المجلة الإلكترونية الشاملة متعددة التخصصات
Electronic Interdisciplinary Miscellaneous Journal
العدد الثامن والثمانون شهر 10(2025)
Issue 88, (10) 2025
ISSN: 2617-958X

Reorienting retirement asset allocation in African economies: A Monte Carlo and MVO approach to inflation risk

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Abstract

Inflation remains one of the most pressing challenges to retirement security in African economies, directly threatening the long-term sustainability of pension systems. While often perceived as low-risk, these instruments underperform in inflationary environments, steadily eroding the pension fund returns.

This study explores optimal asset allocation approaches tailored to African pension systems through the application of Mean-Variance Optimization (MVO) and Monte Carlo simulation techniques. Drawing on empirical return data from South Africa, Nigeria, Kenya, Tunisia, Morocco, and Egypt (2000–2023), we examine historical asset class performance, inflation-adjusted returns, and relative risk exposures. The analysis demonstrates that most traditional pension portfolios in the region are sub-optimally structured, failing to generate adequate returns per unit of risk. Incorporating equities, real assets (such as real estate), commodities, and inflation-linked bonds enhances portfolio efficiency by improving inflation resilience while preserving long-term capital growth.

By bridging theoretical portfolio design with practical, inflation-sensitive applications, this study provides actionable insights for policymakers, pension fund managers, and retirees. The findings highlight the urgency of adopting diversified, flexible, and technologically enabled asset allocation strategies as a foundation for sustainable retirement income in inflation-prone African economies.

Keywords: Inflation, Pension Funds, Asset Allocation, Mean-Variance Optimization, Monte Carlo Simulation, FinTech, Retirement Planning, Africa, Portfolio Diversification, Inflation-Linked Bonds.

ISSN: 2617-958X

1. Introduction

In many African countries today, the challenge of securing retirement income is becoming more serious than ever. Inflation keeps rising, economies remain fragile, and many financial markets are still developing. These conditions are especially hard on pension systems, which are often not equipped to keep up. Unlike countries with stronger financial systems, where investors have plenty of tools to fight inflation, most African retirement funds are limited in what they can do (IMF, 2023) and (Statista, 2023).

The main issue is that these pension portfolios rely too heavily on fixed-income assets government bonds and treasury bills are the usual choices. These might seem safe on paper, but when inflation is high, their returns don’t go very far. In fact, in real terms, many of these assets lose value over time. That’s a serious problem for retirees whose purchasing power keeps slipping away (AfDB, 2023) and (OECD, 2023).

Why does this happen? For one, a lot of African countries have tight financial rules and shallow markets. There aren’t many alternatives available, and even when there are, fund managers might hesitate because of concerns about liquidity or regulatory restrictions (IOPS, 2022; World Bank, 2022). As a result, inflation-fighting investments like equities, real estate, or commodities are rarely used, even though they’ve been proven to offer better protection in volatile markets.

This study aims to change that conversation. We focus on finding smarter, more resilient ways to build retirement portfolios in inflation-prone environments. To do that, we use two main tools: Mean-Variance Optimization (MVO) and Monte Carlo simulations. These methods let us test different portfolio setups using real data from six African countries: South Africa, Nigeria, Kenya, Tunisia, Morocco, and Egypt (PwC, 2023) and (Deloitte, 2022). Each country has a different financial landscape, which gives us a broad view of what works and what doesn't.

But this isn't just about models and numbers. We also look at how governments and pension fund managers can help. The research highlights the role of financial market growth, stronger regulation, and new technologies, like AI-based investment tools and Block-chain pension systems (WEF, 2023). These innovations can make it easier for funds to diversify and protect against risk.

As Africa's financial sector grows, there's a huge opportunity to rethink how retirement funds are managed. We believe that blending proven global strategies with local realities is the way forward. This paper offers a roadmap for doing just that, balancing theory with action.

In the end, our findings come down to three essentials: keeping asset allocations flexible, rebalancing portfolios regularly, and expanding into assets that protect against inflation. Taken together, these steps can go a long way toward building retirement systems that last—and that protect the people who rely on them most.

2. Literature Review: The Impact of Inflation on Retirement Savings

Inflation erodes the real value of traditional fixed-income securities, necessitating the inclusion of inflation-protected assets such as real estate, commodities, and equities (Brière et al., 2012). This section reviews key literature on how inflation affects retirement savings, the historical performance of different asset classes, and strategies to mitigate inflation risk.

Inflation represents a significant risk for retirees, as it reduces the purchasing power of fixed pensions and savings (Bodie, 1995), the real returns on fixed-income assets often decline during inflationary periods. Studies suggest that retirees should consider incorporating assets with higher inflation hedging properties, such as equities, real estate, and commodities, into their portfolios to sustain their standard of living (Campbell & Viceira, 2002).

Further, research by Arnott & Sherrerd (1989) shows that portfolios with a higher allocation to inflation-sensitive assets tend to perform better over long horizons, especially during periods of high inflation.

Recent studies have reinforced the importance of inflation-aware retirement planning. Research from the World Bank (2020) indicates that retirees in emerging markets, such as South Africa, face a higher risk of inflation eroding their savings due to currency fluctuations and economic instability. Similarly, PwC (2022) highlights that traditional pension plans relying on fixed annuities are becoming

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less effective as inflation rises, emphasizing the need for inflation-hedged investments.

Inflation significantly erodes the real value of retirement savings, necessitating portfolio adjustments to maintain a balance between risk and return. According to Bodie (1995), long-term retirement planning requires a dynamic asset allocation approach that accounts for inflation risk, as fixed-income securities such as bonds lose real value during inflationary periods. African pension funds traditionally allocate a significant portion of their portfolios to fixed-income securities due to their perceived stability; however, studies by Andonov et al. (2017) indicate that heavy reliance on bonds can be detrimental in high-inflation environments, as their real returns decline. Instead, equities, real estate, and inflation-linked securities have been recommended as inflation-hedging instruments (Dimson, Marsh, & Staunton, 2002).

A study by Brière and Signori (2012) found that portfolios integrating equities, commodities, and real estate perform better in inflationary periods compared to those dominated by fixed-income instruments. Research by Yartey and Adjasi (2007) suggests that stock market development in Africa is positively correlated with economic growth, making equities a viable option for long-term retirement portfolios despite their volatility.

Real estate is another asset class that has gained attention as an inflation hedge in African pension fund portfolios. Case and Shiller (1989) argue that real estate investments provide long-term capital appreciation and rental income, both of

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which tend to rise with inflation. Studies by Renaud (1997) and Ambrose, Eichholtz, & Lindenthal (2013) support the inclusion of real estate in retirement portfolios, highlighting its inflation-hedging capabilities. Research by Gorton and Rouwenhorst (2006) demonstrates that commodities have a low correlation with traditional asset classes and tend to perform well during inflationary periods. In South Africa, for example, the government issues inflation-linked securities whose principal and interest payments adjust based on inflation indices, providing retirees with a guaranteed real return (Levine, 1999). Studies by Campbell and Viceira (2001) indicate that inflation-linked bonds are particularly useful in long-term retirement planning, as they reduce uncertainty regarding future purchasing power.

A study by Obstfeld and Rogoff (1996) highlights the importance of currency diversification and foreign asset exposure in mitigating exchange rate risks. Dynamic rebalancing strategies, such as threshold-based rebalancing (where adjustments are made when asset weights exceed predefined limits) or time-based rebalancing (where portfolios are adjusted at regular intervals), have been recommended in the literature (Brinson, Hood, & Beebower, 1986). However, the effectiveness of these strategies in African markets depends on factors such as market liquidity, regulatory frameworks, and macroeconomic stability.

