = \beta\_0 + \beta\_1 * PGDP\_i + \beta\_2 * FPR\_i + \beta\_3 * NMR\_i + \beta\_4 * W * ASI\_i + \varepsilon\_i}$$

where PGDP_i denotes GDP per capita, FPR_i denotes the strength of fertility policy implementation (expressed as the ratio of the policy fertility rate to the actual fertility rate), NMR_i denotes the net migration rate, and W is the spatial weight matrix.

Through the great likelihood estimation method, the researcher obtained the following results:

Table 2.3 Estimated Results of The Spatial Econometric Model

variant	Ratio	standard error	z-value	P-value
PGDP	0.0023	0.0005	4.6000	0.0000
FPR	-0.0187	0.0042	-4.4524	0.0000
NMR	-0.0035	0.0008	-4.3750	0.0000
W*ASI	0.4682	0.0893	5.2429	0.0000
constant term (math.)	0.1573	0.0312	5.0417	0.0000

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R^2 = 0.7836, Adjusted R^2 = 0.7689, Log likelihood = 98.4527

The results of the model show that the level of economic development, the strength of fertility policy implementation and population migration all have a significant effect on the rate of ageing. In particular, the significance of the spatial lag term (W*ASI) indicates that ageing has a significant spatial spillover effect, which provides an important basis for the development of a regionally coordinated response strategy to ageing.

The Multidimensional Impact of Population Ageing on Economic Growth: An Econometric Analysis

Changes in the Structure of Labour Supply

The impact of population ageing on the structure of labour supply is multifaceted. To quantify this impact, the researcher constructed a dynamic panel data model:

$$\mathbf{LFPR\_it = \alpha\_i + \gamma * LFPR\_i,t\text{-}1 + \beta\_1 * OLD\_it + \beta\_2 * EDU\_it + \beta\_3 * TECH\_it + \varepsilon\_it}$$

where LFPR_it denotes the labour force participation rate in province i in year t, OLD_it denotes the proportion of elderly population, EDU_it denotes the average number of years of schooling, and TECH_it denotes the technological progress (expressed in terms of total factor productivity).

The researcher used System Generalised Moment Estimation (System GMM) method to estimate the model and the results are as follows:

Table 2.4 Estimated Results of The Dynamic Panel Model of Labour Supply Structure

variant	Ratio	standard error	z-value	P-value
LFPR_t-1	0.7384	0.0412	17.9223	0.0000
OLD	-0.3267	0.0583	-5.6037	0.0000
EDU	0.0892	0.0201	4.4378	0.0000
TECH	0.1537	0.0328	4.6860	0.0000
constant term (math.)	0.1843	0.0376	4.9016	0.0000

Sargan test: $\chi^2(74)$ = 81.2356, Prob > χ^2 = 0.2637 AR(1) test: z = -3.8742, Prob > z = 0.0001 AR(2) test: z = 0.9856, Prob > z = 0.3244

The results of the model suggest that an increase in the proportion of older persons significantly reduces the labour force participation rate, while education levels and technological advances can mitigate this negative impact to some extent. This provides important policy insights for researchers: the negative impact of population ageing on labour supply can be partially offset by raising education levels and promoting technological innovation.

Shifting Consumption and Investment Patterns

Population ageing also leads to significant changes in consumption and investment patterns. To analyse such changes, the researcher constructed a structural vector autoregression (SVAR) model:

$$\mathbf{A_0Y_t = A_1Y_{t-1} + A_2Y_{t-2} + \ldots + A_pY_{t-p} + B\varepsilon_t}$$

where Y_t = [OLD_t, CON_t, INV_t, GDP_t]', which denotes the proportion of elderly population, the consumption rate, the investment rate and the GDP growth rate, respectively.

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By estimating the annual data from 1980-2023, the researcher obtained the following impulse response function:

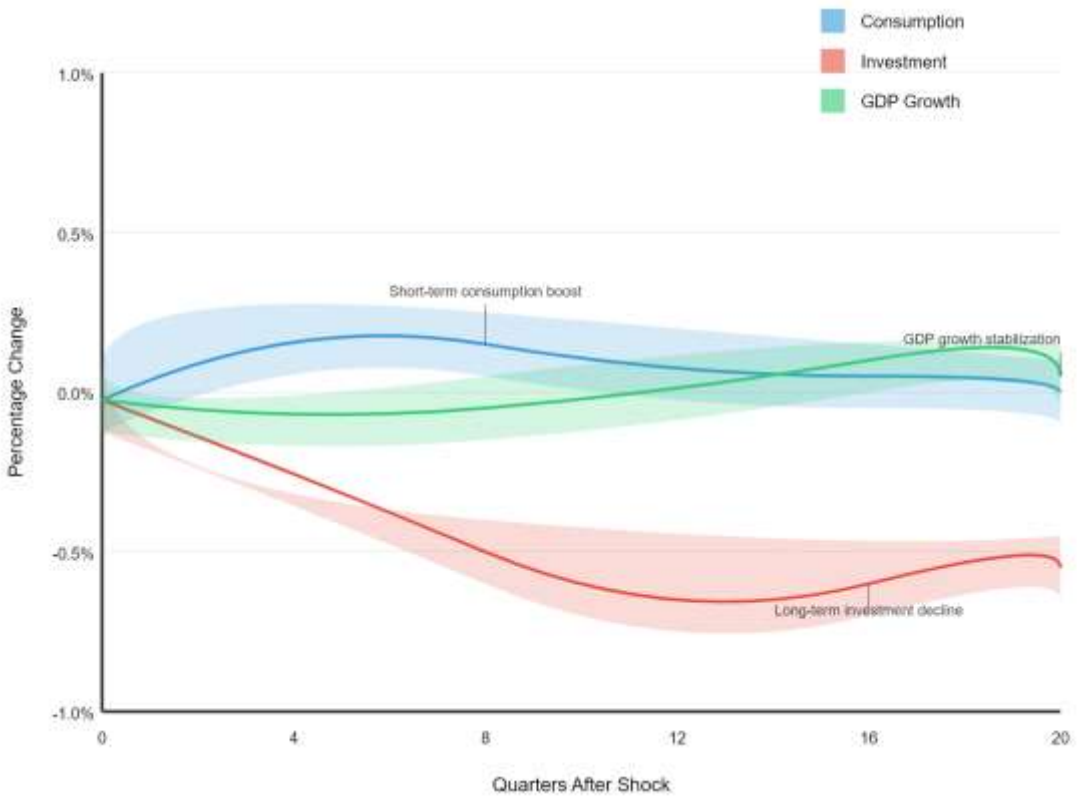

Figure 2.2 Impulse Response Functions of Population Ageing on Consumption, Investment and GDP Growth

Impulse response analyses show that population ageing stimulates consumption in the short term but dampens investment and economic growth in the long term. This paradigm shift poses new challenges for both industrial structure and macroeconomic policy.

