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USING THE MULTIDIMENSIONAL ANALYSIS METHOD IN THE MANAGEMENT OF FINANCIAL ASSETS OF PENSION FUNDS

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Abstract. Effective management of pension assets is crucial for ensuring the long-term financial stability of national pension systems. In Kazakhstan, the Unified Accumulative Pension Fund (UAPF) plays a key role in accumulating and investing pension savings, yet its asset management strategies face challenges due to inflation, market volatility, and limited investment options. As of 2024, UAPF's total assets exceeded 18.6 trillion tenge, growing by 16% year-over-year. However, with inflation surpassing pension returns (9.8% vs. 8.3% in 2023), the real value of savings is declining. This study aims to develop a methodological approach for optimizing pension asset management using multidimensional classification techniques. The research employs a quantitative approach, utilizing data from the Bureau of National Statistics of Kazakhstan for 2013–2023. Statistical and econometric methods, including correlation analysis, cluster analysis, and variance analysis, were applied to classify assets based on risk and return characteristics. The study identifies three pension portfolio categories: (1) moderately aggressive, with returns up to 8.3% and higher risk; (2) moderately conservative, offering 5.5% returns with balanced risk; and (3) conservative, providing stable but low returns, failing to offset inflation. Findings highlight that Kazakhstan's pension system remains highly dependent on government securities (46% of total assets), limiting growth potential. The research suggests diversification strategies, including alternative assets, ESG investments, and digital financial tools. The study contributes to the literature on pension fund management in emerging markets and offers practical recommendations for enhancing investment efficiency and long-term financial security for pensioners.

Key words: pension asset management, investment strategy, financial stability, risk diversification, cluster analysis, pension fund, Kazakhstan, digital financial tools, economic modeling, ESG investments.

Introduction

Effective management of pension assets is one of the key objectives of the state social policy aimed at ensuring the financial stability of the pension system and guaranteeing future payments to citizens. In Kazakhstan, this problem is becoming particularly relevant in connection with the functioning of the Unified Accumulative Pension Fund (UAPF), which accumulates pension savings of citizens and is responsible for their safety and increase. As of 2024, the total assets of the UAPF amounted to more than

18.6 trillion tenge, an increase of 16% compared to the previous year (Bureau of National Statistics of the Republic of Kazakhstan, 2024). However, the challenges associated with high inflation, instability of financial markets and limited investment instruments require the introduction of effective asset management strategies based on modern economic and mathematical methods.

In world practice, pension funds play an important role in financial systems, being the largest institutional investors. According to the OECD (2023), the total assets of pension funds in the organization's

member countries reached 55.4 trillion US dollars, which is about 32% of global GDP. In countries such as the Netherlands, Denmark and Switzerland, pension assets exceed 150% of GDP, while in Kazakhstan this figure is at 14% of GDP, which indicates the potential for further development of the funded pension system.

The use of mathematical models in pension asset management makes it possible to objectively evaluate possible investment strategies, minimize risks and increase portfolio profitability. In Kazakhstan, the UAPF's investment policy focuses on investments in government securities (about 46% of the portfolio), corporate bonds (15%), shares of Kazakhstani and foreign issuers (13%) and deposits with banks (12%) (UAPF, 2024). However, the high concentration of assets in government bonds limits the potential profitability of the fund, which requires the diversification of investments and the introduction of more flexible asset management strategies.

One of the most effective analysis tools is the methods of multidimensional statistical analysis and clustering, which make it possible to identify hidden patterns in data, group assets by risk and profitability, and predict their behavior in the long term. Various models of optimal asset allocation are used in world practice, including Markowitz theory (1952), the financial asset valuation model (Sharpe, 1964), Value-at-Risk and Conditional Value-at-Risk optimization models, as well as approaches based on machine learning and neural network algorithms.

In the context of Kazakhstan, the pension asset management process faces a number of specific challenges, including limited stock market liquidity, high dependence on the commodity sector, insufficient development of private investment instruments, and the need to comply with strict regulatory requirements. For example, the return on pension assets in Kazakhstan in 2023 was 8.3%, while the inflation rate reached 9.8%, which led to a negative real return (National Bank of the Republic of Kazakhstan, 2024). At the same time, in countries with a developed pension system, the average return on pension funds exceeds 5% in real terms, which indicates the need to reform the investment strategy of the UAPF.