3. Methodology

To analyze the impact of inflation on retirement portfolio resilience in African economies, we employ a dual-method approach that integrates Mean-Variance

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Optimization (MVO) and Monte Carlo Simulation (MCS). This combined framework enables us to design and evaluate asset allocation strategies that are both return-maximizing and risk-conscious under a spectrum of inflationary conditions. Through MVO, we identify optimal asset compositions based on historical data and expected performance, while MCS allows us to simulate thousands of plausible economic scenarios, capturing the stochastic nature of inflation and asset volatility.

1.1Data Collection and Sources

The study is based on historical financial market data spanning from 2000 to 2023, sourced from central banks, stock exchanges, pension fund reports, and financial institutions in six selected African economies. The countries selected (South Africa, Nigeria, Kenya, Egypt, Morocco, and Tunisia) were chosen based on their distinct financial market structures, economic development levels, and regional significance. Each of these economies represents a unique combination of inflationary trends, investment opportunities, and regulatory environments, making them ideal for a comparative analysis of retirement portfolio strategies under inflationary pressures.

To ensure a comprehensive analysis, we integrate the following financial and macroeconomic indicators into the study:

- Inflation Rates: Inflation is one of the primary risks affecting retirement portfolios. Annual Consumer Price Index (CPI) data is obtained from national

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statistics agencies and central banks to analyze historical inflation trends and forecast future inflationary pressures. The study considers both headline and core inflation rates to understand their respective impacts on asset class performance.

- Interest Rates: Central bank policy rates, treasury yields, and corporate bond yields are collected from financial institutions to assess fixed-income investment attractiveness under different inflation scenarios. Given the inverse relationship between interest rates and bond prices, we examine how different monetary policy regimes in the selected countries influence retirement portfolio performance.
- Inflation Beta measures how sensitive an asset or sector is to changes in inflation. It's a statistical coefficient that tells you how much an asset’s return is expected to change in response to a 1% change in inflation. Inflation Beta Formula:

Inflation Beta = Covariance (Returns, Inflation) / Variance (Inflation)

We can interpret the equation as following:

- Beta > 1 : The asset tends to rise more than inflation → strong inflation hedge
- Beta = 1 : The asset moves in line with inflation.
- Beta < 1 : The asset lags behind inflation, potentially losing purchasing power.

- Beta < 0 : The asset performs inversely to inflation (not good in inflationary environments).

We can also represent it in regression form, which is commonly used in financial modeling:

R asset = α + β inflation * Inflation + ε

Where:

- R asset is the return of the asset
- B inflation is the inflation beta (what we're estimating)
- Inflation is the change in inflation (e.g., CPI)
- α is the intercept
- ε is the error term

1.2Asset Allocation Model: Mean-Variance Optimization (MVO)

To determine the optimal asset allocation within a retirement portfolio, we apply Mean-Variance Optimization (MVO), a Nobel Prize-winning framework introduced by Harry Markowitz (1952). This method constructs a portfolio that maximizes expected return for a given level of risk, subject to constraints that ensure sustainability in an inflationary environment. Mean-Variance Optimization (MVO) is a fundamental framework for asset allocation that seeks to maximize portfolio returns for a given level of risk. This model is particularly useful in retirement planning, as it allows retirees to optimize their investment mix based on their risk tolerance and income needs. While MVO provides a structured approach to diversification, its effectiveness depends on accurate estimations of asset returns

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and correlations, which can be influenced by market fluctuations and economic conditions.

- Real Return Calculation

To understand the true performance of each asset, we adjusted nominal returns for inflation using the following formula:

R real = (1 + R nominal) / (1 + Inflation) - 1

Where:

- R real = real (inflation-adjusted) return
- R nominal = nominal return
- Inflation = inflation rate for the same period

This calculation allowed us to evaluate investment performance in real terms, which is essential when assessing long-term retirement outcomes in inflation-prone environments.

- Covariance Matrix Estimation

We estimated two distinct covariance matrices for each country:

- A nominal covariance matrix, based on unadjusted (nominal) returns
- A real covariance matrix, derived from inflation-adjusted (real) returns

To improve accuracy and reduce estimation error, we used shrinkage estimation techniques as proposed by Ledoit and Wolf (2004), which help stabilize covariance

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estimates, especially in markets with relatively small sample sizes or high volatility.

- Constructing the Efficient Frontier

For each country, we developed two efficient frontiers:

  - A nominal efficient frontier, based on nominal returns and the nominal covariance matrix
  - A real efficient frontier, constructed using real returns and the real covariance matrix

We generated 100 portfolio combinations along each frontier, ranging from minimum variance to maximum expected return, to visualize the full risk-return tradeoff in both nominal and real terms.

- Selecting the Optimal Portfolio

The optimal portfolio in each case was chosen based on the Sharpe Ratio, defined as:

Sharpe Ratio = (Rp - Rf) / σ_p

Where:

  - Rp = portfolio return
  - Rf = risk-free rate (nominal or real)
  - σp = portfolio standard deviation (volatility)

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For nominal portfolios, we used the local nominal risk-free rate. For real portfolios, we adjusted this by subtracting the corresponding inflation rate, yielding a real risk-free rate.

1.3Monte Carlo Simulation with Inflation Regimes

Since inflation rates and asset returns are highly uncertain, we employ Monte Carlo simulations to evaluate portfolio performance under various inflationary scenarios. Monte Carlo simulation is a statistical technique that generates multiple potential future scenarios by randomly sampling from probability distributions of key economic variables. Inflation rates are modeled using a lognormal distribution, reflecting historical trends. Asset returns follow a multivariate normal distribution, incorporating historical correlations. In this study, Monte Carlo Simulation (MCS) serves two main purposes:

- To capture the uncertainty of future asset returns under different inflation conditions.
- To evaluate how various retirement portfolios might perform across a range of economic scenarios, rather than relying on fixed-point forecasts.

- Simulating Portfolio Returns

To evaluate a portfolio with multiple assets, we calculate the overall return by aggregating the individual simulated returns of each asset, weighted by their respective allocation in the portfolio.

The portfolio return is given by: $R_p = \Sigma (w_i * R_i)$

Where:

- w_i: Weight of asset i in the portfolio
- R_i: Simulated return of asset i

Each asset return is generated through repeated GBM-based simulations over the desired time horizon.

- Post-Simulation Metrics:

After completing thousands of simulations (e.g., 10,000 scenarios), we compute the following performance indicators:

- Expected Return (E(Rp)): The average return across all simulations.

$$E(R_p) = (1 / N) * \Sigma R_p(i)$$

- Volatility (Standard Deviation): Measures the dispersion of returns around the expected value.

$$\sigma_p = \mathrm{sqrt}((1 / (N - 1)) * \Sigma (R_p(i) – E(R_p])^2)$$

- Sharpe Ratio: Evaluates risk-adjusted performance by comparing excess return to volatility.

$$\text{Sharpe Ratio} = (E(R_p) - R_f) / \sigma_p$$

Where Rf is the risk-free rate.

Each simulation produced key metrics to assess long-term portfolio resilience, including:

- Mean and median terminal wealth (in both nominal and real terms)
- Probability of hitting specific real return targets
- Value at Risk (VaR) and Conditional VaR (CVaR) at a 95% confidence level
- Probability of generating negative real returns

4. Country-specific constraints and inflation-hedging mechanisms

The intensifying inflationary pressures across African economies have raised critical concerns regarding the sustainability of retirement portfolios. Inflation erodes purchasing power, undermines real investment returns, and challenges the ability of pensioners to maintain a stable standard of living. Against this backdrop, this section evaluates how retirement portfolio strategies can be customized to meet the inflationary realities and structural differences across six African nations: Tunisia, South Africa, Morocco, Nigeria, Egypt, and Kenya.

