Can gold benefit traditional investment portfolios? Empirical Determination of the Optimal Gold Allocation in Globally Diversified Equity Portfolios

A Fifteen-Year Markowitz Analysis (2010–2025)

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Abstract

This paper investigates the empirically optimal gold allocation within a globally diversified equity portfolio over the sixteen-and-a-half-year period January 2010 to June 2026. Using daily total-return data for EUNL.DE (iShares Core MSCI World UCITS ETF, denominated in EUR; iShares, 2025) and gold priced in EUR (derived from the XAU/USD spot price converted at daily EUR/USD spot rates), a rolling Markowitz mean-variance optimisation is applied across 70 rolling five-year windows (two-month step, start dates January 2010 to July 2021). The central empirical finding distinguishes gold fundamentally from Bitcoin and most other diversifying assets: over the full sample period, gold and global equities exhibit a near-zero, slightly negative correlation ($\rho = -0.0174$), implying that gold lowers absolute portfolio volatility at every tested allocation level from 0 to 30 per cent. The variance-minimising portfolio is achieved at approximately 39 per cent gold, a considerably higher weight than intuition would suggest.

Across all 70 rolling windows, the mean Sharpe-ratio-maximising gold weight is 34.76 per cent (median: 39 per cent). A material recency bias is documented: windows commencing before January 2015 yield a mean optimal weight of 7.9 per cent, whereas windows commencing from January 2015 onwards yield 54.9 per cent, reflecting the extraordinary gold bull market of 2020–2026. Adding 10 per cent gold

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to a pure equity portfolio improved the Sharpe ratio in 53 of 70 windows (75.7 per cent hit rate), with a mean improvement of 0.044 Sharpe units.

A Minimum Variance Portfolio (MVP) analysis across four investor types — Defensive (20% equity / 80% money market), Balanced (40%/60%), Growth-Oriented (60%/40%), and Aggressive (80%/20%) — reveals a robust monotonic relationship: the higher the equity allocation, the greater the MVP gold weight. The analytical MVP ranges from 2.7% (Defensive) to 29.1% (Aggressive). For the Aggressive investor, the analytical MVP is cross-validated by the rolling-window empirical mean of 34.76%, providing exceptional robustness.

The paper concludes that a strategic gold allocation of 5–15 per cent is appropriate for most equity-oriented investors, rising to 20–40 per cent for aggressive investors. Investors are cautioned against chasing recent optimisation results inflated by the post-2020 gold boom and against excessive exposure at prevailing elevated price levels in 2025–2026, which exhibit multiple characteristics of speculative excess.

Keywords: Gold · Portfolio Optimisation · Markowitz · Mean-Variance · Safe Haven · MSCI World · Diversification · Real Interest Rates · Central Bank Demand · Derivatives · ESG

JEL Classification: G11, G12, G15, G17, Q02

Non-Technical Summary

Gold has served humanity as money, jewellery, and store of value for more than 5,000 years. The question addressed in this paper is more specific: how much gold, if any, should an investor who already holds a globally diversified equity portfolio add to improve risk-adjusted returns?

This paper examines sixteen and a half years of monthly return data (2010–2026) and finds that gold is almost uncorrelated with global equities. This seemingly unremarkable fact has a powerful portfolio consequence: adding gold to an equity portfolio consistently reduces the portfolio's total risk without sacrificing proportional return. In 76 out of every 100 five-year periods tested, a 10 per cent gold allocation improved the Sharpe ratio — the standard measure of return per unit of risk.

The practical gold allocation depends critically on the investor's full portfolio composition. An Aggressive investor (80% equity / 20% money market) should target 20–30% gold — the analytical MVP is 29.1%, close to the rolling-window mean. A Growth-Oriented investor (60%/40%) should target 15–25% (MVP: 18.9%). A Balanced investor (40%/60%) should target 8–15% (MVP: 9.6%). A Defensive investor (20%/80%) needs only 0–5% (MVP: 2.7%), as gold's high standalone volatility is counterproductive in an already low-risk portfolio.

However, investors should approach current gold prices (around USD 4,000 per troy ounce at the time of writing, end-June 2026, after an all-time high above USD 5,000 in late January 2026) with caution despite the recent correction. The speculative positioning in gold derivatives has reached record levels, BIS has flagged bubble-like characteristics, and recent optimisation results are materially inflated by the extraordinary 2020–2026 gold rally. A long-term strategic allocation, implemented gradually and reviewed annually, is recommended rather than a tactical lump-sum purchase at current prices.

Contents

1 Introduction

Few questions in private wealth management are posed as frequently — and answered as vaguely — as the question of how much gold a diversified portfolio should hold. The extraordinary gold bull market of 2020–2026, record central bank purchases following the freezing of Russian currency reserves in February 2022, and an all-time high of USD 5,399 per troy ounce in January 2026 have lent this question renewed urgency. After the correction of recent weeks to around USD 4,000 per troy ounce — roughly 26 per cent below the all-time high — gold now appears cheaper again, making the question of how much gold different investor types should add all the more pressing. The conventional practitioner guidance of "5 to 10 per cent" is widely repeated, yet rarely derived from a transparent, replicable empirical procedure.

This paper closes that gap for the euro-based investor. It determines the empirically optimal gold allocation within a globally diversified equity portfolio over the sixteen-and-a-half-year period January 2010 to June 2026, using daily data for the iShares Core MSCI World UCITS ETF (EUNL.DE) as the equity benchmark and gold priced in euro (XAU/EUR), constructed from the XAU/USD spot price (LSEG) converted at daily EUR/USD spot rates. The analytical framework is the classical Markowitz mean-variance optimisation, applied both to the full 198-month sample and to 70 rolling five-year windows advancing in two-month steps.

