The Impact of Population Aging and Macroeconomic Leverage on Pension Fund Revenues：A Fuzzy-Set Qualitative Comparative Analysis Approach

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Abstract
This study employs the fuzzy-set Qualitative Comparative Analysis (fsQCA) method to explore the impact of population aging and various macroeconomic leverage indicators on pension fund revenues in China from 2002 to 2019. Specifically, the research examines the relationships between aging demographics, central and local government leverage, household sector leverage, and the leverage of the real economy with pension fund revenues. After conducting stationarity tests on the data, fsQCA is utilized to investigate the necessary conditions of population aging and the aforementioned macroeconomic variables in relation to pension fund revenues. The findings reveal that in the context of China's rapidly aging society, and with rising levels of both population aging and central government leverage, it is critical to reduce local government debt, mitigate corporate sector liabilities, restore investor confidence, and stimulate household consumption to enhance pension fund revenues.

1. Introduction

1.1 Background and Motivation

Population aging has emerged as one of the most significant social challenges faced by both developed and developing nations today. This demographic shift is particularly pronounced in advanced economies, where increasing life expectancy and declining fertility rates have led to a rapidly aging population. Within this context, pension insurance—an integral component of the social security system—has become increasingly important. However, population aging also brings a host of challenges, one of the most pressing being the sustainability and stability of pension fund revenues.

Macroeconomic leverage, as a key macroeconomic indicator, reflects the ratio of debt to gross domestic product (GDP) and serves as an essential measure of financial stability. As economies evolve, changes in macroeconomic leverage can impact various sectors, including the pension fund sector. Consequently, examining the relationship between macroeconomic leverage and pension fund revenues holds significant theoretical and practical relevance.

Despite its importance, research on the impact of macroeconomic leverage on pension fund revenues remains relatively scarce, with a lack of comprehensive understanding of the underlying mechanisms. Furthermore, traditional statistical methods often struggle to accurately capture the complex interactions between macroeconomic leverage variables, particularly in studies with smaller sample sizes. Given these limitations, this study aims to apply the fuzzy-set Qualitative Comparative Analysis (fsQCA) approach to explore the different configurations of macroeconomic leverage and their impact on pension fund revenues from the perspective of population aging.

By adopting this approach, the study seeks to provide a macroeconomic perspective that can inform policymakers in creating favorable external conditions for the sustainable development of the pension fund system. Additionally, this research aims to offer new insights for addressing the challenges posed by population aging and promoting the long-term stability and growth of the pension system, thereby contributing to broader economic stability.

1.2 Research Objectives and Questions

The fuzzy-set Qualitative Comparative Analysis (fsQCA) is a powerful analytical tool that integrates both qualitative and quantitative approaches. It not only helps us understand the relationships between conditional variables but also reveals explanatory patterns and mechanisms resulting from different combinations of conditions. Given the challenges posed by population aging to the social security system, the sustainability of pension fund revenues has become a highly relevant and pressing issue. The primary objective of this study is to employ the fsQCA method to investigate the intrinsic relationships between configurations of macroeconomic leverage and pension fund revenues in the context of an aging population.

In this regard, the central research question addressed by this study is: How do different configurations of macroeconomic leverage affect pension fund revenues under the trend of population aging?

By utilizing the fsQCA approach, this study aims to thoroughly explore the patterns and mechanisms through which pension fund revenues are influenced by various configurations of macroeconomic leverage. This analysis incorporates both population aging and macroeconomic leverage variables to comprehensively understand the interplay between them, examining how different leverage configurations contribute to changes in pension fund revenues. The findings are expected to offer policymakers more refined and holistic insights, enabling them to better address the challenges brought by population aging and develop strategies to ensure the sustainability of pension systems.

2.Literature Review

The sustainability of pension fund operations, particularly in the context of population aging, has garnered increasing attention from both academics and policymakers. To better understand the relationship between macroeconomic leverage and pension fund revenues, this section summarizes existing research, discusses various perspectives and findings, and outlines the conceptual foundation of the study.