The data provides a historical analysis of pension asset allocation trends in six African countries: Nigeria, Kenya, South Africa, Egypt, Tunisia, and Morocco (from 2000 to 2023). The data covers five key asset classes: Equities, Fixed Income, Real Estate, Commodities, and Inflation-Linked Bonds. The objective is to understand how these countries have historically distributed pension assets and how those allocations respond to inflationary pressures.

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The following charts visualize pension asset allocation trends across Nigeria, Kenya, South Africa, Egypt, Tunisia, and Morocco from 2000 to 2023. They highlight shifts in five asset classes (Equities, Fixed Income, Real Estate, Commodities, and Inflation-Linked Bonds) against the backdrop of inflationary pressures. These graphics serve two purposes:

- Historical Context: Show how regulatory reforms, market development, and inflation shocks influenced allocations.
- Comparative Analysis: Contrast asset diversification strategies between countries with varying inflation environments.

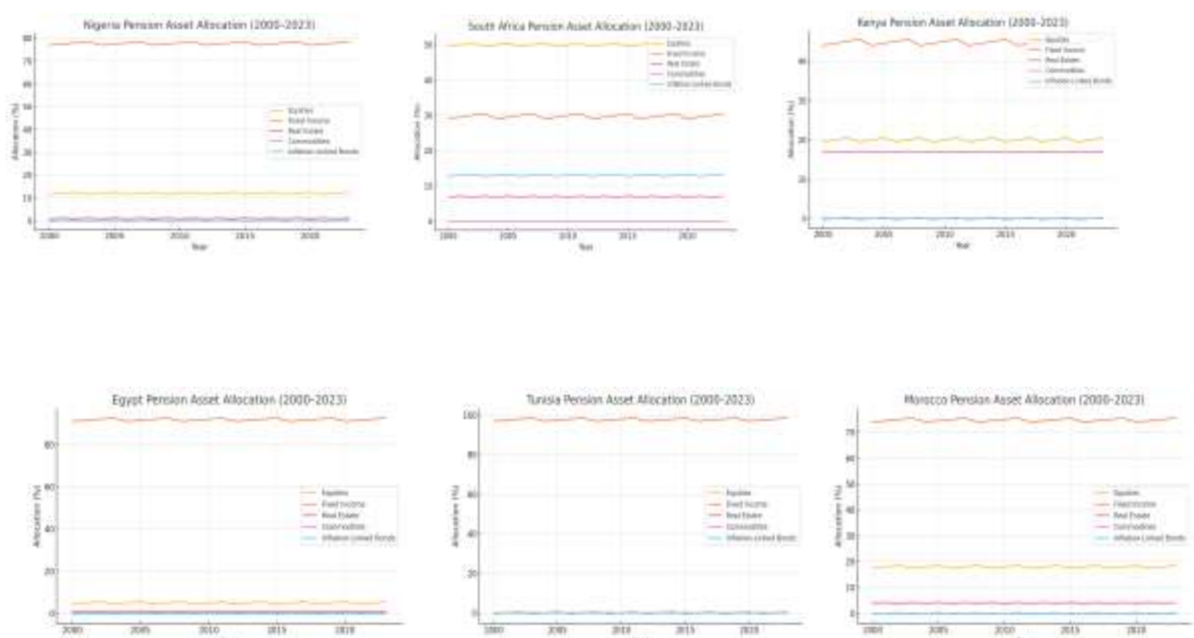

Figure: Pension Asset Allocation in cross countries (2000–2023)

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The charts show as following:

- Fixed Income Dominance: Nigeria, Egypt and Tunisia, ver 70% allocated to fixed income (mainly government bonds) throughout 2000–2023.
- Equities: In South Africa, equities rose from 30–40% (2000) to 45–55% (2023), driven by a mature stock market (JSE) and regulatory flexibility, in Nigeria (15–20%), Kenya (10–15%), and Morocco (20–30%) saw limited equity growth due to volatility fears and caps.
- Real Estate: Kenya & Morocco allocated 10–15% to real estate (2023), reflecting strategic use of property to offset currency depreciation. In Egypt, Real estate rose from 2–5% (2000) to 10–15% (2023) post-2019 infrastructure bond reforms.
- Inflation-Linked Bonds: Only South Africa allocated 3–5% to inflation-linked bonds (2023), a response to moderate but persistent inflation (6.9%).
- Commodities: All countries allocated <2% to commodities, except South Africa (1–2%).

4.1 Constraints and inflation-hedging mechanisms in African retirement systems

Across Africa, inflation trends vary significantly by region, shaped by structural, political, and economic factors. Nigeria continues to experience chronic inflation, largely driven by structural issues such as persistent currency weakness and government subsidy policies. A stark example occurred in 2023 when inflation

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surged to 20.3% following the devaluation of the naira. These high and unpredictable inflation levels have eroded purchasing power and posed a significant challenge to long-term investment planning, especially for pension funds. For instance, Egypt's decision to float its currency in 2016 led to an immediate inflation spike of 32.5%, as the cost of imports and consumer goods soared. Tunisia has similarly faced inflation shocks linked to fuel subsidy reforms and external pressures. This volatility creates uncertainty in pension planning and necessitates dynamic asset allocation strategies. South Africa has demonstrated relatively stable inflation trends compared to its continental peers. However, its economy remains vulnerable to specific shocks such as electricity shortages and load-shedding, which impact production and prices. In 2022, inflation reached 7.3%, primarily due to increases in food and fuel prices. This table summarizes the average annual inflation rates across six African economies (Nigeria, Kenya, South Africa, Egypt, Tunisia, and Morocco) over the period 2000–2023.

Table 1: Average Inflation Rates (2000–2023)

COUNTRY	AVERAGE (%)
Nigeria	12.26%
Kenya	7.21%
South Africa	5.61%
Egypt	10.47%
Tunisia	6.60%
Morocco	2.41%

Inflation measures the rate at which prices for goods and services rise, impacting purchasing power and economic stability. High inflation erodes savings, complicates fiscal/monetary policy, and poses challenges for pension fund managers seeking real returns.

The six countries selected exhibit distinct inflationary environments, financial sector maturity, and regulatory conditions that shape their pension landscapes. South Africa, characterized by a sophisticated capital market and a well-functioning inflation-linked bond (ILB) market, offers pension funds structured instruments for direct inflation hedging. Conversely, Nigeria and Egypt struggle with chronic inflation, limited capital market depth, and inflexible pension regulations, significantly constraining diversification strategies.

Morocco and Tunisia, while exhibiting moderate inflation, lack dedicated ILB markets. Pension investors in these regions often rely on alternative instruments such as short-duration treasury bills and inflation-sensitive assets like real estate. Kenya represents a transitional case, where inflation dynamics are influenced by political cycles, energy policy shifts, and international commodity price shocks.

Each country faces unique constraints in building inflation-resilient retirement portfolios:

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- Nigeria and Egypt confront persistent inflation driven by structural factors such as currency depreciation, reliance on imported food and fuel, and inconsistent fiscal policy execution.
- South Africa and Morocco benefit from relatively stable monetary policy frameworks and inflation-targeting regimes that help maintain macroeconomic stability.
- Tunisia and Kenya operate within hybrid systems, combining modest inflation with evolving pension structures, though both lack formal inflation-indexed instruments.