Three empirical questions guide the analysis. First, what gold weight maximises the risk-adjusted return (Sharpe ratio) of a global equity portfolio, and how stable is this weight over time? Second, how much portfolio volatility does a given gold allocation remove — including under stressed correlation assumptions? Third, how does the optimal allocation vary across investor types with different strategic equity exposures, from defensive to aggressive mandates?

The central findings can be stated succinctly. Gold and global equities are essentially uncorrelated over the sample ($\rho = -0.0174$; $\beta = -0.022$; $R^2 = 0.03$ per cent), so every gold allocation between 0 and 30 per cent lowers absolute portfolio volatility. The mean Sharpe-maximising gold weight across the 70 rolling windows is 34.76 per cent, and a fixed 10 per cent allocation improved the Sharpe ratio in 53 of 70 windows (75.7 per cent hit rate). A minimum variance portfolio analysis across four investor types yields analytical gold weights rising monotonically from 3.6 per cent (Defensive, 20/80) to 29.1 per cent (Aggressive, 80/20). At the same time, a material recency bias is documented: windows commencing from January 2015 onwards — dominated by the 2020–2026 bull market — imply roughly two and a half times the optimal weight of earlier windows, counselling caution against extrapolating recent results.

The contribution of the paper is therefore twofold: a transparent, fully replicable empirical derivation of optimal gold weights for euro-denominated portfolios, and a translation of these results into practical allocation ranges by investor type — 5 to 15 per cent for most equity-oriented investors, rising to 20 to 40 per cent for aggressive mandates — tempered by an explicit assessment of the speculative characteristics of the 2025–2026 gold market.

The paper is structured as follows. Chapter 1 (the present chapter) serves as the introduction and frames the research question. Chapter 2 traces gold's monetary history from Lydian coinage through the classical gold standard and Bretton Woods to the post-1971 floating-rate market. Chapter 3 examines gold as an asset class: supply and demand, the LBMA market structure, and the spectrum of investment instruments. Chapter 4 develops the real interest rate transmission mechanism, including the EUR/USD currency overlay. Chapter 5 documents the structural shift in central bank demand since 2022, and Chapter 6 analyses the derivatives markets and speculative positioning, including the extraordinary call option episode of 2025–2026. Chapter 7 establishes the portfolio-theoretic case for gold. Chapter 8 describes the data and methodology. Chapters 9 and 10 present the empirical results: full-period parameters, the variance decomposition, and the rolling window optimisation. Chapter 11 derives minimum variance gold allocations for four investor types. Chapter 12 addresses risks, ESG, and currency hedging. Chapter 13 concludes with a synthesis of the results, practical recommendations by investor type, and limitations and outlook.

2 Gold as Money, Medium of Exchange, and Store of Value: A Historical Perspective

Gold's monetary role is not a modern convention. Across thousands of years and dozens of civilisations, gold has repeatedly been selected — through a competitive, decentralised process — as the preferred medium of exchange, unit of account, and store of wealth. Understanding why requires a brief excursion into economic history.

2.1 Origins: From Adornment to Currency

The earliest documented use of gold dates to Egypt around 3,100 BC, where gold was fashioned into jewellery and burial artefacts. By 2,600 BC, Sumerian craftsmen in Mesopotamia were casting gold into standardised weights for use in trade. Gold's physical properties — chemical inertness, malleability, scarcity relative to base metals, and unmistakable lustre — made it ideal as a store of value long before the concept of coinage was formalised.

As documented by Bernstein (2000), the first standardised gold coins — with known weight and purity guaranteed by a sovereign authority — are attributed to the Kingdom of Lydia (present-day western Turkey) around 610–560 BC under Kings Alyattes and Croesus. The Lydian stater, struck in electrum (a natural gold-silver alloy), enabled arms-length trade without the need to weigh metal at each transaction. Alexander the Great melted enormous quantities of Persian gold reserves into his own Macedonian coinage, monetising the conquest of the East. Rome's gold aureus, introduced under Julius Caesar at roughly 8 grammes, became the monetary anchor of the Roman Empire for four centuries.

2.2 Medieval and Renaissance Gold Standards

Following the collapse of the Western Roman Empire, the Byzantine solidus carried the Roman gold tradition through the Eastern Empire until 1453. In the West, gold resurfaced commercially in 13th-century Italy: the Florentine florin (minted from 1252 at 3.537 grammes of 24-carat gold) became the first widely accepted international currency of medieval Europe. The Venetian ducat (first struck 1284) followed, and these two coins anchored European trade finance for nearly two centuries.

The discovery of the Americas from 1492 onwards unleashed a torrent of New World gold and silver into Europe, producing the "Price Revolution" — inflation rates of 1–1.5 per cent per annum sustained over a century. Even this sustained monetary expansion merely doubled price levels over 100 years; modern central bank balance-sheet expansions have achieved comparable effects in a single decade.

2.3 The Classical Gold Standard (1870–1914)

The classical gold standard emerged in the 19th century as a multilateral monetary system in which national currencies were defined as fixed weights of gold, and central banks stood ready to exchange notes for gold on demand. Britain anchored the system through the Bank Charter Act of 1844; Germany adopted gold in 1871; the United States followed formally with the Gold Standard Act of 1900. The era is associated with remarkable monetary stability: price levels in Britain in 1914 were roughly equal to those in 1870. For a comprehensive economic history of the gold standard and its collapse, see Eichengreen (1992) and Bordo and Eichengreen (1993). For a comprehensive economic history of the gold standard and its collapse, see Eichengreen (1992) and Bordo and Eichengreen (1993). The mechanism was self-correcting via the price-specie flow model of Hume (1752).