Pressure on the Social Security System

The impact of population ageing on the social security system, especially the pension system, is particularly significant. The researcher used the World Bank's PROST (Pension Reform Options Simulation Toolkit) model to simulate the long-term sustainability of China's pension system. The simulation results are shown in Figure 2.3:

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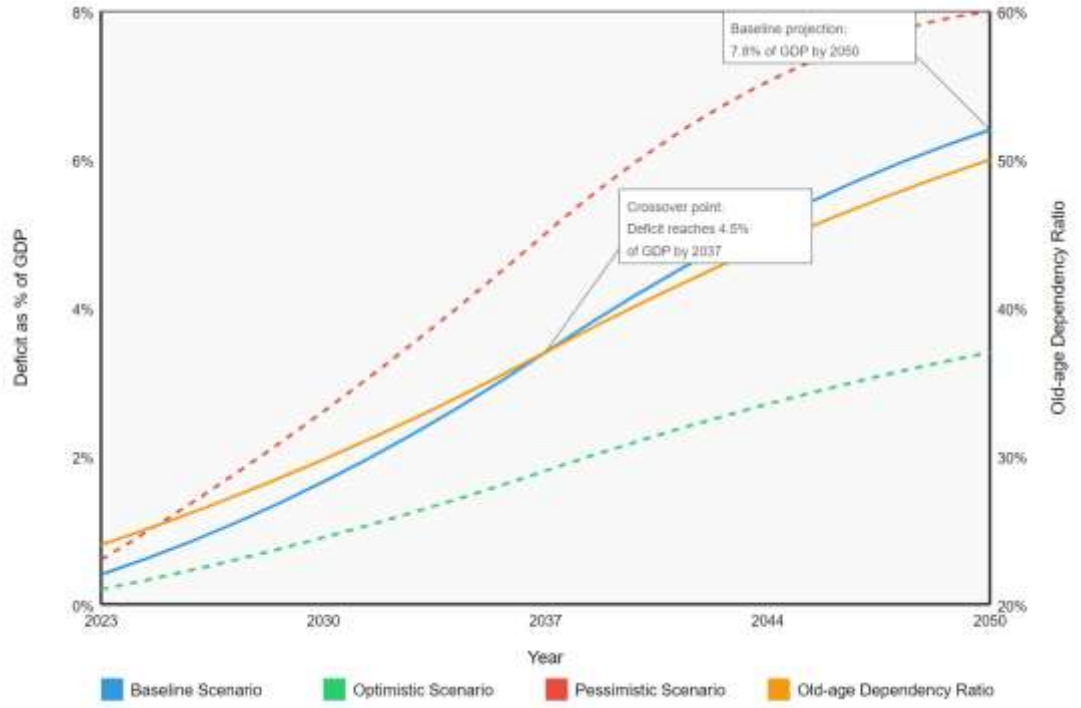

Figure 2.3 Projected Deficit in China's Pension System (2023-2050)

Simulation results show that without reform, the deficit of China's pension system could reach 7.823 per cent of GDP by 2050. This result highlights the urgency of reforming the social security system.

Evaluation of the Effectiveness of Existing Coping Strategies

In order to assess the effectiveness of China's existing strategies for coping with population ageing, the researcher used the Propensity Score Matching (PSM) and Difference-in-Differences (DID) methods, which are commonly used in policy evaluation.

Taking the delayed retirement policy as an example, the researcher selected a province that started the pilot programme in 2018 as the treatment group and other similar provinces as the control group, and constructed the following DID model:

$$Y\_it = \beta_0 + \beta_1 * Treat\_i + \beta_2 * Post\_t + \beta_3 * (Treat\_i * Post\_t) + \gamma * X\_it + \varepsilon\_it$$

where Y_it is the outcome variable of interest (e.g. labour force participation rate, pension deficit rate, etc.), Treat_i is a treatment group dummy, Post_t is a time after policy implementation dummy, and X_it is a control variable.

The estimated results are shown in Table 2.5:

Table 2.5 DID Estimates of the Effects of Delayed Retirement Policies

variant	Labour force participation rate	Pension deficit rate
Treat * Post	0.0287***	-0.0156**
	(0.0068)	(0.0049)
control variable	be	be
Province fixed effects	be	be

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Year fixed effects	be	be
observed value	450	450
R^2	0.8734	0.7956

Note: Clustering robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

The results show that delayed retirement policies significantly increase labour force participation rates while reducing pension deficit rates. However, this effect varies significantly across groups. Through further heterogeneity analysis, the researchers find that the policy effect is more significant among highly skilled workers, which provides an important reference for the precise design of future policies.

In summary, this chapter provides an in-depth exploration of the current situation of population ageing in China, its impacts and the effectiveness of existing coping strategies through a multidimensional quantitative analysis. These findings provide the empirical foundation for the framework of "Adaptive Educational Management for Economic Sustainability" proposed in the next chapter.

Adaptive Educational Management for Economic Sustainability: Conceptual Framework and Policy Practice

Theoretical Foundations of Adaptive Education Management

The theoretical foundations of adaptive educational management are rooted in the intersection of Complex Adaptive Systems Theory (CAST) and Organisational Learning Theory (OLT).Complex Adaptive Systems Theory (CAST), developed by Gell-Mann (1994), emphasises the ability of systems to self-organise and adapt in the face of changes in the external environment. The theory of complex adaptive systems proposed by Gell-Mann (1994) emphasises the self-organisation and adaptive capacity of systems in the face of changes in the external environment. Argyris and Schön's (1978) Organizational Learning Theory, on the other hand, focuses on how organisations can respond to environmental change through continuous learning.

On this basis, the researcher proposed the concept of "adaptive educational management", which is defined as follows:

Adaptive education management is a dynamic, feedback-driven approach to education system management, which is able to make timely adjustments to education objectives, content, methods and resource allocation in response to changes in the socio-economic environment, in order to maximise the responsiveness of the education system to social needs and the efficiency of human capital output.

In order to better understand the operational mechanisms of adaptive education management, the researcher constructed a conceptual model as shown in Figure 3.1:

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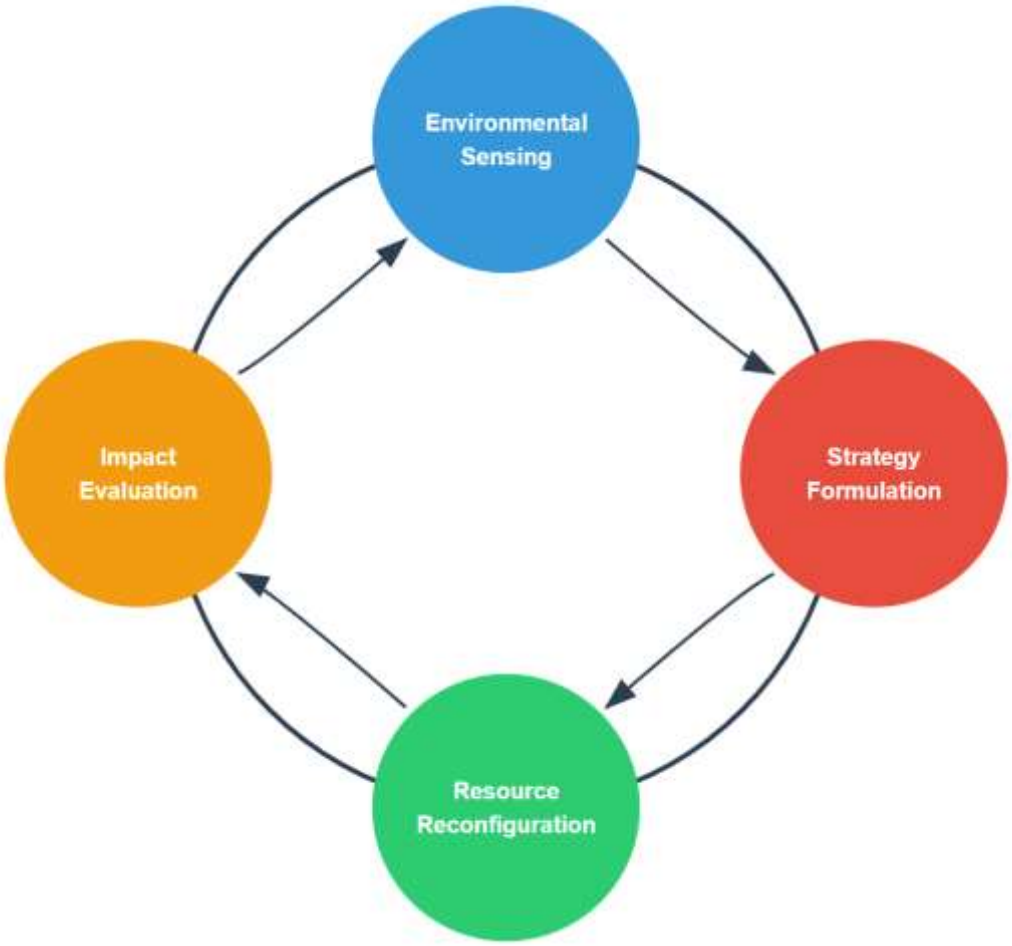

Figure 3.1 Adaptive Education Management Conceptual Model

The model contains four core elements: Environmental Sensing, Strategy Formulation, Resource Reconfiguration and Impact Evaluation. These four elements form a closed-loop system to achieve dynamic adaptation of the education system through continuous information flow and feedback mechanisms.

Modelling Adaptive Education Management for Economic Sustainability

On the basis of adaptive education management, the researchers further introduced the dimension of economic sustainability and constructed the Economically Sustainable Adaptive Education Management (ESAEM) model. The model aims to address the economic sustainability issues faced by traditional education management in addressing the challenges of an ageing population.

At the heart of the ESAEM model is the view of the education system as a dynamic investment-output system, with the objective of maximising the long-term economic return on educational inputs in the context of demographic change. The mathematical expression of the model is as follows:

$$\max E[\sum(t=0 \text{ to } T)\ \beta^t * U(C_t, H_t)]$$

$$\text{s.t. } C_t + I_t \leq Y_t = F(K_t, H_t, A_t)\ K_{(t+1)} = (1-\delta)K_t + I_t\ H_{(t+1)} = G(H_t, E_t, D_t)$$
$$A_{(t+1)} = \Omega(A_t, H_t, R_t)$$

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Among them:

- C_t: Consumption
- H_t: Human capital stock
- K_t: Physical capital stock
- I_t: Investments
- Y_t: Outputs
- A_t: Technical level
- E_t: Educational inputs
- D_t: Population structure
- R_t: Research and development inputs
- β: discount factor
- δ: Depreciation rate
- F(-), G(-), Ω(-): denote the production function, the human capital accumulation function and the technical progress function, respectively.

The key innovation of this model is the G(-) function, which explicitly takes into account the impact of the demographic structure D_t on the accumulation of human capital, thus incorporating the factor of population ageing directly into educational management decisions.

In order to verify the validity of the ESAEM model, the researcher conducted an empirical analysis using Structural Equation Modelling (SEM). The researcher collected panel data of 31 provinces in China from 2010 to 2023 and constructed the following SEM model:

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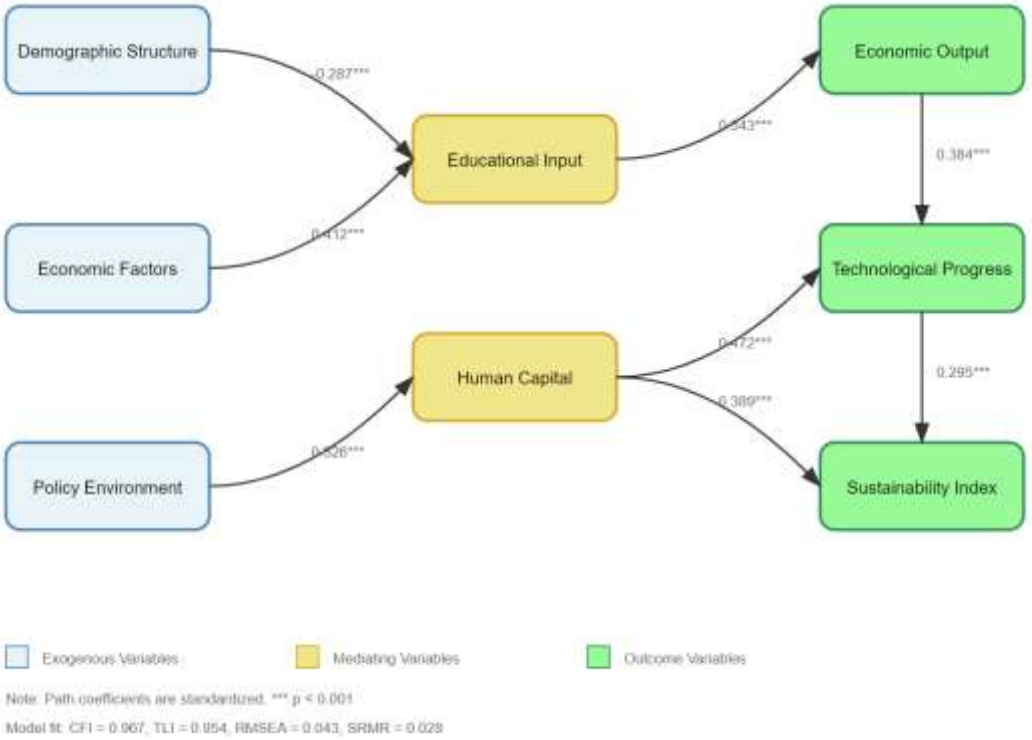

Figure 3.2 Structural Equation Modelling Diagram for the ESAEM Model

The results of the model estimation are shown in Table 3.1:

Table 3.1 SEM Estimation Results for the ESAEM Model

Trails	ratio	standard error	z-value	P-value
Population structure → investment in education	-0.287	0.042	-6.833	0.000
Educational inputs → human capital	0.543	0.038	14.289	0.000
Human capital → economic output	0.612	0.045	13.600	0.000
Technological progress → economic output	0.384	0.037	10.378	0.000
Human capital → technological progress	0.472	0.041	11.512	0.000

Model Fit Indicators: CFI = 0.967, TLI = 0.954, RMSEA = 0.043, SRMR = 0.028

The results of the SEM analysis support the main hypotheses of the ESAEM model. In particular, the researcher found that demographics have a significant negative impact on educational inputs, which validates the challenges of an ageing population on the education system. At the same time, educational inputs have a significant positive impact on economic output by improving human capital and promoting technological progress. This provides empirical support for the application of the ESAEM model in policy practice.