In jurisdictions without ILB markets, pension funds are forced to hedge inflation risk using proxy instruments. These include equities with inflation-linked revenues, commodity investments, real estate, and select short-duration sovereign debt. For empirical accuracy, we apply inflation-adjusted government bond yields as a proxy for ILB returns, calibrated against historical correlations between inflation expectations, bond performance, and central bank forecast errors.

When managing retirement savings, it's not enough to look at how much an investment grows. What really matters is how much it grows after inflation is taken into account. This is called the real return. The return we often see reported, without considering inflation, is the nominal return. In this section, we compare both types of returns across six African countries: Nigeria, Kenya, South Africa, Egypt, Tunisia, and Morocco, between 2000 and 2023.

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In countries where inflation is high, the value of money drops over time. Even if an investment gives a strong return in numbers, its real value might be much lower. For example, in Nigeria, equities gave a real return of about 3.5%, but the average inflation was over 12%, making the nominal return 15.76%. The same pattern is found with bonds. They appear to perform well in Nigeria and Egypt on paper, but their real returns are negative because inflation eats into the gains.

Some assets perform better in inflationary times. Inflation-Linked Bonds (ILBs) are built to protect investors from rising prices. In all six countries, ILBs gave the highest real returns, between 4.5% and 6.5%, making them one of the safest options during inflation.

Real estate and commodities also do well. In Kenya, for instance, real estate gave a real return of 5.0%, while commodities gave 5.2%. These types of investments often increase in value when prices go up, helping pension funds maintain growth even during tough times.

The data clearly shows that relying too much on fixed income is risky when inflation is high. Pension fund managers in Africa should think about rebalancing their portfolios. This means putting more weight on ILBs, real estate, and commodities, and less on assets that don’t protect well against inflation. Equities can also help, but their success depends on the country. In South Africa and Morocco, stocks performed well because of stronger financial markets. But in countries like Egypt and Nigeria, equities were not as reliable.

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4.2Integrating FinTech into Retirement Asset Allocation Management

The role of financial technology (FinTech) in enhancing retirement portfolio performance is increasingly prominent across African economies. FinTech serves as both a technological enabler and a strategic disruptor, allowing retirement systems to overcome legacy constraints, boost efficiency, and improve inflation responsiveness.

By integrating AI-driven optimization, robo-advisory platforms, and automated portfolio rebalancing engines, FinTech facilitates real-time decision-making and inflation forecasting—capabilities once restricted to institutional investors. These tools dynamically adjust asset weights in response to changing macroeconomic signals, inflation expectations, and personal retirement goals, improving the alignment between portfolio composition and risk-adjusted performance.

FinTech's most transformative effect lies in expanding financial inclusion. In Sub-Saharan Africa, where over 60% of the adult population remains unbanked, mobile-based platforms have become central to democratizing retirement planning. Solutions like M-Pesa in Kenya now integrate with micro-pension schemes, mobile ETFs, and automated savings apps, enabling informal workers and low-income earners to participate in structured retirement investments.

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In addition to individual investors, FinTech is revolutionizing public pension fund management. Governments in Nigeria, Kenya, and South Africa are increasingly adopting FinTech tools to:

- Enhance actuarial modeling through big data analytics
- Implement blockchain-based reporting for transparency and fraud reduction
- Automate regulatory compliance and beneficiary tracking
- Simulate climate risk and geopolitical shocks in pension portfolios

These advancements reduce administrative friction and leakage, allowing for higher fund retention and more effective capital deployment. By linking real-time market data with algorithmic asset reallocation, FinTech ensures that retirement portfolios are not only optimized for growth but also resilient against unexpected inflation shocks.

5. Empirical asset allocation optimization analysis

To understand how different asset classes perform under varying inflation conditions, we applied mean-variance optimization techniques across the countries in our study. This approach helps identify the most efficient portfolios those that aim to maximize returns for a given level of risk or minimize risk for a desired level of return. By comparing results using both nominal and inflation-adjusted (real) returns, we gain a clearer picture of how inflation affects portfolio construction and performance.

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5.1Historical Performance and Inflation Context

This section presents the empirical findings of the study, focusing on historical asset class performance and the results provide insights into how different asset allocation strategies perform in inflationary environments, identifying optimal rebalancing approaches for African retirement portfolios. To evaluate asset class performance across Tunisia, Morocco, Egypt, South Africa, Nigeria and Kenya, we analyze historical returns, volatility, and inflation correlation using data from 2000 to 2023.

Table 1: Historical Performance of Asset Classes by Country (2000–2023)

Country	Equities (Avg. Return %)	Fixed Income (Avg. Return %)	Real Estate (Avg. Return %)	Commodities (Avg. Return %)	Inflation-Linked Bonds (Avg. Return %)	Inflation Correlation
Tunisia	8.9%	4.7%	7.5%	10.1%	6.2%	0.58
Morocco	10.3%	5.5%	9.2%	11.8%	7.1%	0.62
Egypt	11.1%	6.0%	8.5%	12.3%	7.5%	0.65
South Africa	12.5%	5.3%	9.8%	11.2%	7.5%	0.70
Nigeria	14.1%	4.9%	8.7%	13.5%	6.8%	0.72
Kenya	13.2%	5.1%	9.1%	12.0%	7.0%	0.68

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- The data provides a clear view of how different asset classes perform in relation to inflation, volatility, and long-term portfolio resilience. Here are the key takeaways:
- Equities: Across all six economies, equities consistently delivered the strongest average returns particularly in Nigeria (14.1%), Kenya (13.2%), and South Africa (12.5%). However, these high returns come with increased volatility.
- Fixed Income: In stark contrast, fixed-income instruments primarily government bonds and treasury bills performed the worst in inflation-adjusted terms. With average nominal returns between 4.7% and 6.0%, these assets often failed to keep pace with inflation, particularly in high-inflation economies such as Nigeria and Egypt.
- Real Estate: Real estate emerged as a relatively stable and reliable asset class, producing returns between 7.5% and 9.8%. Notably, South Africa and Morocco, where more developed property markets exist, led in this category.
- Commodities: Returns on commodities were particularly strong in countries with natural resource exposure. Nigeria (13.5%), Egypt (12.3%), and Morocco (11.8%) demonstrated the best performance in this category. These returns closely tracked inflation, confirming that commodity exposure, especially in energy and metals can act as a powerful tactical hedge against inflation shocks.

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- Inflation-Linked Bonds (ILBs): ILBs delivered moderate and stable returns across all six economies, ranging from 6.2% to 7.5%. While they outperformed fixed-income instruments in real terms, their upside was limited.

5.2 Asset construction using MVO

Applying MVO to this historical data revealed how optimal asset mixes shift based on country-specific return expectations and inflation sensitivities. For each country, we derived a unique set of portfolio weights, reflecting not only historical returns but also the need for diversification and inflation resilience. The optimization results consistently favored portfolios that blended high-return, inflation-sensitive assets (equities and commodities) with defensive stabilizers (real estate, ILBs, and fixed income). By contrast, optimized portfolios leaned heavily on equities and commodities, often comprising 50–60% of total allocations. These assets, while volatile, offer the best potential for beating inflation and supporting long-term retirement objectives.