2.4 Bretton Woods and the Nixon Shock

The Bretton Woods Conference of 1944 constructed a post-war system: major currencies were pegged to the US dollar, which alone maintained gold convertibility at USD 35 per troy ounce. On 15 August 1971, President Nixon "temporarily" suspended dollar-gold convertibility — the so-called Nixon Shock. The temporary suspension became permanent. By 1973, the major currencies floated freely; gold began trading at market prices, surging from USD 35 to USD 850 per ounce by January 1980.

2.5 The Modern Gold Market: 1971 to Present

Since the end of Bretton Woods, gold's price history divides into three broad phases: the inflationary surge of the 1970s (USD 35 → USD 850), the secular bear market of the 1980s and 1990s (USD 850 → USD 250), and the structural bull market from 2001 to the present (USD 250 → USD 4,000+). From January 2010 to June 2026 — the sample period of this paper — gold rose from approximately 780 euro to around 3,500 euro, delivering a compound annual return of 9.57 per cent per annum in EUR terms.

Figure 1 charts the nominal USD gold price from 1975 to 2026. The chart illustrates three structural epochs: the inflation-driven spike and collapse of 1980, the secular bear market of 1981–2001, and two successive multi-decade bull markets culminating in the January 2026 all-time high above 5,000 US dollars per troy ounce.

Figure 1: Gold price history in USD per troy ounce, 1975–2026. The vertical dashed line marks August 1971 (Nixon Shock / end of Bretton Woods).
Source: COMEX (CME Group), Refinitiv.

3 Gold as an Asset Class: Properties, Supply, and Market Structure

3.1 Economic Properties of Gold

Unlike equities, bonds, or real estate, gold generates no cash flows. Its total return consists entirely of price appreciation plus any storage costs subtracted. Gold's four defining monetary properties — durability, divisibility, portability, and scarcity — explain its historical primacy as money and its modern investment appeal. Above-ground stocks estimated at approximately 215,000 tonnes represent accumulated human mining output since antiquity; virtually none is destroyed through consumption.

As an investable asset, gold has three important supply-side characteristics: annual mine production of approximately 3,300–3,500 tonnes (United States Geological Survey, 2025) represents only 1.5–1.6 per cent of above-ground stocks, implying inelastic supply; demand is diverse and multi-regional, providing some demand-side stability; and gold is priced globally in US dollars, introducing currency risk for EUR-denominated investors — an aspect addressed in Chapter 4.

3.2 Global Supply and Demand

The World Gold Council (WGC) estimates global gold demand at approximately 4,500 tonnes per annum, decomposed as follows (World Gold Council, 2025):

Table 1 breaks down estimated annual demand by segment, illustrating the diversity of gold's end-markets and the rising share of investment demand in recent years.

Table 1: Average annual global gold demand by segment, 2020–2024

Demand Segment	**Avg. Annual Tonnage (2020–2024)**	**Share**
Jewellery fabrication	2,100	47%
Investment (bars, coins, ETFs)	1,050	23%
Central bank purchases	975	22%
Technology / industrial	340	8%
Total demand	˜4,465	100%

Source: Own presentation based on data from World Gold Council Gold Demand Trends (2025).

3.3 The London Bullion Market Association (LBMA)

Physical gold trading is primarily intermediated through the London Bullion Market (LBM), overseen by the LBMA. The LBMA Good Delivery List specifies internationally tradable gold bars (400 troy ounces, minimum 99.5% purity) (LBMA, 2025). The LBMA Gold Price — a twice-daily electronic auction by ICE Benchmark Administration — is the global benchmark used in physical contracts, mining offtake agreements, and financial derivatives (ICE Benchmark Administration, 2025). Daily OTC volumes are estimated at USD 60–70 billion, dwarfing exchange-traded volumes. The Responsible Gold Guidance (RGG) establishes due diligence standards for supply chain integrity, increasingly required under institutional ESG mandates.

3.4 Investment Instruments

Retail and institutional investors can access gold through several instrument categories, each with distinct risk, cost, and custody characteristics:

Table 2 provides a comparative overview of the principal investment vehicles, ranked by accessibility and liquidity; the choice of instrument has significant implications for cost and settlement risk.

Table 2: Overview of primary gold investment instruments

Instrument	Examples	Annual Cost	Key Features
Physical bars & coins	Wiener Philharmoniker, Krugerrand, LBMA bars	0.1–0.3% storage	Direct ownership; zero counterparty risk; illiquid
Exchange-traded commodities (ETCs)	Xetra-Gold, SPDR GLD, iShares IAU	0.09–0.40% TER	Exchange-traded; physically backed; high liquidity
Gold futures (COMEX)	GC contract (100 troy oz)	Roll cost + commission	High leverage; rollover risk; institutional use
Gold certificates	Vontobel, HSBC, Commerzbank	Spread + issuer margin	Unsecured issuer credit risk; retail-friendly
Mining equities / ETFs	VanEck GDX, GDXJ	0.51–0.60% TER	Leveraged gold exposure (~2×); operational & political risk

Notes: AT = Austria, DE = Germany. TER = Total Expense Ratio.
Source: Own compilation, including details of issuers and providers, as at mid-2026.

For European retail investors, physical gold coins are popular due to the VAT-exemption for investment gold under EU Directive 2006/112/EC (European Commission, 2006). The individual tax treatment of gold investments is beyond the scope of this paper.