Taking into account these factors, within the framework of this study, pension assets were systematized in the structure of the UAPF using multidimensional classification methods. The use of mul-

tidimensional analysis allows you to group assets by similar characteristics, identify optimal combinations for portfolio diversification and minimize investment risks. This approach makes it possible not only to improve the efficiency of asset management, but also to develop recommendations for the future modernization of the pension system in Kazakhstan.

Thus, this study is aimed at developing a methodological approach to the management of pension assets of the UAPF using economic and mathematical modeling. For this purpose, preliminary data processing, standardization of variables and the use of multidimensional analysis methods were carried out. The results of the study will make it possible to substantiate the most effective pension asset management strategies that will ensure the long-term sustainability of the pension system and increase the level of social protection of the population.

Literature review

Modern management of funds' financial assets requires the use of multidimensional analysis to optimize investment decisions, minimize risks and increase profitability. Statistical, econometric, and machine learning methods are used worldwide to analyze complex relationships between assets and macroeconomic factors (Fama & French, 1993; Jolliffe, 2002). Kazakhstan is also actively implementing digital technologies and adapting international methodologies for the management of public and private investment funds (National Bank of Kazakhstan, 2023).

Markowitz's classical theory of portfolio investment (1952) remains the basic tool for asset optimization. However, taking into account the volatility of markets, more complex models are used, such as GARCH (Bollerslev, 1986) and EGARCH (Nelson, 1991), which make it possible to predict asset instability. In Kazakhstan, these models are used in stock market and currency risk analysis (Kasymkhanov & Akhmetov, 2022). An important role in risk management is played by the VaR (Value-at-Risk) method, which allows estimating potential losses (Fadilah et al. 2024). This approach is actively used in the Unified Accumulative Pension Fund (UAPF) (Amirova et al., 2024). Additionally, the use of copula functions (Sklar, 1959) makes it possible to evaluate non-linear dependencies between assets, which is especially

important in Kazakhstan, where the stock market is closely linked to the commodity sectors of the economy.

To simplify the analysis of financial assets, multivariate statistical analysis methods such as factor analysis and principal component analysis (PCA) are used to identify key factors affecting profitability (Jolliffe, 2002). In Kazakhstan, this approach is used in modeling the dynamics of investments in the stock market (KASE, 2023). Cluster analysis, based on K-means algorithms (MacQueen, 1967) and hierarchical clustering (Ward, 1963), is widely used to group assets by risk and profitability. Shayakhmetova et al. (2015) note that in Kazakhstan, cluster analysis helps diversify pension assets and determine optimal investment strategies.

Econometric methods, including multiple regression (OLS) and vector autoregressive models (VAR), make it possible to identify relationships between macroeconomic variables and financial assets. Studies by Fama and French (1993) demonstrate the effectiveness of regression models for predicting stock market returns. In Kazakhstan, VAR models are used to analyze the impact of inflation, exchange rate, and interest rates on investment funds (Akyzbekov et al., 2023).

With the development of digital technologies, machine learning (ML) and artificial intelligence (AI) methods are increasingly being used in asset management. The Random Forest method (Breiman, 2001) and gradient boosting (XGBoost) (Chen & Guestrin, 2016) demonstrate high accuracy in predicting stock market dynamics. In Kazakhstan, these methods are used for automated analysis of investment strategies and risk assessment (Liu & Cheng, 2022). Deep learning, in particular recurrent neural networks (RNN) and LSTM (Hochreiter & Schmidhuber, 1997), are used to predict time series in public asset management (Bernhart, 2021).

Kazakhstan's experience shows the active development of digitalization in fund management. The National Bank of Kazakhstan and KASE are implementing digital platforms for automated asset analysis and risk forecasting (National Bank of Kazakhstan, 2023). An important area is the use of blockchain technologies that increase the transparency of investment processes. ESG investing is also gaining popularity, requiring new methods of multidimensional analysis to assess the environmental

and social sustainability of investment strategies (D'Amato et al., 2022).

The literature review confirms that multidimensional analysis is a key tool in fund asset management. Kazakhstan is adapting global methodologies, which contributes to the development of the investment market. However, further research is needed to improve the effectiveness of the methods used and adapt international experience to local conditions.

