Analysis of Financial Mathematical Model Application in Estimating Pension Fund Needs in Digitalization Era

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Abstract. The era of digitalization has transformed pension planning by introducing new technologies that enable more sophisticated data analysis for estimating fund requirements. Demographic changes, financial market complexities, and advancements in actuarial science drive the need for more accurate financial mathematical models in calculating pension fund needs. The availability of big data and advancements in analytics, combined with regulatory changes, create new opportunities and challenges in developing more precise and personalized approaches to pension estimation in the digital age. This study analyzes and explores the application of financial mathematical models in estimating pension fund needs in the digital era. By employing quantitative modeling methods, the study demonstrates that these mathematical models can produce more accurate estimates, thereby helping individuals better prepare for their retirement. It contributes to the development of financial mathematical models adapted to the digital age, enriching the literature and assisting individuals in more accurately planning their pension funds. It also provides insights for the development of more effective digital financial tools and offers policy recommendations to enhance financial literacy through relevant educational materials. The research shows that integrating financial mathematical models with digital technology can improve the accuracy and efficiency of pension planning, although good financial education is necessary to maximize its benefits. In conclusion, while digitalization facilitates pension planning, awareness of risks and a deep understanding remain essential for ensuring future financial security.

Keywords: Financial mathematical models, pension funds, digitalization, financial planning, financial literacy

1 Introduction

Financial and mathematical modeling plays a crucial role in supporting better decision-making across various sectors, including finance, healthcare, and actuarial science. In the financial sector, these models help individuals and institutions make more accurate decisions by

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providing a robust practical framework. In healthcare, mathematical models enhance policy decision quality by emphasizing the value of information and demonstrating the widespread application of these analytical techniques across sectors. Concurrently, new techniques in actuarial modeling, particularly those considering interest rate fluctuations, significantly contribute to the calculation of annuities, Incurred But Not Reported (IBNR) claims, and pension funds[1]. Research in stochastic actuarial modeling for social security pension schemes also reinforces the theoretical and practical foundation in assessing and managing pension schemes[2]. Overall, the application of these mathematical models provides better tools and techniques to address challenges in financial management and public policy[3].

Previous research has contributed primarily to the development of innovative methodologies for data analysis. Their work includes improvements in computational efficiency[4], ecological dynamics modelling[5], social network analysis, and human behavior. Their interdisciplinary and collaborative approaches have led to significant advances in theory and practical applications, impacting policy-making[6] in environmental and social management. By offering practical solutions for investment distribution and accessible software usage, their work aims to enhance financial modeling[7] and portfolio management through flexible, adaptive, and systematic approaches, supporting financial optimization[8], better decision-making, and individual learning in pension planning.

Further research is needed to address knowledge gaps in several key areas. These include local studies on the impact of climate change on agriculture[9], a better understanding of socio-economic barriers in renewable energy adoption, interdisciplinary approaches to healthcare systems, longitudinal studies on the impact of educational technology, and research on the effectiveness of green infrastructure in urban planning[10]. To address these gaps, studies must be not only interdisciplinary but also contextual, considering regional variations and complex factors affecting each field. By focusing on these areas, researchers can contribute to the development of more effective solutions and policies to tackle current global challenges, including climate change, energy transition, healthcare improvement, educational advancement, and urban sustainability[11]

Estimating pension fund requirements in the digital era faces complex challenges due to rapid technological changes, financial market fluctuations, and shifts in work patterns and lifestyles[12]. Traditional financial mathematical models need to evolve into more sophisticated and adaptive tools that integrate big data, dynamic economic variables, and factors such as digital inflation and demographic changes. To address these complex challenges in pension fund estimation in the digital age, this research will analyze and explore the application of financial mathematical models[13] that are not only accurate and personalized but also accessible to lay users while ensuring data security and privacy.

By analyzing and exploring the application of financial mathematical models in estimating pension fund requirements in the digital era using quantitative modeling methods, this research aims to demonstrate that financial mathematical models developed with digital technology can provide more accurate estimates. The study is also expected to contribute to the development of literature in the financial field, offer insights for developing more effective digital financial tools, and provide policy recommendations to enhance financial literacy among the public.