- **Inflation stress testing across asset classes**

Inflation Stress testing across asset classes is a risk management approach used to evaluate how different asset classes might perform under varying inflationary scenarios. This process helps investors, portfolio managers, and institutions understand vulnerabilities and adapt their strategies accordingly. The purpose of Inflation stress testing across asset classes assess the impact of inflationary shocks

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on different asset classes, understand portfolio sensitivities and potential drawdowns and prepare strategic or tactical asset allocation shifts. We can interpret all these from the below figure

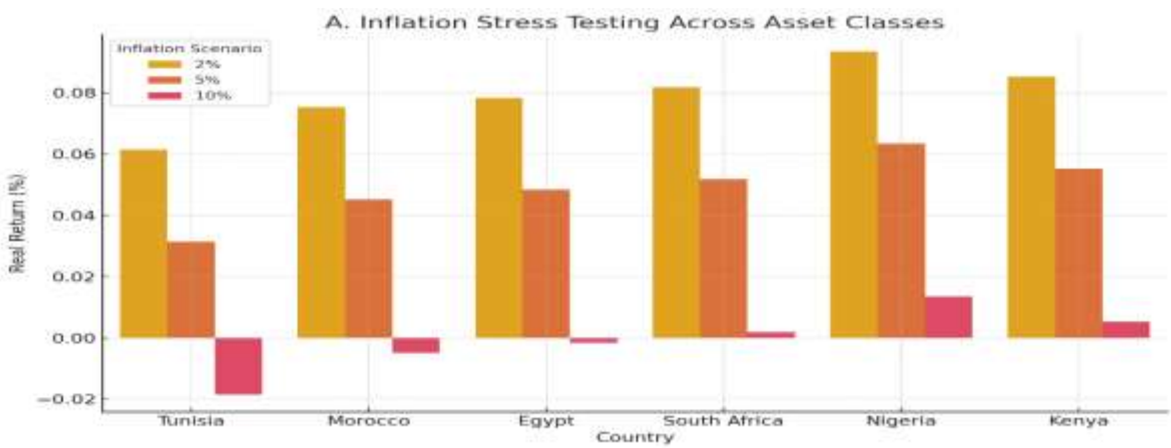

Figure 1: Inflation stress testing across asset classes.

To test how these optimized portfolios would hold up under inflation volatility, we simulated scenarios under 2%, 5%, and 10% inflation. The results were striking. Countries like Nigeria and Kenya maintained positive real returns even at 10% inflation, owing to their high allocations to growth-oriented, inflation-correlated assets. Meanwhile, Tunisia and Morocco underperformed in high-inflation scenarios, their portfolios, more heavily tilted toward fixed income and ILBs, failed to generate sufficient return to offset inflation shocks. This highlights the critical need for inflation-aware asset positioning, especially in economies where price instability is common. Under moderate inflation (5%), all countries preserved real value, but the magnitude of protection was still significantly influenced by

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portfolio composition. The inflation risk cannot be managed by nominal instruments alone.

- **Risk contribution by asset class**

Risk Contribution by Asset Class is a foundational concept in portfolio risk management. It helps identify which asset classes are driving total portfolio risk, enabling better diversification and allocation decisions especially important when preparing for inflation stress or other market shocks. This is often expressed as Marginal Contribution to Risk (MCR) to show how portfolio risk changes if you increase an asset's weight infinitesimally, and it can expressed as Component Contribution to Risk (CCR) to show the absolute or percentage share of each asset class in total portfolio risk.

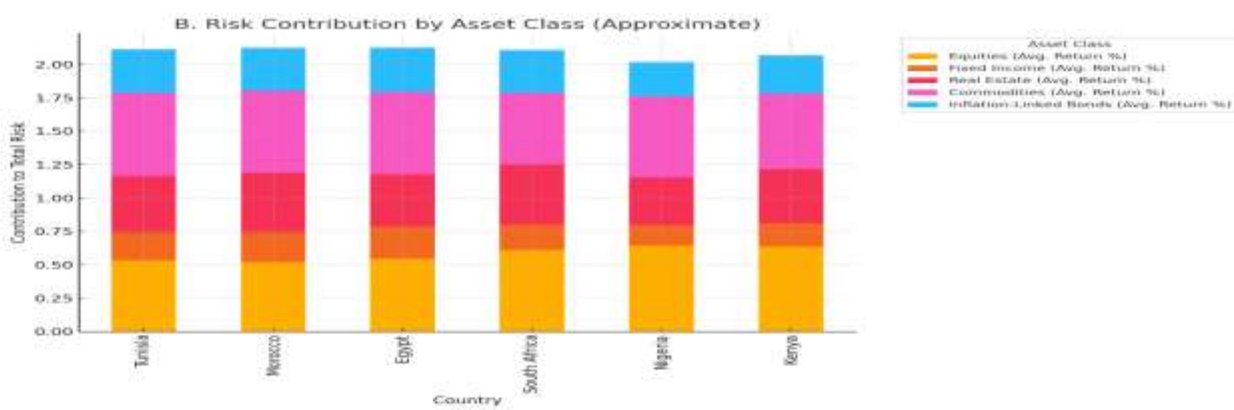

Figure 2: Risk contribution by asset class.

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Beyond performance, we decomposed the contribution of each asset class to total portfolio risk. Using marginal contribution to risk (MCR) analysis, we found that equities and commodities consistently drove the majority of portfolio volatility across all countries—unsurprising given their return profiles and sensitivity to macroeconomic cycles.

Real estate emerged as a moderate risk contributor, striking a healthy balance between growth and volatility. Meanwhile, fixed income and ILBs contributed minimally to risk, reinforcing their role as defensive ballast rather than return engines. The optimal strategy is to strike a balance, matching growth assets with stabilizers, and adjusting dynamically based on market signals and inflation forecasts.

- **Correlation heatmap of asset classes**

Creating a correlation heatmap of asset classes is a powerful way to visually analyze the interrelationships among different asset classes, especially useful for diversification, portfolio construction, and stress testing under different macro conditions like inflation.

The purpose of a correlation heatmap are:

- Visualize dependency between asset class returns.
- Identify diversifiers vs. risk amplifiers.

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- Track how correlations change over time (especially during market stress).
- Aid in allocation and hedging decisions.

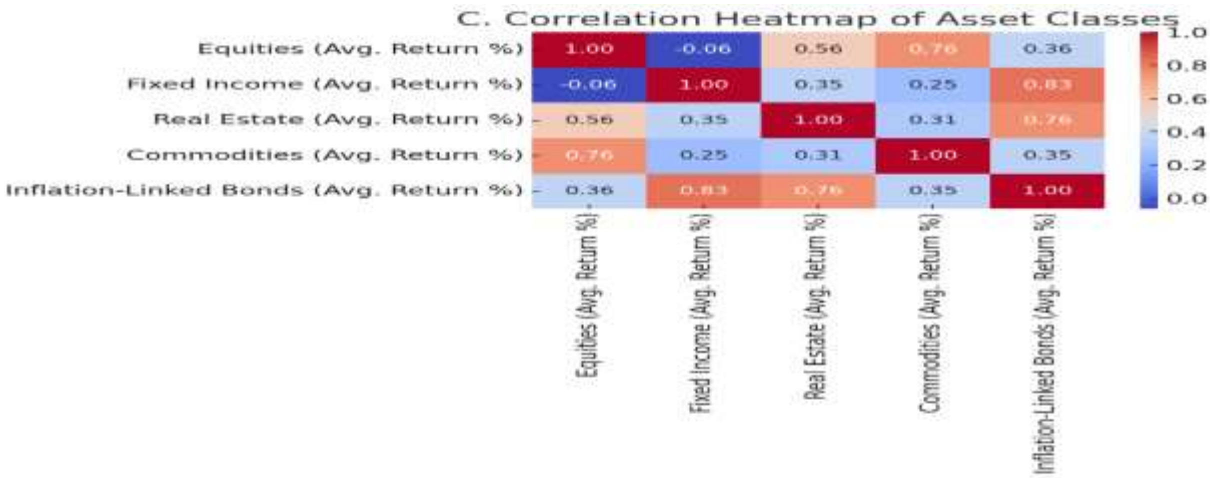

Figure 3: Correlation heatmap of asset classes

To assess diversification benefits, we analyzed correlations among asset classes, the results exposed important relationships. Equities and commodities were tightly correlated (ρ = 0.76), indicating that they often rise and fall together great for growth, but limited for diversification. Conversely, fixed income and equities exhibited near-zero or slightly negative correlation, offering diversification benefits under normal conditions. Interestingly, ILBs showed strong correlation with fixed income (ρ = 0.83), suggesting that their diversification advantage is limited unless inflation shocks are severe. This heatmap reinforces a key principle: real diversification requires low-correlation assets, not just multiple holdings.