4 The Real Interest Rate Transmission Mechanism

4.1 The Opportunity Cost Argument

The most powerful single explanatory variable for medium-term gold price movements is the real interest rate — specifically, the broader inflation hedge literature also supports gold (Gosh et al., 2004), the yield on US Treasury Inflation-Protected Securities (TIPS). Gold produces no yield; its total return consists entirely of price change minus storage costs. Consequently, holding gold involves an opportunity cost equal to the real interest rate forgone on an alternative risk-free investment. When real rates are positive and rising, gold's opportunity cost increases, reducing demand. When real rates are negative or falling, gold's relative attractiveness increases. The empirical literature confirms this inverse relationship across horizons from one to twenty years; see also Reboredo (2013) for the dollar channel and Pukthuanthong and Roll (2011) for currency effects.

Formally, in a Hotelling-type framework (Hotelling, 1931), the equilibrium gold price P^* must satisfy the no-arbitrage condition in Equation (1), where r denotes the real interest rate:

$$\frac{dP^*}{dt} = r \cdot P^* \tag{1}$$

This implies that gold must appreciate at the real rate to remain competitive with TIPS. When $r < 0$ (as in 2011–2013 and 2020–2022), gold's insurance and safe-haven properties support demand beyond the pure carry calculation (Erb and Harvey, 2013).

4.2 Empirical Evidence

The empirical literature consistently confirms the inverse gold-real rate relationship. Erb and Harvey (2013) document that gold spot prices are negatively and significantly correlated with TIPS yields over all horizons from one to twenty years. Over the sample period (2010–2025), three sub-periods are instructive: during 2019–2022, COVID-19 emergency monetary policy drove US real rates to −1.0 per cent or lower; gold surged from 1,400 US dollars to 2,070 US dollars (+48%). The 2022–2024 tightening cycle pushed real rates above +2.0 per cent; theoretically this should have suppressed gold, but structural central bank demand offset the adverse effect. From late 2024 through mid-2026, renewed dollar weakness and geopolitical safe-haven demand propelled gold to above 5,000 US dollars.

4.3 Currency Dynamics and the EUR/USD Effect

Gold is priced globally in US dollars. For EUR-denominated investors, the EUR/USD exchange rate introduces an additional return component. Over the sample period, the EUR/USD moved from approximately 1.44 in January 2010 to 1.14 in June 2026 — a dollar appreciation of approximately 21 per cent. This dollar strengthening mechanically depressed EUR-denominated gold returns relative to USD terms. The empirical results use gold priced in EUR throughout (XAU/EUR = GC continuous futures / EUR/USD spot), ensuring all estimates are relevant to EUR-denominated investors. At current interest rate differentials of approximately 100–200 basis points between the US and Eurozone, a fully hedged EUR gold position pays the differential as a drag — approximately 1–2 per cent per annum.

5 Central Bank Demand and Geopolitical Drivers

5.1 The Structural Shift in Central Bank Buying

Central banks had been net sellers of gold for most of the 1990s and 2000s: European central banks divested substantial reserves under the Central Bank Gold Agreement (CBGA). The decisive inflection came in February 2022 when Western powers froze approximately 300 billion US dollars in Russian central bank foreign exchange reserves following Russia's invasion of Ukraine. This unprecedented act of financial statecraft — of a type documented historically by Reinhart and Rogoff (2009) — demonstrated to every non-Western central bank that foreign exchange reserves held in dollars, euros, or sterling are subject to geopolitical risk from the reserve-currency issuer. Gold, held in domestic vaults, is immune to such freezes.

Central bank gold purchases accelerated sharply: net purchases reached 1,082 tonnes in 2022 (a record since 1950), 1,049 tonnes in 2023, and 1,136 tonnes in 2024, compared with average annual net purchases of approximately 400–500 tonnes in 2010–2021. The primary buyers have been the People's Bank of China, the Reserve Bank of India, the National Bank of Poland, the Central Bank of Turkey, and several Gulf central banks. This non-price-elastic demand is qualitatively different from jewellery or retail investment demand, both of which are highly price-sensitive.

5.2 De-Dollarisation and the Multipolar Monetary Order

Central bank gold buying must be understood in the broader context of gradual de-dollarisation. The dollar still accounts for approximately 58 per cent of global foreign exchange reserves (down from 71 per cent in 2001) (International Monetary Fund, 2025), but the trend is unmistakably toward diversification. Gold, as the one reserve asset without issuer risk, is the natural beneficiary. BIS data show that non-Western central banks have substantially reduced dollar-denominated bond holdings since 2022 (BIS, 2024) and increased gold as a percentage of total reserves.

5.3 Geopolitical Risk Premium

Beyond central bank demand, gold carries a geopolitical risk premium that increases during periods of elevated systemic uncertainty. Baur and McDermott (2010) established that gold acts as a safe haven — its correlation with equities becomes significantly negative during periods of extreme equity market stress. The ongoing Russia-Ukraine conflict, Middle East tensions, and US-China trade and technology rivalry have all contributed to an elevated geopolitical risk premium since 2022. The GPR (Geopolitical Risk) index of Caldara and Iacoviello (Caldara and Iacoviello, 2022) shows sustained elevated readings from 2022 through the sample period end.

6 Derivatives, Futures, and Speculative Positioning

6.1 The COMEX Futures Market

The COMEX gold futures contract (ticker: GC) represents 100 troy ounces of gold and is the world's most liquid gold price discovery vehicle (CME Group, 2025). Daily open interest regularly exceeds 500,000 contracts (equivalent to approximately 1,555 tonnes, worth approximately 200 billion US dollars at 4,000 US dollars/oz). The CFTC publishes weekly Commitments of Traders (COT) data for three participant categories: commercial hedgers, non-commercial traders (speculators), and non-reportable positions (CFTC, 2026).