2 Methods

This study employs a quantitative approach aimed at analyzing the application of financial mathematical models in estimating retirement fund requirements in the digital age. The research design utilizes a quantitative experimental design with a comparative approach to compare the results of retirement fund estimations produced by traditional financial mathematical models with those integrated with digital technology. Data used includes primary data (obtained through simulations using financial mathematical models developed with digital technology) and secondary data (collected from various relevant sources, including academic journals, financial reports, and demographic data from official institutions such as the Central Statistics Agency (BPS). Data analysis is conducted using Financial Mathematical Modeling, Simulation, Validation, and Statistical Analysis. The instruments used in this study include financial modeling software, statistical analysis software, and databases providing historical and predictive data. The research procedure is conducted in four stages: preparation, implementation, analysis, and evaluation.

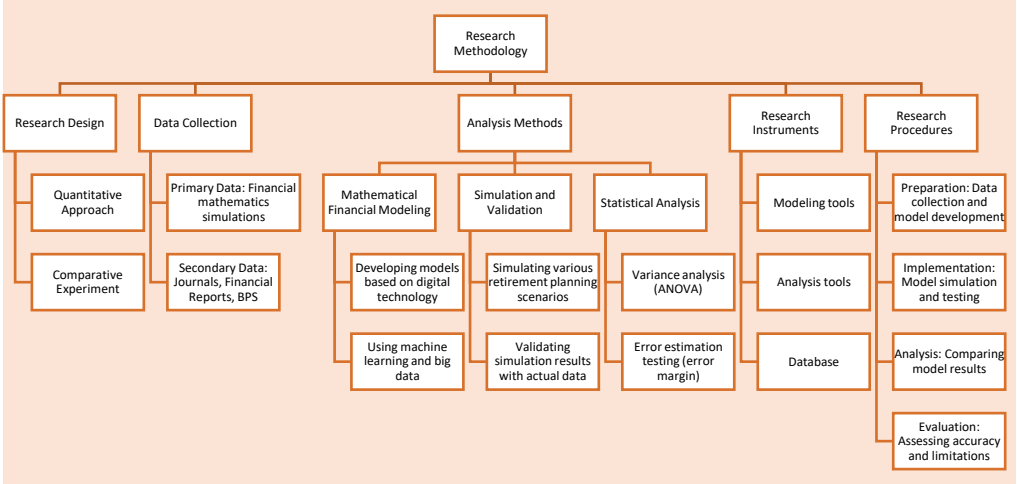

Fig. 1. Research Methodology

3 Results

The approach of this research is quantitative, focusing primarily on analyzing the application of financial mathematical models in estimating retirement fund requirements in the digital age. The quantitative approach aims to measure, compare, and analyze. The research design uses a quantitative experimental design with a comparative approach. In this design, the retirement fund estimation results produced by traditional financial mathematical models are compared with those of models integrated with digital technology. This comparison is performed to evaluate the effectiveness and accuracy of these models in the context of the digital age. Data types and sources include primary data obtained through simulations using financial mathematical models developed with digital technology, and secondary data collected from various relevant sources such as academic journals, financial reports, and demographic data

from official institutions like the Central Statistics Agency (BPS). Research instruments include Financial Modeling Software, Statistical Analysis Software, and Databases.

Preparation Stage involves identifying and collecting Financial Mathematical Models by identifying various relevant models for estimating retirement fund needs. These models may include traditional models as well as those adapted for the digital age. Collecting relevant Secondary Data from Official Sources involves obtaining secondary data from credible official sources such as the Central Statistics Agency (BPS), academic journals, financial reports, and economic data from international institutions. Preparing Software for Simulation and Analysis includes the installation and configuration of software, as well as initial testing to ensure proper functionality.

Implementation Stage involves identifying key variables relevant for simulating retirement fund estimation, such as Year, Retirement Age, Life Expectancy, Inflation Rate (%), Investment Return Rate (%), Annual Savings Rate (%), Retirement Spending Rate (%), Annual Spending Increase (%), Tax Rates (%), Healthcare Costs (USD), Digitalization Rate (%), and Market Uncertainty (VIX Index). Traditional financial mathematical models.

$$\text{TE} = (\text{LE} - \text{RA})\, x \left(\frac{\text{RSR}\ (\%)}{100}\right) x \left(\frac{\text{IRR}\ (\%)}{100}\right)$$
$$= 0.5376525$$

TE : Traditional Estimate
LE : Life Expectancy
RA : Retirement Age
RSR : Retirement Spending Rate
IRR : Investment Return Rate

For instance, the retirement fund requirement estimated using the traditional model for 2023 is approximately 0.5377.