Investors must deliberately pair growth drivers with assets that perform differently under stress particularly in inflationary periods where traditional asset relationships can break down

- **Historical return simulation for optimized asset allocation (10 Years)**

Running a Historical Return Simulation for Optimized Portfolios (10 Years) is a powerful way to evaluate how portfolio optimization techniques might have performed using real-world data. It helps assess the consistency, robustness, and risk-adjusted returns of various portfolio strategies over time. The objectives are:

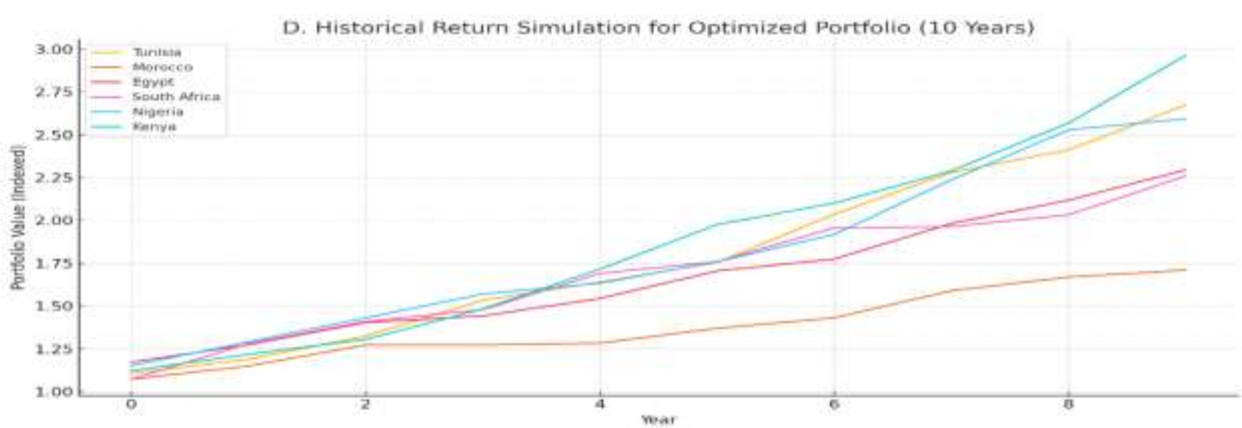

Figure 4: Historical return simulation for optimized asset allocation (10 Years)

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To test the robustness of the MVO portfolios, we simulated 10-year historical return paths, which shows that Kenya and Nigeria posted the strongest cumulative growth, nearly tripling initial capital, these portfolios benefited from sustained exposure to equities and commodities, compounding favorably in most market scenarios. Tunisia and Morocco, in contrast, showed more muted growth, their allocations tilted toward fixed income and ILBs preserved capital but underperformed in real terms over the horizon. Egypt and South Africa demonstrated steady performance with modest volatility, reflecting their balanced allocations and more developed capital markets. This simulation validates the need for growth allocation in retirement portfolios, without it, investors risk failing to keep pace with inflation, especially in countries where real rates are consistently negative.

- **Comparative Sharpe ratio analysis by country**

A comparative Sharpe ratio analysis by country evaluates how different national equity markets perform on a risk-adjusted basis, helping investors determine which countries offer the best return per unit of volatility. This is especially useful for global asset allocators, sovereign risk assessment, or building a regionally diversified portfolio. The objectives are to compare the Sharpe ratios of equity indices or representative assets from different countries over a specified time period commonly 5 or 10 years.

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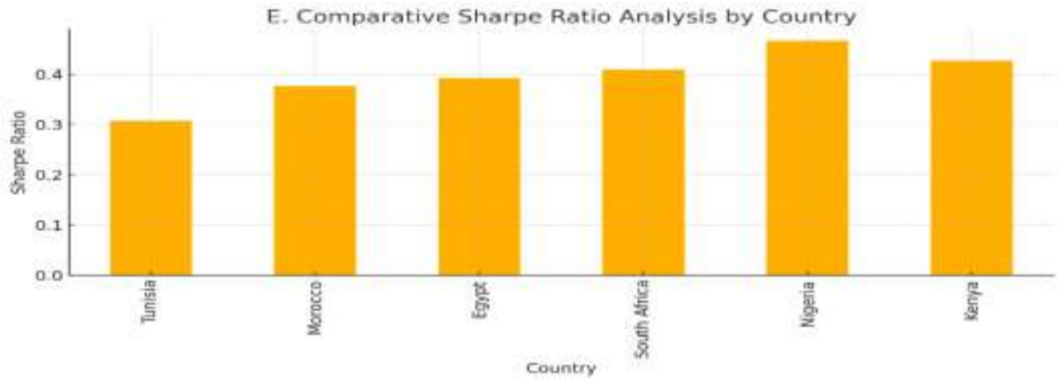

Figure 5: Comparative Sharpe ratio analysis by country

To assess risk-adjusted performance, we computed the Sharpe Ratio for each country's optimized portfolio. This metric reveals how much return an investor earns per unit of volatility. Nigeria achieved the highest Sharpe Ratio (~0.47), confirming that its high-return portfolio also delivers strong compensation for risk. Kenya, South Africa, and Egypt followed closely, each showcasing a balance between reward and stability. Tunisia and Morocco posted the lowest Sharpe Ratios. This analysis demonstrates that risk alone does not dictate strategy the reward must be sufficient to justify it. High-risk portfolios must be efficient, while low-risk portfolios must be re-engineered to improve real return potential.

- **Mean-Variance Optimized asset allocation**

This chart illustrates the average optimal asset allocation resulting from a Mean-Variance Optimization (MVO) strategy applied across six African economies: Tunisia, Morocco, Egypt, South Africa, Nigeria, and Kenya. The goal of MVO is

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to maximize the Sharpe Ratio, ensuring the highest expected return for a given level of risk. This aggregated chart represents the central tendency of optimal portfolio structures, highlighting which asset classes offer the most strategic value across diverse inflationary and macroeconomic contexts.