COT data for gold in early 2026 revealed non-commercial net long positions reaching a record 78 billion US dollars in notional value (CFTC, 2026). This represents an extreme concentration of speculative positioning historically preceding sharp corrections: comparable positioning peaks occurred in September 2011 (before a 45 per cent correction) and August 2020 (before a 15 per cent correction).

6.2 Call Option Positioning in 2025–2026: An Extraordinary Episode

The most striking development in gold derivatives markets has been the extraordinary accumulation of far out-of-the-money call options with strikes of 10,000 US dollars, 15,000 US dollars, and 20,000 US dollars per troy ounce, expiring in December 2025 and December 2026. These contracts represent an asymmetric bet on a catastrophic dollar debasement scenario or a gold price target approximately three to five times current spot levels. The existence of liquid bid-ask spreads for 10,000 US dollar strike options is remarkable in itself, reflecting genuine demand from institutional buyers. This author estimated open interest in calls with strikes above 5,000 US dollars at several hundred thousand contracts, representing notional exposure in excess of 200 billion US dollars (Rupprechter, 2026).

6.3 The Kevin Warsh Event

On 12 February 2026, Bloomberg reported that Kevin Warsh — a leading candidate for Federal Reserve Chair — had advocated for a return to a gold-price anchor for monetary policy. Gold initially surged to approximately 3,450 US dollars intraday. Following Federal Reserve and White House clarifications, gold sold off approximately 9 per cent in three trading sessions to 3,130 US dollars before recovering. The episode illustrates two points: gold is sensitive to monetary policy regime expectations in a highly non-linear fashion, and derivative markets amplify volatility via forced liquidation cascades (Rupprechter, 2026).

6.4 Warning Signs and Risk Assessment

The Bank for International Settlements (BIS) Annual Economic Report 2025 included an extended discussion of asset markets showing "prolonged bubble characteristics", explicitly citing gold (BIS, 2025). Technical indicators as of June 2026 include: COMEX open interest at a 5-year high; CFTC net speculative long positions above the 95th historical percentile; the gold-to-M2 ratio at levels comparable to the 1980 peak; and the gold-to-oil ratio at approximately 34 (versus a 50-year average of approximately 16). Collectively, these suggest the risk-return profile for new gold investments at current prices is substantially less favourable than the long-run empirical evidence indicates. Gradual cost-averaging over 12–24 months is preferred over lump-sum investment.

7 Portfolio Theory and the Case for Gold

7.1 The Markowitz Framework

The theoretical foundation for this paper's empirical analysis is Markowitz's mean-variance optimisation (MVO), introduced in the seminal 1952 paper "Portfolio Selection" (Markowitz, 1952). In the Markowitz framework, investors choose portfolios that maximise expected return for a given level of variance. For a two-asset portfolio of gold (weight w) and equities (weight 1—w), Equations (2) and (3) apply:

$$\mu_p = w \cdot \mu_G + (1 - w) \cdot \mu_E \tag{2}$$

$$\sigma_p^2 = w^2\sigma_G^2 + (1 - w)^2\sigma_E^2 + 2w(1 - w)\rho\sigma_G\sigma_E \tag{3}$$

where μ denotes expected return, σ denotes standard deviation, and ρ denotes the Pearson correlation. The Sharpe ratio S (Sharpe, 1966), maximised over w, identifies the tangency portfolio as given in Equation (4):

$$S = \frac{\mu_p - r_f}{\sigma_p} \tag{4}$$

7.2 Why Gold's Near-Zero Correlation Is Remarkable

The vast majority of global assets exhibit positive unconditional correlations — a fact well-established by Tobin (1958) and formalised in the Capital Asset Pricing Model by Jensen (1968) and Black, Jensen and Scholes (1972) — — a fact well-established by Tobin (1958) and formalised in the Capital Asset Pricing Model by Jensen (1968) and Black, Jensen and Scholes (1972) — with a globally diversified equity index. During risk-off episodes, correlations across risky assets increase sharply ("correlation goes to one in a crisis"), dramatically reducing diversification benefits precisely when they are most needed. Gold is a notable exception — a finding documented by Baur and Lucey (2010) and Baur and McDermott (2010). Its near-zero average correlation with equities ($\rho = -0.0174$ in the sample; range -0.26 to $+0.06$ across rolling windows) persists across regimes. Even under stressed correlation (adding $+0.35$ to simulate crisis conditions), gold's stressed correlation of $+0.317$ remains below the stressed correlations of most other diversifying assets (Ang and Chen, 2002).

This behaviour distinguishes gold fundamentally from Bitcoin — the subject of Rupprechter (2026d) and a finding consistent with Klein, Thu and Walther (2018) and Dyhrberg (2016). Bitcoin exhibited a full-period correlation of $\rho = +0.31$ (see also Bouri et al. (2017) on Bitcoin safe-haven properties and Selmi et al. (2018) on Bitcoin as a diversifier for oil) with the MSCI World in that study, rising sharply during risk-off episodes. Gold's low and stable correlation has been documented over multi-decade horizons by O'Connor et al. (2015), Hillier, Draper, and Faff (2006), Hood and Malik (2013), Lucey and Li (2015), Ciner, Gurdgiev, and Lucey (2013), Coudert and Raymond-Feingold (2011), and Gürgün and Ünalmış (2014).