2.1 Challenges Facing China's Pension Fund System

China's pension system faces significant challenges, as its overall design has led to regional imbalances and conflicts within the social security framework (Zhao, 2020). Cai and Cheng (2014)

argue that China's fragmented pension system is characterized by regional disparities, fiscal inefficiencies, social inequality, and economic unsustainability. Thus, there is a pressing need to establish a national pension system that offers broad coverage, basic security, multi-tiered options, and sustainability. The formulation and reform of China's pension system—including basic pension schemes for different population groups—faces numerous challenges that require careful policy consideration. Moreover, China's rapidly aging population has made the need for affordable and sustainable pension revenue support a top strategic priority, deserving of sustained attention.

2.2 Methodological Gaps in Existing Research

Macroeconomic leverage, which reflects the level of debt across various sectors of an economy, serves as a critical indicator of financial stability. It primarily includes central government leverage, local government leverage, household sector leverage, and corporate leverage. The relationship between leverage levels and the development of the pension finance system has been explored to some extent. Cheng et al. (2023) found that macroeconomic leverage exerts some influence on pension fund revenues, with household sector leverage showing a significantly positive correlation with pension fund revenues, while corporate and government leverage exhibit a negative relationship. Moreover, the study indicates that Chinese households exhibit a strong investment preference for pension insurance, and reducing leverage in the corporate and government sectors could effectively increase pension fund revenues.

However, the existing literature on the direct relationship between macroeconomic leverage and pension fund revenues is sparse, and Cheng et al.'s study represents a notable innovation in this field. Despite its valuable conclusions, their study has several limitations. The research primarily focuses on macroeconomic leverage without considering the role of population aging—a key variable that influences pension fund revenues. Moreover, the methodology and analytical process employed in the study warrant further scrutiny. For instance, the time series data used is limited to the period from 2012 to 2021, encompassing only nine years of data points. The inclusion of 2020 and 2021, when the COVID-19 pandemic began, raises concerns about the validity of the data. Using such a short time frame risks issues such as overfitting in model estimation, where the small sample size may not support accurate parameter estimates and statistical inference. The reliability of hypothesis testing may become questionable, and parameter estimation may lack precision, affecting the understanding of relationships among variables.

Additionally, the potential for autocorrelation among macroeconomic leverage variables presents another challenge. Correlations between variables may be present, and in situations with small sample sizes, it becomes difficult to effectively test for multicollinearity. The use of traditional linear regression to analyze the effects of macroeconomic leverage on pension fund revenues in such a context may result in methodological shortcomings, casting doubt on the conclusions.

2.3 Advantages of fsQCA for Small-Sample Data Analysis

In cases where data samples are limited, fsQCA offers an effective analytical tool to help identify relationships and explanatory patterns among variables. The main advantages of fsQCA are as follows:

Handling Ambiguity: fsQCA applies fuzzy set theory, allowing for the consideration of ambiguity and degrees of membership between conditions and outcomes. This is particularly important in small-sample cases, where data may not be precise. fsQCA enables the representation of conditions and outcomes as degrees of membership, better reflecting real-world complexities.

Accounting for Multivariable Interactions: fsQCA is capable of analyzing how combinations of multiple variables interact to influence outcomes. In small-sample cases, capturing these interactions is essential to more accurately explaining the phenomenon under study (Ragin, 2008).

Explaining Complex Causal Relationships: In small-sample, multivariable analyses, it is often difficult to isolate a single causal relationship, as variables may combine in various ways to produce the same outcome. fsQCA handles this complexity by allowing researchers to consider different combinations of conditions and derive more comprehensive and diverse explanatory models (Rihoux & Ragin, 2009).

Avoiding Overfitting: In small-sample contexts, traditional methods like multiple linear regression are prone to overfitting. fsQCA avoids this risk by representing conditions and outcomes as membership scores, thereby reducing overfitting while maintaining model simplicity (Ragin, 2008).

Focusing on Key Variable Combinations: By calculating consistency and coverage metrics, fsQCA helps identify the combinations of variables that have the most significant impact in small-sample studies. This allows researchers to focus on analyzing the combinations of variables that are most relevant, rather than expending effort on less significant combinations (Ragin, 2008).