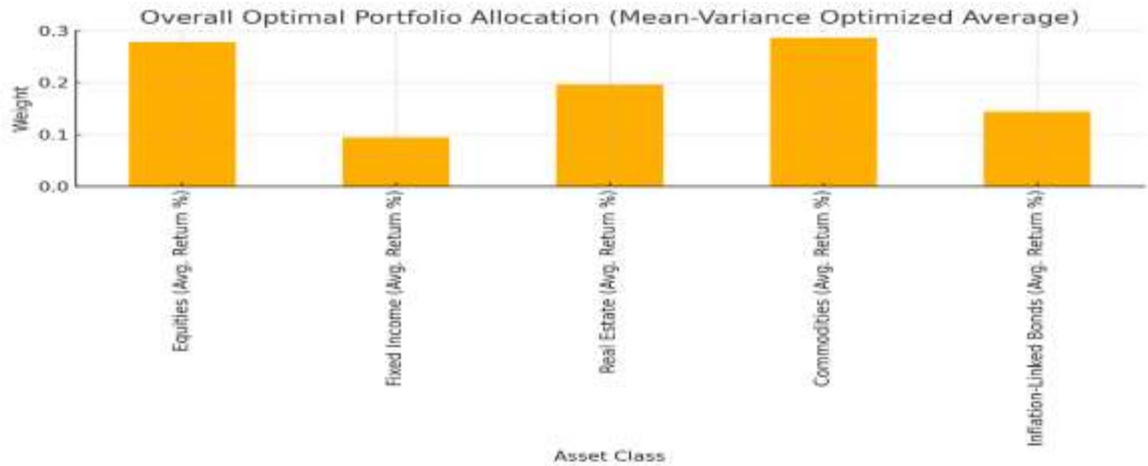

Figure 6: Mean-Variance Optimized asset allocation.

By averaging the optimal weights across all countries, we identified a regional benchmark portfolio structure optimized for inflation protection and long-term growth. The resulting allocation is both intuitive and empirically sound:

- Equities (~28.5%) and Commodities (~28.6%) form the core growth engine.
- Real Estate (~19.6%) adds income stability and inflation defense.
- Inflation-Linked Bonds (~14.4%) serve as a capital preservation buffer.

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- Fixed Income (~9.4%) plays a minimal role due to its limited inflation resilience.

This portfolio structure represents a paradigm shift away from traditional bond-heavy retirement portfolios. Instead, it embodies a forward-looking, inflation-aware allocation—suited to the demographic and macroeconomic realities of African economies.

6. Monte Carlo simulation results

To deepen our understanding of how different retirement portfolio strategies perform under uncertainty, we employed Monte Carlo simulations a stochastic modeling technique widely used in finance to estimate the probability distribution of potential outcomes. In this study, we conducted 1,000 simulations over a 10-year horizon to evaluate the behavior of mean-variance optimized portfolios under different economic and inflationary conditions across six African countries: Tunisia, Morocco, Egypt, South Africa, Nigeria, and Kenya. Monte Carlo simulations account for random variations in returns, compounding effects, and volatility, allowing us to evaluate not only average outcomes but also the full spectrum of possible trajectories, from downside risk to growth potential. This section explores three key outputs: median growth paths, confidence bands, and the distribution of final portfolio values.

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6.1Asset allocation performance distribution

The first chart presents the median portfolio growth path—that is, the 50th percentile of all simulated outcomes over the 10-year investment horizon for each country's optimized portfolio. These paths are indexed to a starting value of 1.0, ensuring a level playing field for cross-country comparison. The results offer profound insight into the most likely investment journey for a retiree in each country, assuming a disciplined, MVO-based allocation strategy is followed without deviation.

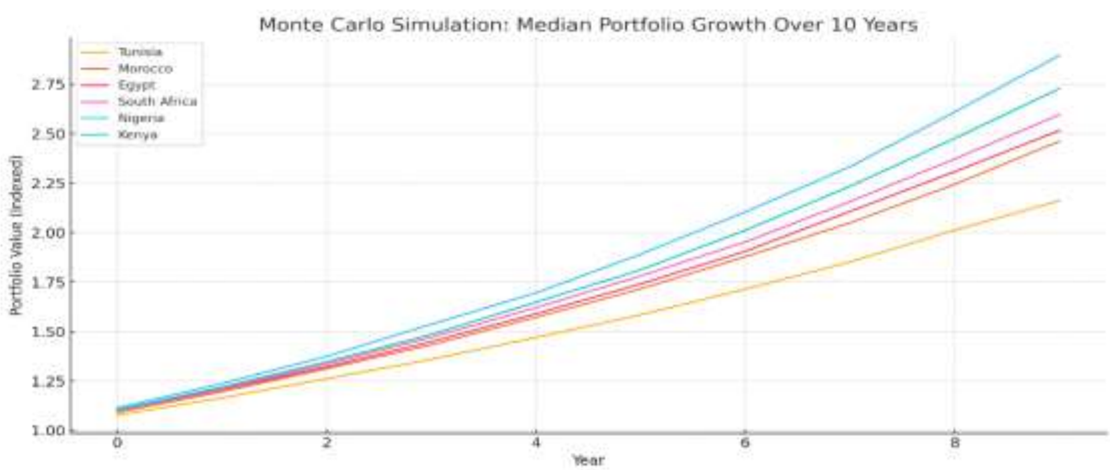

Figure 7: Asset allocation performance distribution

Among all countries, Nigeria's median path rises the steepest, underscoring its remarkable long-term growth potential. This performance is driven by its high allocations to equities and commodities, two asset classes known for strong compounding but also greater volatility. Kenya closely follows, showcasing a

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similarly robust trajectory supported by a slightly more balanced allocation that includes real estate and inflation-linked bonds alongside growth assets.

In contrast, Tunisia and Morocco exhibit flatter growth curves, indicating more conservative profiles. These portfolios are characterized by heavier weightings in fixed income and inflation-linked bonds assets that prioritize capital preservation over return maximization. South Africa and Egypt occupy the middle ground, showing stable and consistent compounding. These countries' simulations demonstrate that well-diversified portfolios can maintain steady momentum even without taking on excessive risk.

6.2 Confidence bands (5th to 95th Percentile)

The second simulation output visualizes the uncertainty range surrounding each portfolio by plotting the 5th and 95th percentiles of the simulated returns forming shaded bands that encapsulate 90% of potential outcomes. These confidence bands serve as a visual envelope of risk, illustrating how wide or narrow a portfolio's future path could be based on its underlying volatility and return structure.

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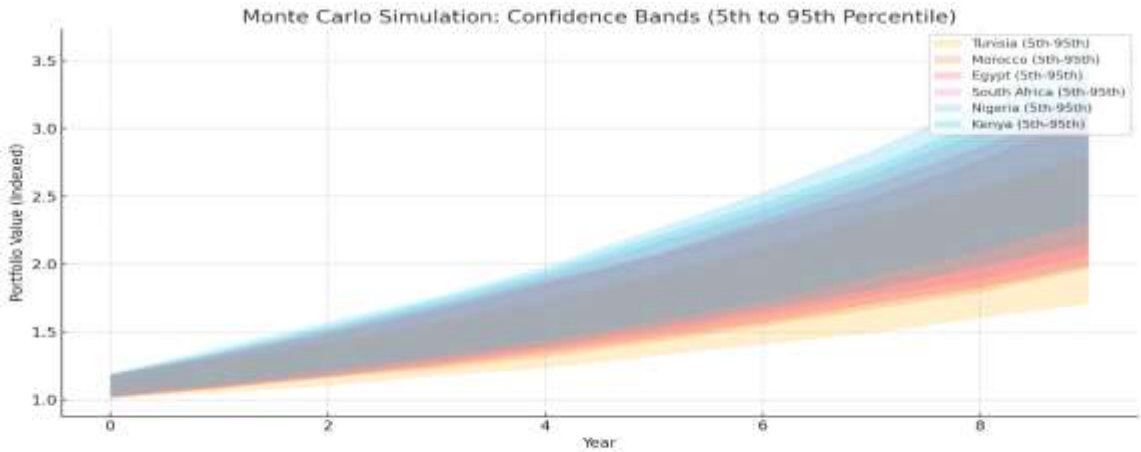

Figure 8: Asset allocation performance distribution

Again, Nigeria stands out with the widest confidence band, reflecting both its high upside and high risk. Its returns could potentially grow the portfolio by over 3.6x over ten years, but it also exposes investors to wider performance variability. This underscores the importance of risk-mitigation tools such as rebalancing and downside protection when pursuing aggressive growth strategies.