Methodology

The initial data was the structure of pension assets presented on the official website of the UAPF, which is grouped by issuers, within the group the data is presented by types of securities and identifiers, rating, nominal and current value and share in the total volume (UAPF, 2024). The amount of data is 876 records. However, with this presentation of information, there is a fairly large number of matching classification objects by issuer, type of security, rating, urgency, only the identifiers differ. In this form, the data is not directly applicable to solving the problem, since the classification results in clusters that cannot unambiguously identify significant differences between groups of pension assets. The data was rearranged using Excel tools. The types of securities with the indication of the issuer were identified as objects of classification. The same-named objects with the same rating and urgency values were assigned to one group, the average yield was calculated for the group based on the price lists of the official website of the stock exchange (KASE, 2024), as well as the group's share in the total current value of assets. The financial instrument identifiers were associated with the corresponding group at the next lowest level of the hierarchy.

Thus, by choosing not a single paper as objects of classification, but groups of securities of the same type and urgency, but with different identifiers, their number was reduced to 125. The indicators of rating, urgency, specific weight in the total current value of the portfolio and the average profitability for the group were determined as classification features. Since the rating of the securities included in the UAPF investment portfolio is given in the assessment of different agencies (Moody's, Standard & Poor's and Fitch), they were ranked for comparability of estimates, Table 1.

Table 1 – Correspondence of the rating and assigned ranks

Moody's	Standard & Poor's	Rang	Rating characteristics
Aaa	AAA	9	The highest quality. Ratings of this level are assigned only if the ability to repay financial obligations is exceptionally high.
Aa1 Aa2 Aa3	AA+ AA AA-	8	Very low expectations of default risk. Very high ability to repay financial obligations. The exposure to negative conditions is low.
A1 A2 A3	A+ A A-	7	Low expectations of default risk. The ability to repay financial obligations is high. However, this ability is more susceptible to negative economic conditions than in the case of higher ratings.
Baa1 Baa2 Baa3	BBB+ BBB BBB-	6	Expectations of default risk are low at the moment. The ability to repay financial obligations is assessed as adequate, however, there is a high probability of negative economic conditions.
Ba1 Ba2 Ba3	BB+ BB BB-	5	Vulnerability to default risk, especially in case of negative changes in economic conditions over time. However, business flexibility or financial flexibility supports the ability to service financial obligations.
B1 B2 B3	B+ B B-	4	There are significant risks of default, however, while there remains a limited margin of safety. At the moment, financial obligations are being fulfilled, but the ability to continue payments is vulnerable in the event of a deterioration in economic conditions.
Caa	CCC+ CCC CCC-	3	Low quality, high level of speculation, high risk of non-fulfillment by the issuer of its obligations.
Ca C	CC C	2	The lowest quality of the Central Bank. Very high levels of credit risk. Default in one form or another seems likely.
	D	1	Default status. Liquidation or other official termination procedures have been initiated.

Note: The ranking was carried out by the author based on the characteristics of the ratings Lyalin & Vorobyev (2011).

As follows from Table 1, the same rank was assigned to rating categories of different agencies having the same characteristics based on work Lyalin & Vorobyev (2011). Each category usually includes three levels of ratings.

A rank of 10 was adopted for government securities, and a rank of 0 was established for securities of issuers without a rating

The “term” indicator is ranked as follows:

1. Short – term – 1;
2. Medium – term – 2;
3. Long-term – 3.

Before applying the method of multidimensional classification – cluster analysis, the interrelationships of the initial classification features were evaluated using correlation analysis. The correlation matrix is shown in Table 2.

Table 2 – Correlation matrix of classification features

	Rating	Term	Share	Profitability
Rating	1			
Term	-0,17677	1		
Share	0,317991	0,0296276	1	
Profitability	-0,56964	0,057839	-0,315029704	1

Note: Calculated by the authors

As follows from Table 2, multicollinearity between the factors (classification features) is not observed, which makes it possible for the subsequent application of the cluster analysis method with the Euclidean metric. Further, hierarchical agglomerative methods and the “k-means” method were used to obtain options for dividing the investment structure of UAPF pension assets into model portfolios of various types.