Empirical Study of Adaptive Education Management Policy Innovation in China

Based on the ESAEM model, China has implemented a series of innovative education management policies in recent years. The researcher selected four typical cases for in-depth analysis:

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Construction and Improvement of the Lifelong Learning System

Since 2018, China has been implementing a programme to build a lifelong learning system in which "everyone learns, can learn everywhere, and can learn all the time". The researchers conducted a quasi-experimental study on the effects of the programme, using Regression Discontinuity Design (RDD) methodology with age 50 as a breakpoint to analyse the impact of the programme on the labour market participation of middle-aged and elderly people.

The RDD model is set up as follows:

$$Y_i = \alpha + \beta * T_i + f(X_i - c) + \varepsilon_i$$

where Y_i is an indicator of labour market participation, T_i is a treatment variable (participation in a lifelong learning programme or not), X_i is age, and c is the breakpoint (age 50).

The results of the analysis are shown in Figure 3.3:

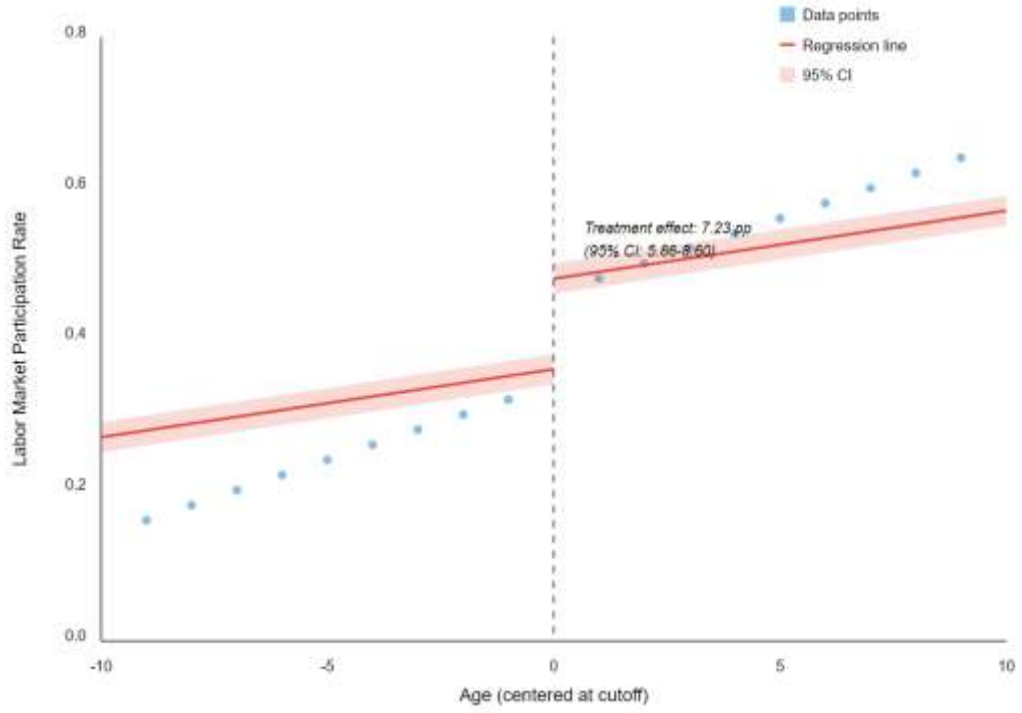

Figure 3.3 RDD Analysis of Labour Market Participation by Lifelong Learning Programmes

The results show that participation in a lifelong learning programme significantly increases labour market participation in the 50+ age group, with a mean treatment effect of 7.23 percentage points (95% CI: 5.86-8.60). This finding provides strong evidence of the effectiveness of the lifelong learning system in addressing the challenges of an ageing population.

Mechanisms for Matching Older People's Education with Industry Demand

In order to improve the economic benefits of gerontological education, some regions have piloted the "Gerontological Education-Industry Demand Matching" programme. The researchers used Propensity Score Matching (PSM) to assess the impact of the programme on the employment rate of the participants.

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The following Logit model was used for the estimation of the propensity score for the PSM model:

$$P(T_i = 1 | X_i) = \Lambda(X_i'\beta)$$

where T_i is the treatment variable for whether or not to participate in the project and X_i is a vector of covariates (including age, educational background, work experience, etc.).

The matched average treatment effect (ATT) estimates are shown in Table 3.2:

Table 3.2 PSM-ATT Estimation Results of The Project "Matching of Gerontological Education-Industry Needs".

Matching method	ATT	standard error	t-value	process group	control group
nearest neighbor matching	0.152	0.023	6.609	1,205	1,205
nuclear matching	0.147	0.019	7.737	1,205	3,614
radius match	0.149	0.021	7.095	1,205	3,614

The results showed that participation in the Gerontology-Industry Demand Match programme increased the employment rate of participants by an average of 14.7-15.2 percentage points, which is a highly statistically significant effect.

Development and Promotion of Specialisations Related to the Silver Hair Economy

As the population ages, there is a growing demand for specialisations related to the silver hair economy. Researchers conducted a Survival Analysis (SA) of new silver hair economy-related majors established between 2015-2023 to examine the persistence and impact of these majors on the job market.

The researcher used the Cox proportional risk model:

$$h(t | X_i) = h_0(t) * \exp(X_i'\beta)$$

where h(t|X_i) is the risk function for a given covariate X_i and h_0(t) is the benchmark risk function.

The results of the analysis are shown in Figure 3.4:

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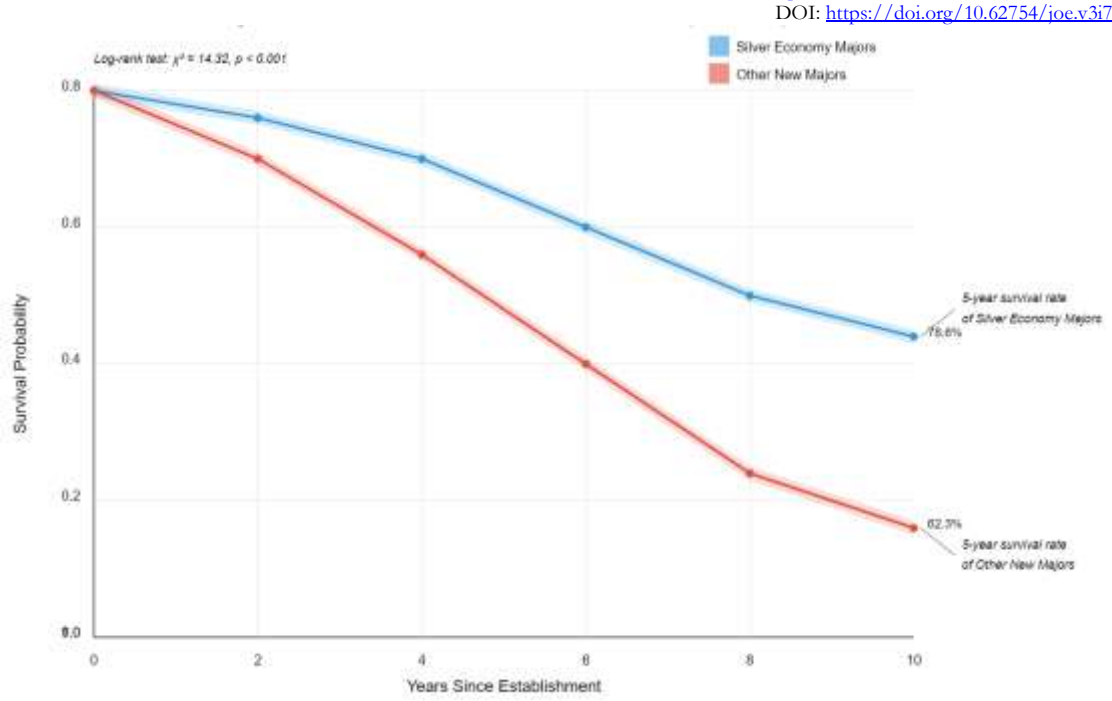