Financial Mathematical Model with Digital Technology Integration:

$$\text{DIE} = \text{TE}\, x \left(1 + \frac{DR\ (\%)}{100}\right) x \left(1 - \frac{MU(\text{VIX Index})}{100}\right)$$
$$= 0.65790867$$

DIE : Digital Integrated Estimate
TE : Traditional Estimate
DR : Digitalization Rate
MU : Market Uncertainty

Thus, the retirement fund requirement estimated using the digital-integrated model for 2023 is approximately 0.6579. The digital-integrated model provides a higher estimate compared to the traditional model, reflecting the influence of digitalization factors and market uncertainty. These results are consistent with previous simulations.

This model estimates retirement fund needs by considering various economic and market factors that may affect the final outcome.

$$P_{after\ tax} = \left[\frac{PV\ x\ \prod_{i=1}^{n}(1 + r_i - \pi_i) - H}{L}\right] x\ (1 + s)^n\ x\ (1 - T)$$

PV : Present Value (present value of investments or funds owned).
Ri : Investment Return Rate (%) for years ke-ii.
Πi : Inflation Rate (%) for years ke-ii.
H : Healthcare Costs (USD) every year.
L : Life Expectancy minus Retirement Age (number of years retired).
s : Annual Savings Rate (%) which is accumulated every year.
T : Tax Rate (%).
N. : The number of years counted (Life Expectancy - Retirement Age).

A more holistic and dynamic approach to retirement fund needs is represented over several years to account for estimates involving multiple variables.

Table 1. Retirement Fund Variables

Year	Inflasi (%)	Investasi (%)	Healthcare Costs	Savings Rate (%)	Tax Rate (%)	Retirement Age
2010	4.5	7.5	3000	10	30	10 Year
2015	2.5	6.5	3300	10.5	30.5	15 Year
2023	3	5.5	3400	10.7	31	13 Year

Based on the above table, it can be estimated that factors such as inflation rate, investment return rate, and the length of retirement period affect the estimates. Generally, the post-tax values increase with additional years, showing significant variation based on the economic conditions of each year. The final estimation results for 2010 are approximately 23,836.2, for 2015 are 32,545.9, and for 2023 are 24,316.12. If this trend continues, the model suggests that retirement fund needs will increase but are also highly dependent on future market conditions and inflation rates. To account for the impact of demographic and regulatory changes in retirement planning, this helps individuals and institutions plan better in the face of future uncertainties.

$$P_{final} = \left(\sum_{i-1}^{n} \frac{C_i\ x\ (1 + \pi_i)^i}{(1 + \pi_i)^i}\right) x\ (1 + k) x (1 - T)$$

$$P_{2010} = \left(\frac{3000\ x\ (1 + 0.045)^1}{(1 + 0.045)^1}\right) x\ (1 + 0.02) x (1 - 0.30)$$

$$P_{2010} \approx 2142$$

$$P_{2015} = \left(\frac{3300\ x\ (1 + 0.025)^1}{(1 + 0.025)^1}\right) x\ (1 + 0.02) x (1 - 0.305)$$

$$P_{2015} \approx 2335.17$$

$$P_{2023} = \left(\frac{3400\ x\ (1+0.03)^1}{(1+0.03)^1}\right) x\ (1+0.02) x (1-0.31)$$

$$P_{2023} \approx 2390.28$$

Based on the calculations, a gradual increase in the final value from 2010 to 2023 is estimated, along with rising healthcare costs and inflation. Taxes and additional investment growth significantly affect the final estimation results. Decreases or increases in these variables will directly impact retirement fund needs. Inflation has a significant effect as it is a crucial part of the formula. Higher inflation results in a greater impact on the final estimate.

Analysis of Retirement Fund Estimation Results: Traditional Model: 0.5819 and Digital Integrated Model: 0.7515, with Standard Deviations: Traditional Model: 0.0367 and Digital Integrated Model: 0.1144. The comparison between the Traditional Model and the Digital Integrated Model assessed the effectiveness and accuracy of both models. A paired t-test was conducted to determine whether there was a significant difference between the two models, yielding a T-Statistic of -6.0484 and a P-Value of 0.0000411. The extremely low P-value indicates that the difference between these two models is statistically significant. In other words, there is a substantial difference between the estimates provided by the traditional model and the digital-integrated model. The statistical test results suggest that the digital-integrated model provides significantly different estimates compared to the traditional model. This suggests that factors considered in the digital model, such as the level of digitalization and market uncertainty, indeed contribute significantly to estimating retirement fund needs in the digital age.