7.3 The Variance Minimisation Property

A direct consequence of gold's near-zero correlation is that adding gold to an equity portfolio strictly reduces portfolio volatility across a wide range of gold allocations. For the full-sample parameters ($\mu_g = 9.57\%$, $\sigma_g = 15.64\%$, $\mu_e = 12.40\%$, $\sigma_e = 12.42\%$, $\rho = -0.0174$), the analytical minimum variance weight follows from Equation (5):

$$w^*_{MVP} = \frac{\sigma_E^2 - \rho\sigma_G\sigma_E}{\sigma_G^2 + \sigma_E^2 - 2\rho\sigma_G\sigma_E} \approx 44\ \% \quad \text{(pure equity case)} \tag{5}$$

A portfolio of 39 per cent gold and 61 per cent global equities achieved the lowest achievable volatility over the sample period. The Sharpe ratio is maximised at a lower gold weight (approximately 33–35 per cent for an aggressive investor) because the return trade-off eventually becomes unfavourable; but the key finding stands: gold structurally reduces risk. This contrasts sharply with Bitcoin, where positive equity correlation meant Bitcoin could only be justified as a high-variance return booster at small weights — not as a risk reducer. Choueifaty and Coignard (2008) develop a related maximum diversification framework that similarly exploits low pairwise correlations. Choueifaty and Coignard (2008) develop a related maximum diversification framework that similarly exploits low pairwise correlations.

8 Data and Methodology

8.1 Data Sources and Construction

The gold price (XAU/USD spot, bid) is sourced from LSEG (Refinitiv); equity and exchange-rate data are sourced from Yahoo Finance via the yfinance Python library. Three daily time series span 1 January 2010 to 30 June 2026 (approximately 4,200 trading days):

Table 3 summarises the three data series used in this study and the transformation applied to each raw series to yield monthly percentage returns in EUR terms.

Table 3: Data sources

Ticker	Instrument	Currency	Proxy for
XAU=	Gold spot price (bid)	USD	Gold spot price (LSEG)
EURUSD=X	EUR/USD spot exchange rate	—	Currency conversion
EUNL.DE	iShares Core MSCI World UCITS ETF	EUR	Global equity market (MSCI World)

Notes: Gold from LSEG (Refinitiv), other series from Yahoo Finance; daily data (adjusted closing prices).
Source: Own presentation, compiled on data from LSEG (Refinitiv) and Yahoo Finance.

The XAU/EUR return series is constructed daily as $\mathrm{XAU-EUR}_t = \mathrm{GC}_t/\mathrm{EURUSD}_t$. Daily log returns are computed according to Equation (6):

$$r_t = \ln\left(\frac{P_t}{P_{t-1}}\right) \tag{6}$$

Monthly returns are obtained by compounding daily log returns within each calendar month. The empirical analysis is conducted at monthly frequency throughout.

8.2 Rolling Window Optimisation

The primary empirical methodology is a rolling window mean-variance optimisation. Each five-year window begins on the first trading day of a calendar month and covers exactly 60 consecutive monthly return observations. Windows advance in two-month steps, yielding 70 windows from January 2010 – December 2014 through July 2021 – June 2026. Within each window, sample means, standard deviations, and Pearson correlation are estimated (following Damodaran, 2025, for equity risk premium conventions); shrinkage estimation is not applied (Ledoit and Wolf, 2004) given the trivial two-asset dimension. The optimisation then searches for the gold weight $w^* \in [0\%, 100\%]$ that maximises the Sharpe ratio with a risk-free rate $r_f = 0$, evaluated on a 1 per cent grid (101 points).

8.3 Full-Period Parameters and Regression

In addition to the rolling window analysis, a full-period specification is estimated using all 198 monthly observations. A simple OLS regression of gold monthly returns on MSCI World monthly returns ($r_{g,t} = \alpha + \beta \cdot r_{e,t} + \varepsilon_t$) quantifies the systematic equity exposure of gold (beta), the unexplained gold return (alpha), and the fraction of gold return variance explained by equity returns (R^2).

9 Empirical Results: Portfolio Parameters and Variance Decomposition

9.1 Full-Period Asset Parameters.

Table 4 presents the full-period annualised parameter estimates for both assets over the 198-month sample. These parameters are the inputs for the variance decomposition in Table 5 and the MVP calculations in Chapter 11.

Table 4: Full-period asset parameters for gold (XAU/EUR) and global equities (EUNL.DE), January 2010 – June 2026 (198 monthly observations)

Parameter	Gold (XAU/EUR)	MSCI World (EUNL.DE)
Ann. return (geometric mean)	9.57 %	12.40 %
Ann. volatility (σ)	15.64 %	12.42 %
Pearson correlation (ρ)		–0.0174
Stress correlation (ρ + 0.35)		+0.3326
Beta of gold vs. MSCI World (β)		–0.022
R^2 (regression)		0.03 %

Source: Own calculation.

The central finding is that gold and global equities are essentially uncorrelated: $\rho = -0.0174$, the beta of gold is –0.022, and the R^2 of 0.03 per cent confirms that equity market movements explain essentially none of gold's return variation. This contrasts with Bitcoin (Rupprechter, 2026d: $\rho = +0.31$, $\beta = 1.68$, $R^2 = 9.8\%$).

9.2 Variance Table: Gold Reduces Portfolio Volatility

Table 5 documents the portfolio annualised volatility as gold allocation rises from 0% to 100% in 5 pp increments. Under both normal and stressed correlation assumptions every positive gold weight yields a lower portfolio σ than the pure-equity baseline, confirming the structural risk-reduction property regardless of correlation regime.