Kenya’s band, while still broad, is slightly more contained. Its portfolio maintains high return expectations with less exposure to tail risk, likely due to a diversified mix that includes a larger share of stabilizing assets. On the other hand, South Africa and Egypt show moderate-width bands with smooth contours, these portfolios are clearly engineered for predictability and consistency, with well-diversified structures that minimize the chance of significant underperformance. By contrast, Morocco and Tunisia display the narrowest bands, reflecting

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conservative asset mixes with limited deviation from expected outcomes, while this makes them highly predictable and suitable for risk-averse investors, their restricted upside potential limits wealth accumulation in real terms.

6.3Distribution of final asset values after 10 Years

The final Monte Carlo output aggregates the simulation results into a probability distribution of final portfolio values. This histogram-style visualization offers a snapshot of where each country's portfolio is most likely to end up after 10 years, showcasing both the frequency and magnitude of possible outcomes.

Figure 9: Distribution of final asset values after 10 Years

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In this analysis, Nigeria once again leads, with the most right-skewed distribution. Its portfolio not only delivers the highest average final value (~2.94x initial capital) but also a higher probability of outperforming the median. This suggests a favorable risk-reward asymmetry, albeit with broader variance.

Kenya’s distribution follows a similar shape, slightly more symmetrical, indicating less extreme dispersion while maintaining high performance. Both countries demonstrate that strategic exposure to growth and inflation-hedged assets can deliver strong outcomes, provided investors are prepared for higher volatility. South Africa and Egypt, with more balanced portfolios, show bell-shaped distributions centered around ~2.6x and ~2.5x final value respectively. These countries exemplify stable long-term growth, making them ideal for portfolios that aim to balance return generation and capital preservation.

Meanwhile, Morocco and Tunisia exhibit compressed distributions, with final values clustering around 2.4x and 2.2x, respectively. These results reflect a lower-growth strategy that prioritizes risk minimization over wealth expansion, suitable for ultra-conservative investors or near-retirement capital protection strategies.

7. Strategic insights for pension fund reorienting

The findings of this study confirm that traditional pension funds in Africa struggle to maintain purchasing power due to their over-reliance on fixed-income securities, which consistently underperform in high-inflation environments. The structural

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weakness of these portfolios stems from their susceptibility to inflation-induced depreciation, as bonds and treasury securities often fail to generate real positive returns when inflation rates surge. Given the persistent inflationary pressures affecting African economies, pension funds must adopt more resilient investment strategies to safeguard retirees' wealth.

7.1 Inflation-protection strategies for African pension funds

A key approach to improving pension fund performance is increasing allocations to inflation-hedging assets. Commodities such as gold and oil have historically served as strong inflationary hedges, offering protection against currency depreciation and rising consumer prices. Similarly, real estate investments provide long-term capital appreciation and rental income, which tend to rise in tandem with inflation. Inflation-linked bonds (ILBs), where available, offer a direct hedge by adjusting interest payments in line with inflation indices.

While bonds and treasury bills provide nominal stability, they expose retirees to substantial real losses during inflationary periods. Instead, pension funds should balance their portfolios by incorporating growth assets such as equities and infrastructure investments, which have historically delivered higher long-term returns and greater resilience against inflation shocks. By adopting dynamic rebalancing strategies, pension funds can adjust asset allocations based on inflation forecasts, macroeconomic trends, and changing market conditions, ensuring that portfolios remain aligned with evolving economic realities.

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7.2The Role of Alternative Investments in Portfolio Resilience

The inclusion of alternative investments is another critical factor in enhancing the resilience of pension funds. Traditional asset classes often fall short in providing adequate diversification and inflation protection, particularly in emerging economies with volatile market conditions. Private equity investments provide access to high-growth businesses and industries that may not be available in public markets. In Africa, sectors such as technology, renewable energy, and consumer goods have demonstrated strong long-term growth potential, making them viable options for pension fund diversification. Infrastructure investments, including transportation, energy, and utilities, offer an additional avenue for inflation protection, as these assets generate revenue streams that are often inflation-linked, particularly in public-private partnerships.

Many alternative assets, such as infrastructure projects and private equity funds, have longer investment horizons and limited secondary market liquidity, making them less accessible for pension funds that require regular capital rebalancing. To address this issue, structured allocations to alternative assets should be carefully managed to balance long-term growth potential with the need for portfolio liquidity. Additionally, regulatory adjustments may be necessary to facilitate pension fund participation in alternative asset markets, ensuring that these investments contribute to overall portfolio stability rather than introducing excessive risk.

To enhance the inflation resilience of pension funds across Africa, policymakers should prioritize the development of regional ILB markets to support economies without domestic issuance. Additionally, regulatory frameworks must become more flexible, allowing pension funds greater exposure to real assets and alternative instruments. Finally, fintech integration should be accelerated to enable dynamic portfolio rebalancing, automated risk-adjusted strategies, and improved access to inflation-protected securities. By implementing these reforms, African pension systems will be better positioned to generate sustainable real returns and ensure long-term financial security for their retirees despite persistent inflationary pressures.

8. Conclusion

This study has delivered a comprehensive, empirically grounded exploration into how African pension funds can adapt their asset allocation strategies to protect retirement savings from the corrosive effects of inflation. Using a dual-framework approach combining Mean-Variance Optimization (MVO) with Monte Carlo Simulations (MCS) we demonstrated that traditional portfolio models, which lean heavily on nominal fixed-income instruments, consistently fail to deliver real returns in inflationary environments. The resulting erosion of purchasing power poses serious long-term risks for retirees, particularly in economies already grappling with macroeconomic instability.

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In contrast, portfolios designed with inflation resilience at their core featuring diversified allocations to equities, real estate, commodities, and inflation-linked securities achieve superior real returns, improved Sharpe ratios, and greater downside protection across varying inflation regimes. This trend holds true across all six countries studied (Tunisia, South Africa, Morocco, Nigeria, Egypt, and Kenya) regardless of differences in regulatory maturity or economic structure.

The South African case stands out as a model of effective portfolio design and institutional support. Its well-developed capital markets and functioning inflation-linked bond (ILB) ecosystem enable pension funds to deploy more sophisticated and protective investment strategies. Conversely, pension systems in countries such as Egypt and Nigeria remain constrained by rigid regulatory mandates, shallow ILB markets, and limited diversification tools factors that exacerbate portfolio fragility during inflationary surges.

A reorientation of pension fund strategy must include:

- Relaxing fixed-income mandates to allow greater exposure to equities, real assets, and alternatives.
- Establishing or expanding ILB markets to give funds direct tools for inflation hedging.
- Encouraging investment in real estate, REITs, and infrastructure, which can provide both growth and inflation protection.

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- Easing cross-border investment restrictions, enabling regional and global diversification.
- Investing in governance capacity, financial literacy, and market data infrastructure to improve decision-making and risk oversight.

As inflation continues to be driven by currency depreciation, global commodity shocks, and persistent supply-side constraints, pension systems that fail to evolve risk placing millions of retirees in financial jeopardy. More broadly, poorly performing pension systems may also increase pressure on public finances, heighten inequality, and undermine the social contract in aging African societies.

This research concludes that a modern, adaptive, and inflation-aware investment strategy is no longer optional it is a fundamental necessity. The success of African pension systems over the next two decades will depend not just on returns, but on resilience, flexibility, and the strategic embrace of innovation and diversification.

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