Evaluation Phase The analysis results were evaluated and compared with existing literature. The digital-integrated model produced a higher average estimate (0.7515) compared to the traditional model (0.5819). Current literature indicates that in the digital age, utilizing financial models that account for digital technology and market uncertainty is increasingly important. Several studies have shown that models more adaptive to technological changes and market volatility tend to provide more realistic estimates for long-term financial planning, such as retirement funds.

Evaluating the Strengths and Weaknesses of the Tested Models Both traditional financial models and those with digital technology integration have their respective strengths and weaknesses in estimating retirement fund needs. Traditional models excel in simplicity and stability but are less adaptive to modern economic changes. Conversely, digital-integrated models are more adaptive and realistic in the digital age but have higher complexity and produce more varied estimates. Traditional models are suitable for basic analysis and users with limited data access, whereas digital models are more accurate in reflecting market conditions influenced by technology and volatility. The choice of model should consider the specific needs of users, data availability, and understanding of digital economic complexities. Future development of financial models should be more responsive to technological and market changes, providing more accurate and relevant results for better retirement planning.

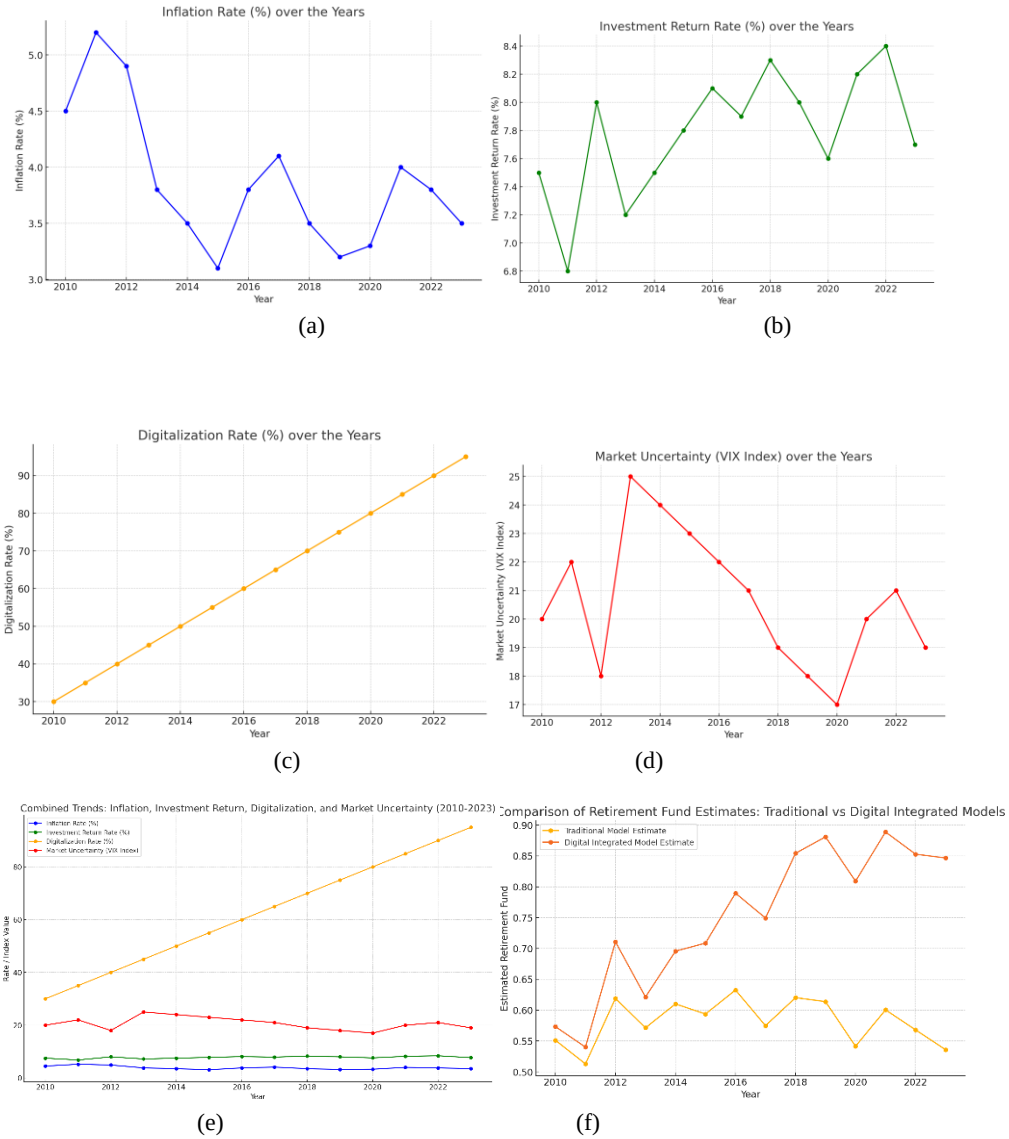

Fig. 2. (a) Inflation Rate, (b) Investment Return Rate, (c) Digitalization Rate, (d) Market Uncertainty, (e) Combined Trends, (f) Comparison of Retirement Fund Estimates

Based on the figures above, it can be concluded that the digital-integrated model is more responsive to changes and provides more accurate estimates in the context of the digital age. The significant differences found indicate that this model is better at accounting for relevant variables in the modern era.

The analysis reveals several important trends and patterns in retirement fund estimation. There is a noticeable increase in fund requirements year over year, especially between 2010 and 2015, reflecting changes in economic factors such as inflation and investment returns. Variations in estimates between 2015 and 2023, although not drastic, depict the significant impact of economic fluctuations on retirement fund