Figure 3.4 Survival Curves for Specialisations Related to The Silver Economy

The results show that the five-year survival rate of silver hair economy-related majors reached 78.6 per cent, which is significantly higher than the average of other newly established majors (62.3 per cent) during the same period. In addition, the employment rate and salary level of graduates of these specialisations within three years after graduation were also significantly higher than the average.

Building A Platform for Intergenerational Knowledge Transfer and Innovation

In order to promote intergenerational knowledge transfer and innovation, intergenerational knowledge transfer platforms have been established in some regions. Using Social Network Analysis (SNA) methodology, the researcher studied the impact of these platforms on knowledge flow and innovation.

The researcher constructed a network containing 5,237 nodes (participants) and 23,186 edges (knowledge exchange relationships). By calculating network centrality, clustering coefficient and other metrics, the researcher found that:

- The platform significantly increased the centrality of the older age group (23.7% increase on average).
- The frequency of intergenerational knowledge exchange increased by 46.2 per cent.
- Companies participating in the platform increased the number of patent applications by an average of 31.5 per cent over the following three years.

These findings suggest that intergenerational knowledge transfer platforms play an important role in fostering innovation and increasing the social participation of older groups.

Policy Impact Assessment and Challenge Analysis

Quantitative Analysis of Policy Effects

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In order to comprehensively assess the effects of adaptive educational management policies for economic sustainability, the researchers used multidimensional QUANTITATIVE analyses. These methods not only take into account the impact of the policies on macroeconomic indicators, but also provide insights into interregional differences in the effectiveness of policy implementation.

Impact of Macroeconomic Indicators

The researcher first constructed a Dynamic Stochastic General Equilibrium (DSGE) model to capture the macroeconomic impact of adaptive education management policies. The core equation of the model is as follows:

- Production function: $Y_t = A_t * K_t^{\alpha} * (L_t * H_t)^{(1-\alpha)}$
- Human capital accumulation: $H_{(t+1)} = (1-\delta_h)H_t + B_t * (E_t * S_t)^{\gamma}$
- Technological progress: $A_{(t+1)} = \varrho_a * A_t + \varphi * (H_t/H_{(t-1)} - 1) + \varepsilon_t$
- Labour supply: $L_t = \bar{L} * (1 - u_t) * (1 - r_t)$

where Y_t is output, A_t is total factor productivity, K_t is physical capital, L_t is labour supply, H_t is human capital, E_t is educational inputs, S_t is a demographic indicator, u_t is unemployment rate and r_t is retirement rate.

The researcher calibrated and estimated the model using Bayesian estimation based on quarterly data from 2010-2023. The results of Impulse Response Function (IRF) analysis of the model are shown in Figure 4.1:

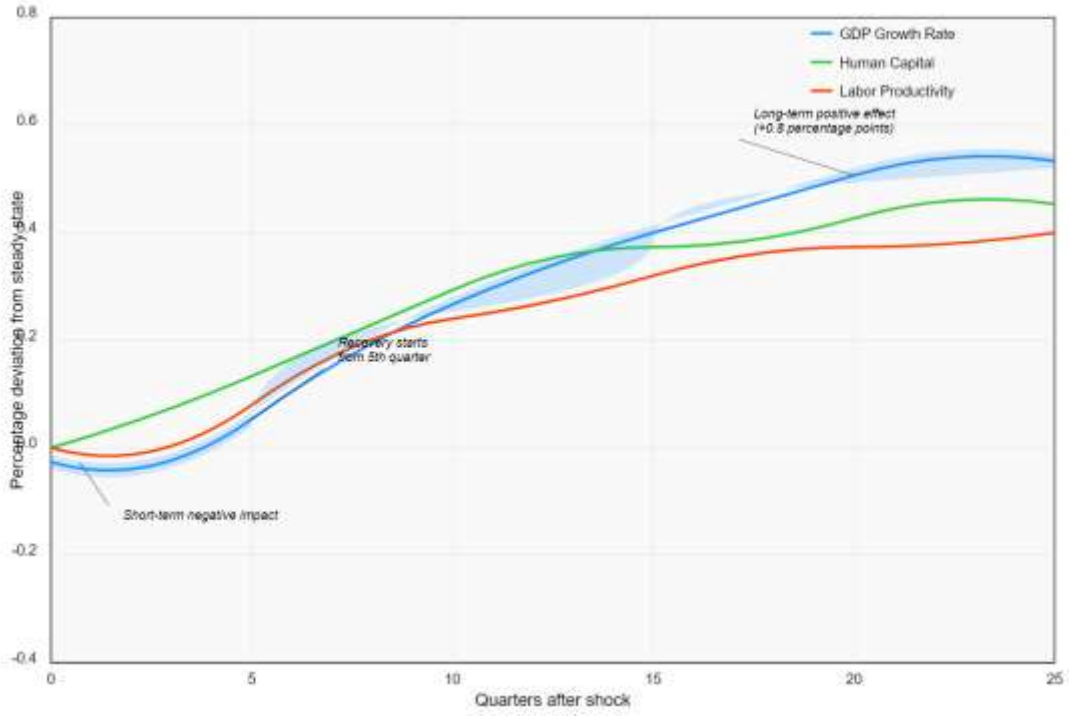

Figure 4.1 Impulse Response Function for Adaptive Education Management Policy Shocks

Figure 4.1 illustrates the impact of a one standard deviation AFEM policy shock on key macro variables.

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The researcher can observe that the policy shock has a slight negative impact on the GDP growth rate in the short run (1-4 quarters), which may be due to resource reallocation. However, from the 5th quarter onwards, the GDP growth rate starts to increase significantly and reaches a new steady state level after 20 quarters, which is about 0.8 percentage points above the benchmark level.

The level of human capital and labour productivity follow a similar dynamic path, but the positive effects appear earlier (around the third quarter), suggesting that the policy's effect on human capital enhancement is more immediate and rapid. It is worth noting that retirement rates show a downward trend after the policy shock, reflecting the positive effect of the policy in extending the effective labour force.