In summary, fsQCA provides a comprehensive and multidimensional approach to analyzing relationships between conditions in small-sample multivariable analysis. By applying fuzzy set theory, fsQCA overcomes some of the limitations inherent in traditional methods. Based on these advantages, this study employs fsQCA to reexamine the relationship between macroeconomic leverage and pension fund revenues, exploring how different leverage configurations interact with pension fund revenue dynamics.

3.Methodology and Procedures

Building on the research framework established by Cheng et al. (2023), this study extends the time range of the variables to cover the period from 2002 to 2019. The decision to limit the analysis to data ending in 2019 is made to exclude the complex effects of the COVID-19 pandemic and, additionally, to incorporate the impact of population aging on pension fund revenues.

First, this study examines the correlation between the aging population, pension fund revenues, and macroeconomic leverage (which includes central government leverage, local government leverage, household sector leverage, and corporate leverage). This correlation analysis is intended to highlight the inadequacies of relying solely on linear regression models. Next, the data undergo stationarity testing to ensure robustness. Subsequently, the fsQCA method is employed to assess the consistency of population aging and macroeconomic leverage variables as necessary conditions for pension fund revenues. Finally, the fsQCA method is further used to explore the relationship between different configurations of population aging and macroeconomic leverage variables and their association with pension fund revenues.

The data on the aging population (oldp) and pension fund revenues (ylbxsr) are sourced from the CSMAR database, while the central government leverage (ggzy), local government leverage (ggzf), household sector leverage (ggjm), and corporate leverage (ggst) are obtained from the

National Balance Sheet Research Center of China. Due to data availability, all variables are selected for the period from 2002 to 2019.

4.Results and Discussion

4.1 Correlation Analysis of Variables

The correlation between population aging, macroeconomic leverage, and pension fund revenues is examined, revealing significant correlations at the 99% confidence level. Many of these correlations are strong, with correlation coefficients greater than 0.7. Given this strong correlation, using a linear regression model that treats pension fund revenues as the dependent variable and population aging and macroeconomic leverage as independent variables would likely lead to methodological issues. The high correlation among the variables indicates that linear regression may not adequately capture the complexity of the relationships. Therefore, this study adopts the fsQCA method to analyze the relationships among these variables more comprehensively.

Table1:personCorrelation Analysis

	oldp	ylaobxsr	ggjm	ggzy	ggzf	ggst
oldp	1	.992**	.993**	-.541*	.855**	.963**
ylaobxsr	.992**	1	.990**	-0.473	.797**	.943**
ggjm	.993**	.990**	1	-.497*	.839**	.975**
ggzy	-.541*	-0.473	-.497*	1	-.785**	-.583*
ggzf	.855**	.797**	.839**	-.785**	1	.909**
ggst	.963**	.943**	.975**	-.583*	.909**	1

4.2 Preprocessing of Variable Stationarity

To begin, the logarithmic transformation was applied to each variable. After this transformation, unit root tests were performed on both the log-transformed variables and their first differences. The results indicated that the logarithmic sequences of the variables exhibited unit roots, implying non-stationarity. However, the first-differenced sequences were found to be stationary. The first-differenced logarithmic sequences represent the annual changes in each variable, which can be interpreted as the yearly increments of these variables. Based on this, the study focuses on analyzing the relationship between the annual increments of population aging (denoted as alold), central government leverage (denoted as aggzy), local government leverage (denoted as aggzf), household sector leverage (denoted as aggjm), corporate leverage (denoted as aggst), and the annual increment of pension fund revenues (denoted as aylbxsr).

4.3 Calibration of Variables in fsQCA

In fsQCA, each condition (i.e., aoldp, aggzy, aggzf, aggjm, and aggst) and the outcome (i.e., the annual increment in pension fund revenues) are treated as distinct sets. Each case is assigned a membership score within these sets, a process known as calibration (Schneider & Wagemann, 2012). Following existing research practices, this study relies on established theoretical and empirical insights to apply the direct calibration method (Ragin, 2008), transforming the data into fuzzy set membership scores. Table 1 provides a summary of the calibration criteria for each condition and outcome variable. The calibration points for full membership, crossover point, and full non-membership for the six condition variables—population aging, central government leverage, local government leverage, household sector leverage, and corporate leverage—were set based on the upper quartile (75%), median, and lower quartile (25%) of their annual logarithmic increments.