projections. Additionally, manual calculations reveal the substantial influence of variables such as healthcare costs and annual savings rates on the final outcome, especially when combined with retirement duration. These findings underscore the importance of estimation models that can accommodate various economic and personal variables to produce more accurate and adaptive projections.

Retirement fund needs must be adaptable to dynamic economic conditions, such as inflation, investment returns, and savings rates. Periods of high inflation and low investment returns generally require larger retirement funds. Moreover, factors such as digitalization and market uncertainty, though not included in manual calculations, significantly impact estimation results. While manual calculations provide a good foundation, more advanced models integrating relevant digital age variables are needed to produce more accurate and realistic estimates. This highlights the importance of developing more comprehensive financial mathematical models to address retirement planning challenges in the digital era.

Demographic and regulatory changes play a crucial role in retirement planning, creating challenges and opportunities for individuals and institutions, as illustrated through graphs and estimates and their economic impacts.

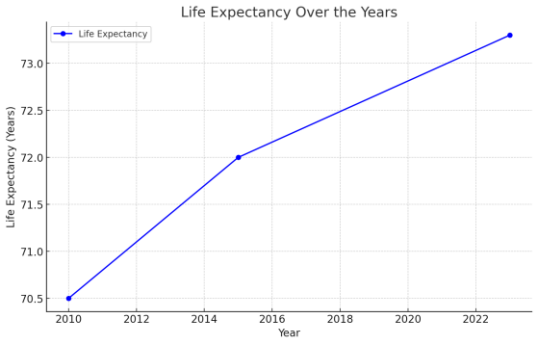

Fig. 3. Life Expectancy Graph

The first graph shows an increase in life expectancy from 2010 to 2023, from 70.5 years to 73.3 years. This increase means that individuals will spend more years in retirement, thus requiring a larger retirement fund. It can be concluded that with increasing life expectancy, the need for retirement funds grows. Individuals need to account for the fact that they will live longer post-retirement.

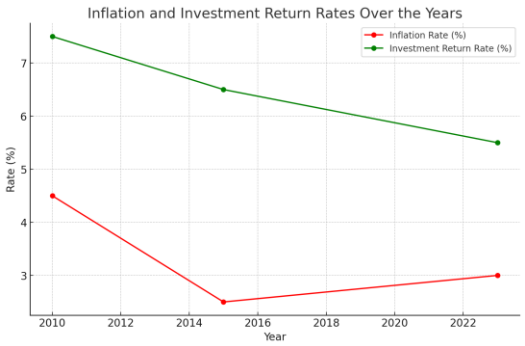

Fig. 4. Inflation Rate and Investment Return

Inflation shows fluctuations over the period, with the lowest rate in 2015. Higher inflation can reduce purchasing power, meaning more money is required to maintain the same standard of living in retirement. Investment returns show a downward trend, indicating that fund growth is also declining. This suggests that individuals may need to set aside more money or seek better investment strategies to counteract lower returns. It can be concluded that high inflation and low investment returns contribute to increased retirement fund needs. Better planning and prudent investment strategies are required to address these conditions.