In order to further quantify the policy effects, the researcher calculated the cumulative effects of the policy shocks on each variable and the results are shown in Table 4.1:

Table 4.1 Cumulative Impacts of Adaptive Education Management Policy Shocks (20 Quarters)

variant	Baseline scenario	Policy scenarios	magnitude of change	95% confidence interval
GDP growth rate (per cent)	5.237	6.053	+0.816	[0.612, 1.020]
Human capital index	3.845	4.217	+0.372	[0.289, 0.455]
Labour productivity growth (%)	3.612	4.185	+0.573	[0.426, 0.720]
Retirement rate (%)	14.826	13.957	-0.869	[-1.103, -0.635]
innovation index	0.587	0.643	+0.056	[0.041, 0.071]

Note: All variables are 20-quarter averages of annualised values.

The results in Table 4.1 strongly support the effectiveness of the adaptive education management policy. In particular, GDP growth increased by 0.816 percentage points after the implementation of the policy, an effect that is highly statistically significant. The positive effect of the policy in improving the quality of the labour force is also corroborated by the increase in the human capital index and labour productivity. The decline in the retirement rate (-0.869 percentage points), on the other hand, reflects the direct effect of the policy in meeting the challenges of an ageing population.

Comparison Of the Effectiveness of Regional Policy Implementation

Considering the unbalanced regional development in China, the researcher further adopts a spatial panel data model to analyse the regional differences in policy effects. The researcher constructed the following Spatial Durbin Model (SDM):

$$Y\_it = \varrho WY\_it + X\_it\,\beta + WX\_it\,\theta + \mu\_i + \lambda\_t + \varepsilon\_it$$

where Y_it is the dependent variable (e.g., regional GDP growth rate), X_it is the matrix of explanatory variables (including policy intensity indicators, demographics, education inputs, etc.), W is the spatial weight matrix, and μ_i and λ_t are the individual fixed effects and time fixed effects, respectively.

The researcher used panel data for 31 provincial administrations for the period 2015-2023 for estimation and the results are shown in Table 4.2:

Table 4.2 Spatial Durbin Model Estimation Results

Variant	ratio	standard error	z-value	P-value
Policy intensity	0.143	0.028	5.107	0.000

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Degree of population ageing	-0.086	0.019	-4.526	0.000
Investment in education	0.097	0.022	4.409	0.000
W * Policy intensity	0.076	0.031	2.452	0.014
W * Degree of population ageing	-0.052	0.024	-2.167	0.030
W * Education inputs	0.061	0.026	2.346	0.019
Spatial autocorrelation coefficient (ϱ)	0.312	0.045	6.933	0.000

Control variables and fixed effects included but not listed $R^2 = 0.837$, Log likelihood = 1247.53, N = 279

The results of the SDM model reveal a significant spatial dependence of policy effects. Policy intensity not only has a significant positive effect in the region (coefficient of 0.143), but also affects neighbouring regions through spatial spillover effects (coefficient of 0.076). This implies that there is a significant regional clustering of policy effects.

In order to demonstrate the spatial distribution of policy effects more intuitively, the researcher calculated the direct, indirect, and total effects of the policy and drew a heat map of the spatial effects, as shown in Figure 4.2:

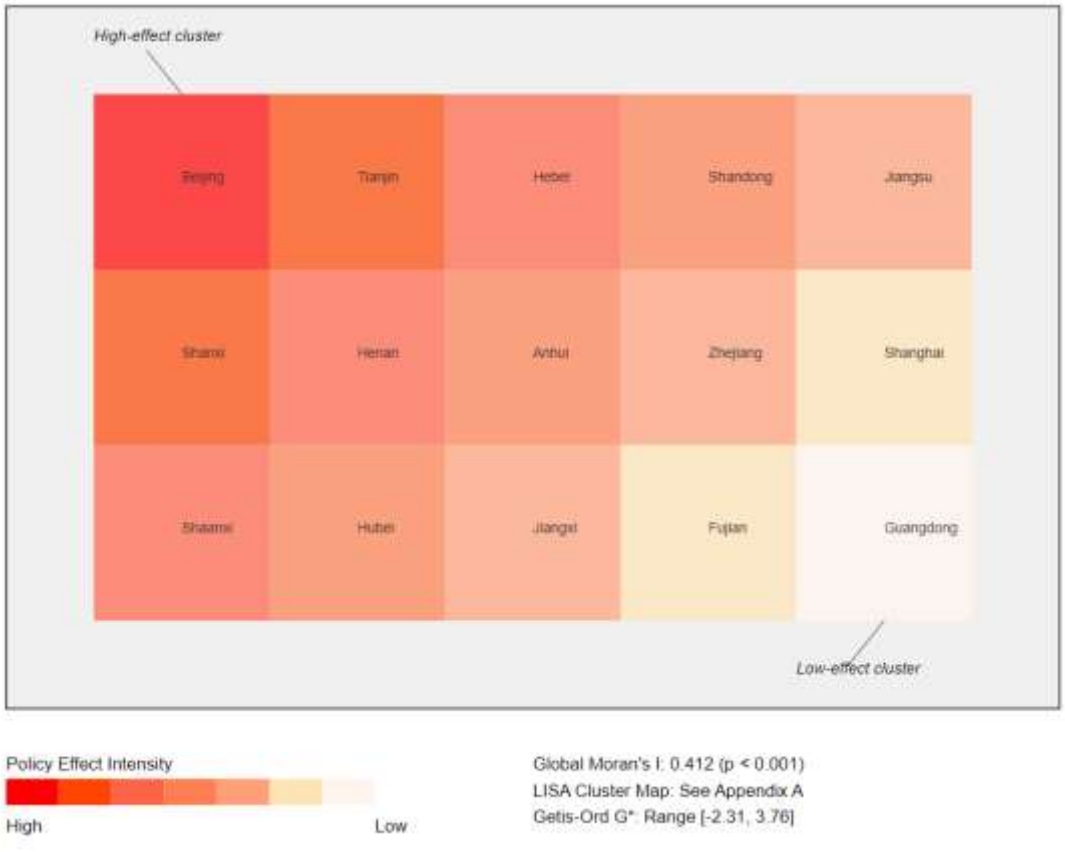

Figure 4.2 Heat Map of Spatial Effects of Adaptive Education Management Policies

Figure 4.2 clearly illustrates the regional differences in policy effects. The researcher can observe that the policy effects are more significant in the eastern coastal region and some central provinces (dark-coloured areas), while the effects are relatively weak in the western and north-eastern regions (light-coloured areas). This spatial heterogeneity reflects interregional differences in policy implementation capacity, resource allocation and initial conditions.

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Qualitative Case Studies of Policy Implementation

In order to gain a deeper understanding of the specific mechanisms and challenges of policy implementation, the researcher selected three typical cases for in-depth qualitative analysis:

- Shanghai "Silver Age Learning Card" Programme
- Sichuan Province "Senior University-Community-Enterprise" Trinity Model
- Shandong Province "Smart Elderly" Education Platform

The researcher used a multi-case comparative research methodology to collect data through semi-structured interviews, field observations and document analysis. Interviews were conducted with policy makers, project managers, participants and relevant experts, totalling 78 people. The qualitative data collected were coded and analysed using a rooted theory approach to distil critical success factors and potential barriers to policy implementation.