Results

The essence of hierarchical agglomerative clustering is the sequential unification of smaller clusters into large ones, i.e. initially each object (issuer/Cen-

tral bank group) is a cluster. In the following stages, the objects that are most similar in all their features are combined to form a new cluster. There are a number of rules for clustering. The Ward method was chosen for cluster construction in this work. The advantage of this method is that at each step clusters are combined that lead to a minimal increase in the objective function (intra-group sum of squares), i.e. clusters with the smallest variation in their properties are combined.

As follows from the graph, all three clusters have identical averages in terms of “term” and very similar averages in terms of “share”. The results of the variance analysis are presented in Table 3.

Table 3 – Results of variance analysis

	Between	df	Within	df	F	signif.
Rating	758,04	2	266,39	104	147,97	0,00
Term	2,18	2	50,46	104	2,25	0,11
Share	22,12	2	246,66	104	4,66	0,01
Profitability	478,11	2	395,75	104	62,82	0,00
Note: Calculated by the authors in the Statistica 6.0 package						

As follows from Table 3, in terms of “term” and “share”, the sum of the squares of the differences between clusters is less than the sum of the squares of the differences within the cluster, and for the “term” indicator, the tabular Fisher value $F = 2.25$ is less than $F_{cr} = 3.94$, based on the latter, the hypothesis of equality of averages is accepted. It follows that the split is insignificant for this indicator. The Fischer criterion for the “share” attribute shows the difference between clusters in terms of averages, but the excess of the sum of the squares of the differences between clusters over the sum of the squares within the group and the proximity of the averages for this feature on the graph allow us to conclude that this factor is of lit-

tle importance. Similarly, a study of the division into five clusters based on the same classification criteria was conducted, which confirmed the insignificance of the “term” indicator for cluster differences, and the weak influence of the “share” indicator. Therefore, the indicators “urgency” and “share” should be excluded when classifying into clusters. Thus, from the considered indicators of the UAPF pension asset structure, two criteria can be used to identify model portfolios based on a multidimensional classification: rating and profitability.

The significance of the estimates obtained can be judged by the results of the analysis of variance presented in Table 4.

Table 4 – Results of the analysis of variance in clustering by two criteria

	Between	df	Within	df	F	signif.
Rating	729,35	2	304,84	104	124,41	0,00
Profitability	536,27	2	355,97	104	78,34	0,00
Note: Calculated by the authors in the Statistica 6.0 package						

Based on the multidimensional analysis method, it can be said that most of the pension assets are bonds, while there are practically no speculative fast-growing stocks. Therefore, investors under the age of 35 of the UAPF can currently be offered a moderately aggressive portfolio with an average yield of up to 8.3%. This is slightly higher than the expected inflation rate (5.5% – 6%). The probability of risk in this portfolio is quite high, and lies in the range [0.5 – 1]. For the time being, a moderately conservative investor (over 35 to 50 years old) can be recommended a model portfolio of the second type, with a yield of 5.5%, with a risk probability of 0.3 – 0.5. The yield is about slightly higher than the inflation rate in 2023 (5%) and less than projected in 2024. The conservative portfolio is the most reliable, it can be recommended to citizens of pre-retirement age (over 50). But its profitability does not cover inflation, besides, it contains most of the long-term securities, which obviously does not satisfy the older generation.

Thus, in the structure of the UAPF investment portfolio, based on the classification carried out, we can identify three clusters of assets that differ in rating and profitability, which are part of them.

Discussion

The results of the study demonstrate that multidimensional analysis makes it possible to classify pension assets in more detail and identify optimal management strategies. In particular, the clustering of UAPF assets based on rating and profitability revealed three groups that differ in terms of risk and potential profitability. This confirms that traditional asset management methods based on conservative investments may need to be reviewed to improve the efficiency of the pension system. A comparison with international practices shows that pension funds in developed countries are striving for more diversified investment strategies. According to the OECD (2023), the world's largest pension funds, such as the Canadian Pension Plan (CPP Investments) and the Norwegian State Pension Fund, are actively investing in stocks, real estate, infrastructure, and even alternative assets such as venture capital and private equity funds. In Kazakhstan, pension assets are mainly concentrated in government bonds and corporate debts, which reduces potential profitability and increases dependence on internal macroeconomic stability.