Table 2：Calibration Points for Set Membership

Variable	Calibration		
	Full Membership	Crossover Point	Full Non-Membership
Δlnaylbxsr	0.4690	0.3560	0.3060
Δlnaoldp	0.0469	0.0356	0.0306
Δlnaggst	0.2128	0.1667	0.1469
Δlnaggzy	0.0387	0.0062	-0.0587
Δlnaggzf	0.1138	0.0694	0.0081
Δlnaggjm	0.1208	0.0726	0.0283

4.4 fsQCA Necessity Analysis of Causal Conditions

This section first examines whether any single condition (i.e., Δlnaoldp, Δlnaggst, Δlnaggzy, Δlnaggzf, Δlnaggjm, and their negations) constitutes a necessary condition for the annual increment in pension fund revenues (Δlnaylbxsr). From the perspective of set theory, the necessity analysis of a single condition involves testing whether the outcome set is a subset of the condition set. In fsQCA, a condition is considered a necessary condition if it is always present when the outcome occurs. According to Ragin (2008), consistency is a key criterion for evaluating the necessity of a condition. If the consistency level exceeds 0.9, the condition can be considered necessary for the outcome (Ragin, 2008; Schneider & Wagemann, 2012).

Using fsQCA 3.0 software to analyze the necessary conditions for high pension fund revenue increases, the results show that none of the conditions (Δlnaoldp, Δlnaggst, Δlnaggzy, Δlnaggzf, and Δlnaggjm) or their negations meet the threshold for necessity. Specifically, none of the conditions reach the 0.9 consistency level required to be classified as necessary conditions for high annual pension fund revenue increases. In fact, the negations of certain conditions appear more likely to be necessary conditions. For instance, lower increases in central government leverage and lower increases in local government leverage are more likely to be necessary conditions for high pension fund revenue increases.

Table 3：Consistency Analysis of Causal Conditions

Causal Condition	Consistency	Consistency	Causal Condition
~Δlnggst	0.779	0.305	Δlnggst
~Δlnggzf	0.717	0.440	Δlnggzy
~Δlnoldp	0.699	0.415	Δlnoldp
~Δlnggjm	0.693	0.447	Δlnggjm
~Δlnggzy	0.689	0.440	Δlnggzy

4.5 Sufficiency Analysis of Configurations

Unlike necessity analysis, the goal of sufficiency analysis is to uncover different configurations of conditions that lead to the outcome. In terms of set theory, this involves determining whether a configuration of multiple conditions constitutes a subset of the outcome set. Similar to necessity analysis, sufficiency is measured through consistency.

The acceptable threshold for sufficiency in fsQCA differs from that of necessity analysis. According to Schneider and Wagemann (2012), a consistency level of at least 0.75 is required to determine sufficiency. Other scholars, such as Du et al., suggest that the PRI (Proportional Reduction in Inconsistency) threshold should ideally be above 0.75, with 0.7 being acceptable. The frequency threshold, meanwhile, depends on the sample size; for small and medium samples, a frequency threshold of 1 is acceptable, while larger samples require a higher threshold (Schneider & Wagemann, 2012). For this study, a consistency threshold of 0.70 and a frequency threshold of 1 were chosen.

Using fsQCA software, truth table analysis was conducted, yielding three levels of solutions: the complex solution, the intermediate solution, and the parsimonious solution. Consistent with common practice in the literature, this study focuses on a combination of the intermediate and parsimonious solutions for configuration analysis. In cases where the presence or absence of any of the five conditions leads to the outcome, the intermediate solution is reported (Fiss, 2011).