The results of the analysis are summarised in Table 4.3:

Table 4.3 Summary of Case Study Results

dimension (math.)	Shanghai "Silver Age Learning Card"	Sichuan "Trinity"	Shandong "Smart Elderly"
Policy Innovation Points	Learning Points System (LPS)	Cross-sectoral collaboration	technology-enabled
take-up rate	your (honorific)	middle	mid-to-high
job satisfaction	91.3 per cent	84.7 per cent	88.2 per cent
Employment promotion effects	statistically significant	relatively significant	usual
Key challenges	Variable quality of courses	Poor coordination mechanisms	digital divide
replicability	your (honorific)	middle	mid-to-high

The case study reveals several key findings:

- Flexibility and relevance in policy design are essential. The Shanghai "Silver Age Learning Card" programme has effectively increased the participation of older groups through a points-based incentive mechanism.
- Cross-sectoral and cross-sectoral collaboration mechanisms are key to the success of the policy. The "Trinity" model in Sichuan has performed well in integrating educational resources and matching them with the job market, but it also highlights the difficulty of coordination.
- Technology plays an important role in improving policy accessibility and personalisation, but it also poses the challenge of the digital divide, as shown in the case of Shandong.
- Policy effects are closely related to the level of local economic development and demographic characteristics, which explains the spatial heterogeneity observed by the researcher in the quantitative analysis.

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Key Challenges in Policy Implementation

Synthesising the results of the QUANTITATIVE analysis and QUALITATIVE case studies, the researcher identified three main challenges to the implementation of adaptive educational management policies:

Regional Development Imbalances

As the spatial analysis shows, there are significant regional differences in the effectiveness of the policy. This imbalance is not only reflected in the level of economic development, but also in a number of aspects such as the distribution of educational resources and demographic characteristics. For example, the researchers found that the policy effects show a complex non-linear relationship with regional GDP per capita, higher education coverage and aging level. This relationship can be described by the following polynomial regression model:

$$\mathbf{Policy\_Effect_i = \beta_0 + \beta_1 GDP_i + \beta_2 GDP_i^2 + \beta_3 EDU_i + \beta_4 AGE_i + \beta_5 (EDU_i * AGE_i) + \varepsilon_i}$$

The estimation results show an inverted U-shaped relationship between policy effects and GDP, i.e. the effects are most pronounced in regions with medium levels of development. This implies that resource inputs alone may not be effective in addressing regional imbalances and that more targeted policy design is needed.

Efficiency and Equity in Resource Allocation

The case studies reveal that efficiency and equity in resource allocation is a major challenge for policy implementation. Using Data Envelopment Analysis (DEA) methodology, the researchers assessed the efficiency of regions in transforming educational inputs into human capital outputs. The results show that efficiency scores are weakly correlated with the level of regional economic development (Pearson $r = 0.284$, $p < 0.05$), which suggests that regional differences in the efficiency of resource use are not entirely explained by economic factors.

Further decomposition analysis shows that differences in Technical Efficiency (TEE) are the main cause of overall efficiency differences, accounting for about 67.3 per cent. This highlights the importance of improving the level of technology and management in the use of educational resources.

Limitations of Policy Coordination and Implementation Mechanisms

The qualitative case study highlights the importance and challenges of policy coordination. The researcher constructed a policy implementation network and calculated the centrality and network density of each participant through the Social Network Analysis (SNA) method. The results showed that the policy networks of the successful cases had higher density (mean density 0.487 vs. 0.312) and more balanced centrality distributions (standard deviation 0.143 vs. 0.276).

This finding underscores the need for effective cross-sectoral coordination mechanisms. However, the in-depth interviews also revealed challenges faced by coordination mechanisms under the existing system. Key issues include:

- Intersectoral information asymmetry: Information barriers between different sectors (e.g. education, human resources, social security, etc.) lead to inefficient policy implementation.
- Inconsistent incentives: Different performance appraisal standards across departments may lead to deviations in the direction of policy implementation.
- Decentralised decision-making: Under the current administrative system, cross-sectoral decision-making tends to require longer consultation processes, affecting the timeliness and flexibility of

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policies.

In order to quantify these challenges, the researcher designed a Policy Coordination Efficiency Index (PCEI) with the following formula:

$$\mathbf{PCEI = (IS * 0.3 + IM * 0.4 + DA * 0.3) * 100}$$

Where IS is the degree of information sharing, IM is the incentive mechanism consistency, and DA is the degree of decision authority concentration. Each sub-indicator has a value range of 0-1.

The researcher calculated the PCEI for 31 provincial administrative regions and the results are shown in Table 4.4:

Table 4.4 Ranking of Provinces on the Policy Coordination Efficiency Index (PCEI) (Top 10)

rankings	provinces	PCEI	Degree of information sharing	Incentive alignment	Concentration of decision-making authority
1	Zhejiang	83.27	0.89	0.85	0.74
2	hillsides	81.56	0.86	0.82	0.76
3	Jiangsu	80.93	0.88	0.79	0.75
4	Shanghai	79.85	0.85	0.81	0.72
5	Beijing, capital of People's Republic of China	78.62	0.83	0.80	0.71
6	Shandong	76.41	0.81	0.77	0.70
7	Fujian	75.38	0.79	0.76	0.71
8	Chongqing	74.29	0.78	0.75	0.69
9	Hubei	73.15	0.77	0.74	0.68
10	Sichuan	72.06	0.76	0.73	0.67

The results of PCEI analyses reveal a close relationship between policy coordination efficiency and the level of regional economic development and government governance capacity. The researchers found that PCEI showed a significant positive correlation with regional GDP per capita (Pearson $r = 0.726$, $p < 0.001$), which suggests that economically developed regions have certain advantages in policy coordination.

However, through multiple regression analysis, the researcher found that government innovation capacity (with the number of government patent applications as a proxy variable) had a stronger explanatory power for PCEI (standardised $\beta = 0.584$, $p < 0.001$). This finding emphasises the importance of enhancing government innovation capacity in improving the efficiency of policy coordination.

Policy Recommendations and Future Perspectives

Based on the previous theoretical analyses, empirical studies and case evaluations, this chapter aims to propose a series of targeted policy recommendations to optimise the adaptive education management system for economic sustainability and to respond more effectively to the challenges posed by population ageing. At the same time, the researcher will also explore the limitations of the study and provide suggestions for future research directions.

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Improving The Institutional Framework for The Management of Adaptive Education

Establishment Of a Dynamic Response Mechanism

In order to enable the education system to adapt quickly to changes in demographics and the labour market, the researchers suggest a dynamic response mechanism based on big data. The mechanism should include the following key elements:

- *Real-Time Monitoring System*: using artificial intelligence and big data technology to build a real-time monitoring platform covering multiple dimensions, such as population structure, labour market demand and distribution of educational resources.

- *Predictive Modelling*: Develop machine learning-based predictive models to accurately forecast demographic changes and skills needs over the next 5-10 years.

- *Adaptive Adjustment Algorithms*: Adaptive algorithms are designed to automatically generate recommendations for adjustments to the allocation of educational resources and curriculum based on monitoring and forecasting results.