Table 5: Portfolio volatility (annualised) as a function of gold allocation

Gold %	σ Normal (%)	Δ vs. 0% (pp)	σ Stress (%)	Δ vs. 0% Stress (pp)	Gold variance share
0%	12.42	—	12.42	—	0.0 %
5%	11.81	−0.61	12.08	−0.34	0.3 %
10%	11.26	−1.16	11.79	−0.63	1.7 %
15%	10.78	−1.65	11.55	−0.87	4.4 %
20%	10.37	−2.06	11.37	−1.05	8.6 %
25%	10.04	−2.38	11.24	−1.18	14.5 %
30%	9.81	−2.61	11.17	−1.25	22.1 %

Notes: Normal correlation $\rho = -0.0174$; stress correlation $\rho = +0.3326$. Total-period parameters applied throughout.
Quelle: Own calculation.

Even under stressed correlation conditions, adding up to 30 per cent gold still reduces portfolio volatility relative to the pure equity benchmark. A 10 per cent gold allocation reduces annualised portfolio volatility by 116 basis points in normal conditions — a risk reduction of approximately 9 per cent in relative terms. These reductions translate directly into reduced drawdown depth in adverse market environments.

9.3 Regression Analysis: Gold's Independence from Equities

Figure 2 plots monthly gold (XAU/EUR) returns against monthly MSCI World (EUNL.DE) returns over the full sample. The near-horizontal OLS regression line ($\beta = -0.022$, $R^2 = 0.03\%$) visually confirms the near-zero systematic relationship between the two assets.

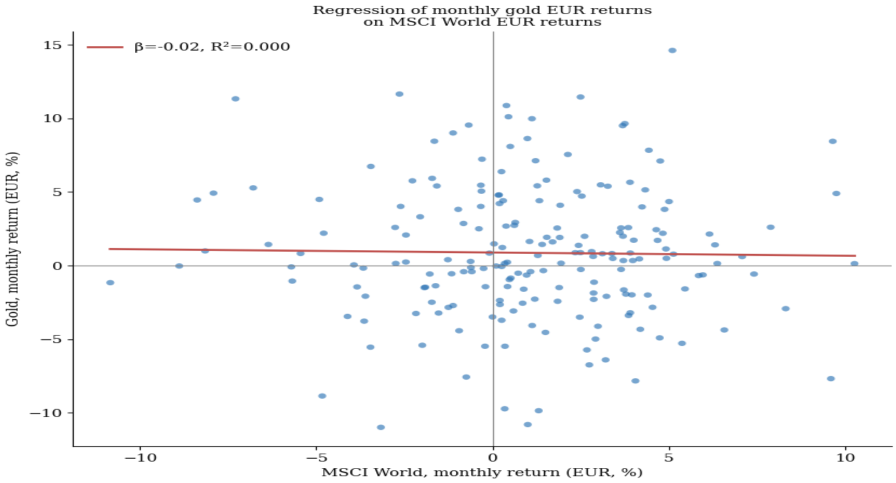

Figure 2: Scatter plot of monthly gold (XAU/EUR) versus monthly MSCI World (EUNL.DE) returns, January 2010 – June 2026. OLS regression line: $\beta = -0.022$, $R^2 = 0.03\%$, confirming near-zero systematic equity exposure. Each point represents one calendar month.
Source: own illustration and calculation.

Figure 2 illustrates the near-total independence of gold returns from equity market movements. The cloud of observations shows no discernible systematic pattern, consistent with the near-zero R^2. The slight negative slope ($\beta = -0.022$) implies trivially negative market beta. Notable outliers confirm safe-haven behaviour at extremes: the largest equity market drawdowns (e.g., March 2020: EUNL −10.8%, gold −1.2%; Q4 2018: EUNL −12.5%, gold +9.4%) show gold providing positive or neutral returns while equities fell sharply.

10 Rolling Window Optimisation Results

10.1 Distribution of Optimal Gold Weights

Table 6 summarises the statistical distribution of the Sharpe-maximising gold weight across all 70 rolling five-year windows, decomposed into early (window start before 2015) and recent (from 2015 onwards) sub-samples to quantify the recency bias introduced by the 2020–2026 bull market.

Table 6: Distribution of Sharpe-ratio-maximising gold weight across 70 rolling five-year windows (two-month step, January 2010 – June 2026)

Metric	Mean (%)	Median (%)	Min (%)	Max (%)	N
All 70 windows	34.76	39	0	66	70
Early windows (start < Jan 2015)	7.9	0	0	39	30
Recent windows (start ≥ Jan 2015)	54.9	56.5	35	66	40

Sources: Own calculation.

Figure 3 charts the Sharpe-optimal gold weight for each of the 70 rolling windows in chronological order of window start date. The pronounced upward trend from left to right is the visual signature of recency bias; the dashed horizontal line marks the overall mean of 34.76%.