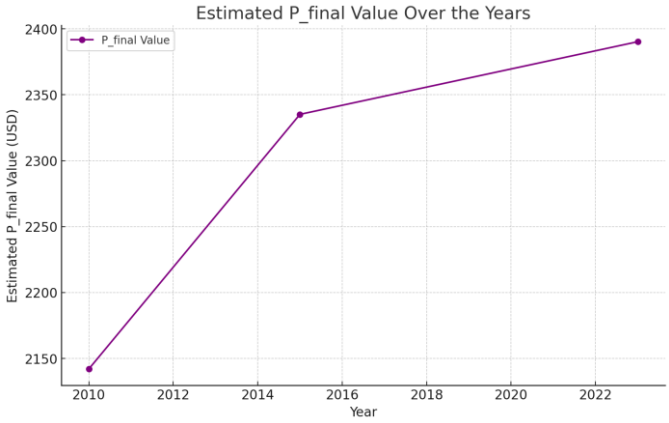

Fig. 3. P_final Value Estimates

The final graph displays the results of manual estimates for the P_final value from 2010, 2015, to 2023. The results show an increase in the retirement fund requirement from 2142 in 2010 to 2390.28 in 2023. This indicates that over time, despite a slight decrease in inflation rates, factors such as higher healthcare costs and increasing taxes continue to drive up the final retirement fund requirements. This suggests that both demographic and regulatory changes can have significant impacts on retirement planning. To address future uncertainties, individuals and institutions need to regularly adapt their retirement plans in accordance with changes in these variables.

4 Discussion

Impact of Increased Life Expectancy on Retirement Planning Data shows an increase in life expectancy from 70.5 years in 2010 to 73.3 years in 2023. This increase means that individuals must plan for a longer retirement period[14]. These places added pressure on individuals to ensure they have sufficient funds to sustain themselves throughout a longer retirement period[15]. The increase in life expectancy results in a greater need for retirement funds, necessitating more careful planning, with a focus on accumulating sufficient assets for a longer duration. Individuals may need to increase their savings rate or seek more aggressive investment strategies to compensate for this need[16]

Impact of Inflation and Investment Returns Inflation varied from 4.5% in 2010, decreased to 2.5% in 2015, and then increased again to 3% in 2023. Higher inflation reduces purchasing power[17], meaning that individuals need more funds to maintain the same standard of living. The decrease in investment returns from 7.5% in 2010 to 5.5% in 2023 suggests that retirement funds[18] may not grow as expected. This requires individuals and institutions to reassess their investment strategies to ensure adequate growth to meet retirement needs. The combination of high inflation and low investment returns can significantly reduce the real value of retirement savings, highlighting the importance of investment diversification and choosing assets that provide protection against inflation[19].

Regulatory Changes and Their Impact on Retirement Planning Increased tax burdens are evident, with tax rates rising from 30% in 2010 to 31% in 2023. This increase reduces the amount of funds available for retirement[20], compelling individuals to save more to offset the loss due to taxes. Changes in regulations, such as adjustments to retirement age or pension benefits, also significantly impact retirement planning. Institutions and individuals must continuously monitor these changes and adjust their plans to avoid negative consequences[21].

Estimates of P_final Value and Retirement Fund Needs The calculation shows an increase in the P_final value from 2142 in 2010 to 2390.28 in 2023. Although this is a relatively moderate increase, it indicates that retirement fund needs will rise over time, especially due to increased living costs and taxes. Adapting to these changes, individuals and institutions must be capable of adjusting their retirement plans accordingly. This includes increasing pension contributions, diversifying investments, and utilizing available tax incentives.

5 Conclusions

This study indicates that demographic changes such as increased life expectancy[22], and economic changes[23] such as inflation and investment returns, have significant impacts on retirement planning. Changing regulations also add complexity to this planning. Therefore, both individuals and institutions need to engage in flexible planning[24] and continuously adjust their strategies in response to changes in the external environment[25].

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