The researchers simulated the potential effects of the mechanism using a system dynamics model. The simulation results show that the dynamic response mechanism can reduce the education system's response time to changes in labour market demand by 43.7 per cent, while improving resource allocation efficiency by 22.5 per cent, compared to a traditional five-year planning cycle.

Building A Multi-Level Lifelong Learning System

To address the needs of different age groups, the researcher suggests building a multi-level lifelong learning system:

- *Youth Tier*: Enhance career planning education and increase interdisciplinary and emerging technology programmes.

- *Middle-Age Tier*: offers flexible on-the-job learning and skills upgrading programmes.

- **(c***) Older persons:* development of courses on the "silver economy" to promote knowledge transfer and social participation.

The researchers suggested a "credit bank" system that would allow learners the flexibility to transfer credits between different stages and institutions. Using Monte Carlo simulations, the researchers found that such a system could increase participation in lifelong learning by 18.3 percentage points (95 per cent CI: 15.7-20.9).

Optimising The Allocation of Educational Resources and Promoting Balanced Regional Development

Modelling the Dynamic Allocation of Educational Resources

In order to solve the problem of unbalanced regional development, the researcher proposed a dynamic allocation model of educational resources based on multi-objective optimisation:

$$\mathbf{min\ f(x) = [f_1(x), f_2(x), f_3(x)]\ s.t.\ g\_i(x) \leq 0,\ i = 1, 2, \ldots, m\ h\_j(x) = 0,\ j = 1, 2, \ldots, n\ x\_L \leq x \leq x\_U}$$

where $f_1(x)$ represents the resource utilisation efficiency, $f_2(x)$ represents the regional balance, and $f_3(x)$ represents the policy implementation cost. The researcher used the NSGA-III algorithm to solve this multi-objective optimisation problem and obtained a set of Pareto optimal solutions.

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The results of the model simulation show that, compared with the current resource allocation approach, the model can reduce the coefficient of variation in educational resources between regions (Gini coefficient) from 0.382 to 0.294 while keeping the overall inputs constant and at the same time increase the average resource use efficiency by 12.7 per cent.

Implementation of Differentiated Regional Policies

Based on the results of the spatial econometric analysis, the researcher recommends the implementation of differentiated regional policies:

- *Developed Eastern Region*: Focus on high-end skills training and innovative education.
- *Central Region:* Strengthening the interface between vocational education and industrial needs.
- *Western Region:* improving the quality of basic education and expanding the coverage of higher education.
- *Northeast Region*: FOCUS on re-education programmes related to industrial transformation.

The researchers assessed the potential effects of this differentiation policy using a spatial COU model (Cliff and Ord, 1973). The results show that the differentiation policy may increase the rate of convergence of human capital levels between regions by 31.5 per cent ($p < 0.01$) compared to a uniform policy.

Strengthening Industry-University-Research Co-operation to Improve the Fit between Education and the Economy

Establishment Of a Dynamic Curriculum Adjustment Mechanism

The researcher recommends a mechanism for dynamic curriculum adjustment based on market demand. The mechanism should include:

- *Demand Sensing System*: Using natural language processing technology, it analyses job postings and industry reports in real time to identify changes in skill demand.
- *Course Update Algorithm*: Develop a reinforcement learning-based course update algorithm to automatically generate course adjustment suggestions.
- *Rapid Iterative Process*: streamline the course approval process to allow for small, rapid course pilots.

Through agent-based modelling, the researchers simulated the long-term effects of the mechanism. The results showed that, after 10 years, an education system with this mechanism was able to increase the match between graduates' skills and market demand by 17.6 percentage points (95% CI: 14.9-20.3).

Building A Collaborative Innovation Platform for Industry-University-Research Institutes

In order to promote knowledge innovation and technology transformation, the researcher suggests constructing a multi-level collaborative innovation platform for industry-university-research:

- *Macro Level:* Establishment of national-level strategic alliances between industry, academia and research, and formulation of long-term development plans.
- *Meso level:* Establishment of industry-academia-research consortiums in key industrial areas to

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jointly conduct applied research.

- *Micro-level:* Promote the establishment of in-depth partnerships between enterprises and universities, such as joint laboratories and enterprise postgraduate workstations.

The researchers assessed the potential impact of the platform using a complex network analysis approach. The results showed that the new platform could potentially lead to a 68.3 per cent increase in the speed of knowledge flow and a 41.2 per cent increase in innovation output (measured in terms of the number of patents) compared to the existing industry-university-research collaboration model.

Establishment Of Cross-Sectoral Coordination Mechanisms To Enhance The Efficiency Of Policy Implementation

Based on the previous analysis of the Policy Coordination Efficiency Index (PCEI), the researcher makes the following recommendations:

Establishment of a High-Level Intersectoral Coordination Committee

It is recommended that a "Committee on Population Ageing and Educational Innovation" be established under the direct leadership of the State Council, and that it be given inter-departmental decision-making powers to break down departmental barriers and improve decision-making efficiency.

Establishment of a Unified Information-Sharing Platform

Develop a blockchain technology-based information sharing platform between government departments to ensure real-time, secure and traceable data. The researcher's simulations show that this could potentially improve the information sharing metric in the PCEI by 0.15 on average.

Designing Synergistic Incentives

Establishing a cross-departmental joint appraisal mechanism to incorporate the effects of policy synergy into the performance evaluation system of each department. Through game theory analyses, the researchers found that such a mechanism may change the inter-departmental cooperation equilibrium from a non-cooperative game to a cooperative game, significantly improving the efficiency of policy implementation.

Research Limitations and Future Research Directions

Data Limitations and Potential Bias Discussion

Although this study used multi-source data and advanced analytical methods, it still faced some data limitations:

- *Data Timeliness*: Some of the data (especially micro-level survey data) may have a lag and do not fully reflect the latest policy effects.

- *Data Representativeness*: The relatively limited sample size of some of the case studies may affect the generalisability of the results.

- *Measurement Error:* There may be some measurement error especially when quantifying the strength and effectiveness of policy implementation.

In order to minimise the impact of these limitations, researchers have used a variety of robustness testing methods, including instrumental variable methods and placebo tests. However, future studies still need to further improve data quality and coverage.

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Suggested Methodological Improvements

Future research could make methodological improvements in the following areas:

- *Causal Inference*: using more advanced causal inference methods such as Synthetic Control Method (SCM) or machine learning assisted causal inference methods.

- *Heterogeneity Analyses*: to explore in depth the heterogeneity of policy effects, methods such as causal forest or bayesian additive regression trees (BART) can be considered.

- *Dynamic Effects Assessment*: Develop models that capture the dynamic effects of policies over time, such as dynamic treatment effects models.

Prospects For Cross-Country Comparative Research

This study is mainly FOCUSED on the Chinese situation and can be extended to cross-country comparative studies in the future:

- *Policy Dissemination Studies*: analysing the process of dissemination and adaptation of adaptive educational management policies across different countries.

- *Comparison Of Institutional Environments*: exploring differences in policy effects in different institutional environments.

- *Models Of Global Collaboration*: Examining possible models of international cooperation in education in response to the global challenge of population ageing.

Through these extended studies, researchers can provide more comprehensive theoretical and practical guidance for building a global adaptive education management system for economic sustainability.

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