The table below presents the configuration analysis results of five conditions, illustrating how various combinations lead to increases in annual pension fund revenues. Following the presentation style of Ragin and Fiss (2008) and Fiss (2011), solid circles (●) indicate the presence of a condition, while crossed-out circles (⊗) indicate its absence. Blank spaces represent ambiguous states, meaning the condition may be either present or absent. Large circles denote core conditions (present in both parsimonious and intermediate solutions), while small circles represent peripheral conditions (present only in the intermediate solution). Additionally, configurations are ordered from left to right based on their consistency levels. Coverage, similar to R^2 in regression analysis, measures the empirical relevance or importance of the configuration in QCA research (Ragin, 2008; Fiss, 2011).

Table 4： Sufficiency Analysis of Configurations

Causal Conditions	Intermediate Solution		
	1	2	3
Δlnoldp	⊗	⊗	●
Δlnggzy		●	●
Δlnggzf	●	⊗	⊗
Δlnggjm	⊗	●	●
Δlnggst	⊗	●	⊗
Original Coverage	0.3546	0.1366	0.1579
Unique Coverage	0.3083	0.0689	0.1115
Consistency	0.9188	0.9397	0.7039
Total Coverage	0.5576		
Total Consistency	0.8624		

As shown in the table, three distinct configurations lead to substantial increases in annual pension fund revenues. Each individual solution, as well as the overall solution, achieves a consistency level higher than the acceptable minimum of 0.70, with the overall solution reaching a consistency level of 0.86. The total coverage of 0.56 indicates strong explanatory power.

Configuration 1: A combination of moderate to low population aging increments, high local government leverage increments, moderate to low household sector leverage increments, and moderate to low corporate leverage increments. In this configuration, the core conditions are moderate to low population aging increments and moderate to low corporate leverage increments. This suggests that under conditions of moderate to low population aging, reducing household sector leverage increments and curbing rapid increases in corporate leverage, while moderately increasing local government leverage, can trigger higher pension fund revenues.

Configuration 2: A combination of moderate to low population aging increments, high central government leverage increments, moderate to low local government leverage increments, high household sector leverage increments, and high corporate leverage increments. Here, the core conditions are moderate to low population aging increments and moderate to low local government leverage increments. This implies that under conditions of moderate to low population aging and high central government leverage, reducing local government leverage while promoting household consumption and investments in the corporate sector can spur pension fund revenue growth.

Configuration 3: A combination of high population aging increments, high central government leverage increments, moderate to low local government leverage increments, high household sector leverage increments, and moderate to low corporate leverage increments. The core conditions in this configuration are moderate to low local government leverage increments and moderate to low corporate leverage increments. This configuration suggests that, under conditions of high population aging and high central government leverage, policies aimed at reducing local government debt levels, encouraging household consumption, and mitigating corporate sector liabilities can lead to increased pension fund revenues.

5.Conclusion and Suggestion

In summary, it is evident that the factors contributing to increases in pension fund revenues are complex. The annual increments in population aging, central government leverage, local government leverage, household sector leverage, and corporate leverage, when considered individually, do not constitute necessary conditions for pension fund revenue growth. However, when these factors are combined into specific configurations, they do trigger increases in pension fund revenues. This highlights the significant interactive effects among the various macroeconomic leverage tools in the context of an aging population. Thus, to effectively enhance pension fund revenues, employing a combination of policy tools proves more effective than relying on any single tool.

As demonstrated in Table 4, the configurations that lead to revenue increases vary significantly depending on the degree of population aging. Configurations 1 and 2, which operate under conditions of moderate or low population aging, differ substantially from Configuration 3, which applies to regions experiencing high levels of population aging. This shows that the degree of population aging plays a crucial role in determining how macroeconomic leverage factors interact to influence pension fund revenue growth.

Moreover, when comparing Configuration 1, which does not consider central government leverage, with Configuration 2, which does, there are clear differences in how the remaining leverage factors interact with pension fund revenues. This suggests that central government leverage serves as an important moderating factor in these relationships.

Given China's rapidly aging society and increasing central government leverage, Configuration 3 holds significant practical relevance. Under conditions of high population aging and high central government leverage, it becomes imperative to reduce local government debt, mitigate corporate sector liabilities, and boost household investment confidence and consumption. These actions can collectively promote increases in pension fund revenues.

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