One of the challenges for the Kazakh pension system is to maintain the real purchasing power of pension savings. As shown in the analysis, in 2023, the return on pension assets was 8.3%, while inflation

reached 9.8%, which led to negative real returns. In countries with developed financial markets, pension funds use more flexible strategies, including inflation-protected assets (TIPS – Treasury Inflation-Protected Securities), as well as active portfolio management with elements of dynamic rebalancing. This confirms the need to review the investment policy of the UAPF with an emphasis on long-term sustainability.

The results of the variance analysis presented in Tables 3 and 4 indicate the importance of factors such as rating and return on assets in classifying the retirement savings portfolio. The exclusion of the “urgency” and “proportion” indicators from the classification indicates that they do not have a significant impact on investment decisions. This may be explained by the high concentration of investments in long-term government bonds, which, despite their reliability, have relatively low yields. The use of cluster analysis has made it possible to identify three groups of assets that may correspond to different categories of depositors.:

1. A moderately aggressive portfolio – includes assets with a rating from “A” to “BBB”, with yields in the range of 7-8.3%. Such a portfolio can be recommended to young investors (up to 35 years old) who can afford a higher level of risk in exchange for potentially greater returns. However, the risk of such investments is higher than in traditional portfolios.

2. A moderately conservative portfolio – includes assets with a rating from “AA” to “BBB+” and a yield of 5.5-6%. This portfolio is aimed at middle-aged investors (35-50 years old) who need a balance between profitability and reliability. Despite the relative stability, the profitability of such a portfolio remains at the level of inflation, which does not ensure a real increase in pension savings.

3. Conservative portfolio – represents the least risky strategy, including government bonds with a rating of “AAA” and long-term instruments with a yield of 3.5-5%. It is intended for people of pre-retirement age (over 50 years old), but its profitability does not cover inflation, which makes it less attractive for protecting retirement savings.

Based on these findings, it can be argued that the current structure of pension assets in Kazakhstan requires diversification and the introduction of new investment instruments. For example, the inclusion of shares in large international companies, investments in infrastructure projects, and the use of ESG tools (environmentally, socially, and managerially sustainable investments) can increase profitability without significantly increasing risks.

Additionally, international experience shows that pension funds are increasingly using machine learning and artificial intelligence models to predict market trends and optimize their portfolios. Such technologies are still being used to a limited extent in Kazakhstan, which may become a promising area for improving the investment strategy of the UAPF. Thus, the study confirms the need to modernize the investment policy of the Pension Fund of Kazakhstan. The use of multidimensional analysis methods makes it possible to more accurately assess the risks and profitability of assets, which can become the basis for the formation of individualized retirement savings strategies. However, the successful implementation of these recommendations requires further development of the financial market, improvement of the regulatory framework and improvement of investment literacy of the population.

Conclusion

Effective management of pension assets is a key element of the long-term sustainability of Kazakhstan's pension system. The study showed that the existing asset structure of the UAPF is characterized by a high concentration in government bonds, which limits potential profitability and reduces protection against inflationary risks. An analysis of international experience indicates the need to diversify the investment portfolio by including stocks, infrastructure projects, ESG assets and other instruments capable of providing a higher level of profitability with an acceptable level of risk.

The use of multidimensional analysis methods made it possible to classify pension assets according to the degree of risk and profitability, identifying three main categories: moderately aggressive, moderately conservative and conservative portfolios. This approach allows for a more accurate selection of investment strategies depending on the age of depositors and their risk preferences. In particular, young investors may be offered a more profitable but also more volatile portfolio, while investors of pre-retirement age should focus on less risky assets with guaranteed returns. Despite the positive trends in the development of the pension system, the study revealed a number of problems that need to be addressed. These include the limited opportunities of the Kazakh stock market, high dependence on the commodity sector, low liquidity of investment instruments and the lack of a sufficient number of high-yielding assets. To improve the efficiency of pension asset management, it is necessary to improve the regulatory framework, develop financial infrastructure and introduce modern technologies, including artificial intelligence and machine learning to predict investment risks.

The results of the study can be used to further improve the investment policy of the UAPF, increase the transparency of asset management and develop individualized strategies for depositors. In the long term, the implementation of the proposed measures will increase the profitability of pension savings, minimize risks and ensure the sustainability of Kazakhstan's pension system in a dynamically changing economic environment.

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