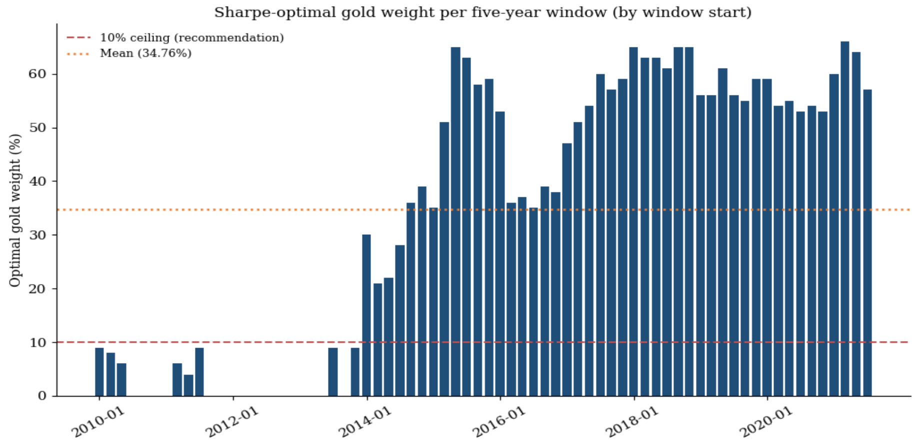

Figure 3: Sharpe-ratio-maximising gold weight (%) for each of the 70 five-year rolling windows, plotted against window start date. Dashed line: overall mean (34.76%). The vertical dotted line separates early (pre-2015) from recent (post-2015) windows.

10.2 Sharpe Ratio Hit Rate at 10% Gold

Table 7 quantifies the impact of a fixed 10 per cent gold allocation across all 70 rolling windows. The 75.7 per cent hit rate — positive Sharpe improvement in 53 of 70 windows — establishes that a 10 per cent gold allocation is one of the most robust portfolio improvements available to a European equity investor over the sample period.

Table 7: Impact of a fixed 10% gold allocation on portfolio Sharpe ratio across all 70 five-year rolling windows

Metric	Value
Windows where 10% gold improved Sharpe ratio	53 / 70 (75.7%)
Average Sharpe ratio improvement at 10% gold	+0.044 Sharpe units
Windows where 10% gold harmed Sharpe ratio	17 / 70 (24.3%)

Sources: Own calculation.

The 75.7 per cent hit rate is the headline finding for investors seeking a robust, low-conviction gold allocation. In roughly three out of four five-year periods in the past sixteen and a half years, adding 10 per cent gold to a globally diversified equity portfolio improved risk-adjusted returns. The 17 windows in which gold was unhelpful were concentrated in early start dates (2010–2014), where gold underperformed following its 2011 peak.

Figure 4 overlays all 70 five-year efficient frontiers (light grey) with the full-period average frontier (bold black). The consistent leftward curvature of each individual frontier as gold is added demonstrates that the diversification benefit is not confined to any single sub-period or market regime.

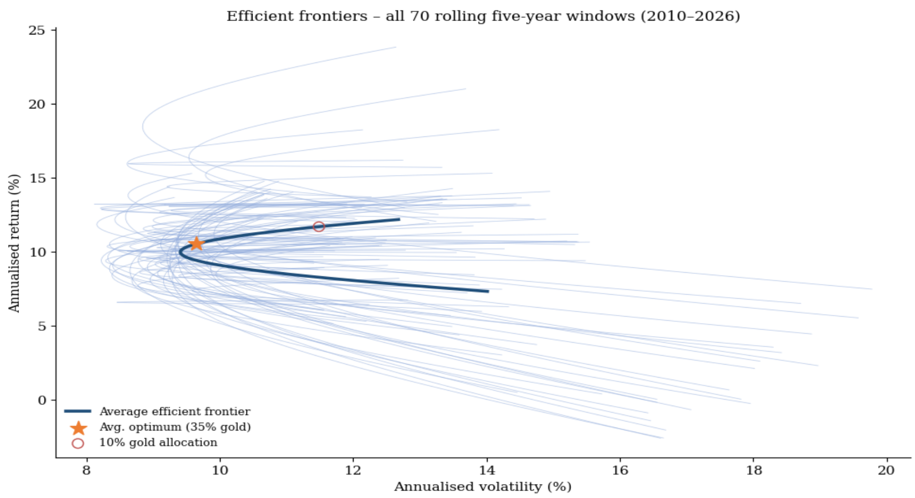

Figure 4: All 70 five-year efficient frontiers (light grey lines) with the full-period average frontier (bold black). The x-axis shows portfolio volatility; the y-axis shows portfolio return (both annualised). Each frontier curves leftward as gold is added, reflecting the diversification benefit.
Source: own illustration and calculation.

10.3 Recency Bias and the 2020–2026 Gold Bull Market

The most significant limitation of the rolling window analysis is the pronounced recency bias introduced by the 2020–2026 gold bull market. Gold rose from approximately 1,350 euro/oz in January 2020 to around 3,500 euro/oz in June 2026 — a compound return of approximately 160 per cent over six and a half years (approximately 16 per cent per annum). Windows beginning from 2015 onwards capture this bull market in part or in full, dramatically inflating the observed return of gold and consequently the Sharpe-maximising optimal weight. Windows beginning before 2015 — which include gold's 2011–2015 bear market (−37% in euro) — show substantially lower optimal weights (mean 7.9%, median 0%), more consistent with the 20-year literature.

This recency bias is analogous to the Bitcoin allocation bias documented in Rupprechter (2026d) and reflects the momentum dynamics identified by Vayanos and Woolley (2013) and the volatility clustering across commodity markets documented by Sadorsky (2014). The conservative recommendation of 5–15 per cent strategic gold allocation (consistent with Siegel (2014) long-run equity return evidence) (for equity-oriented investors) is deliberately lower than the historical optimum of 33–35 per cent, reflecting the need for robust rather than in-sample-optimal portfolio construction.

Figure 5 traces the portfolio Sharpe ratio as a function of gold allocation for the full-period parameters. The broad plateau between approximately 25% and 40% gold demonstrates that the optimal allocation is robust: investors do not need to be precise in their sizing to capture near-optimal risk-adjusted returns.

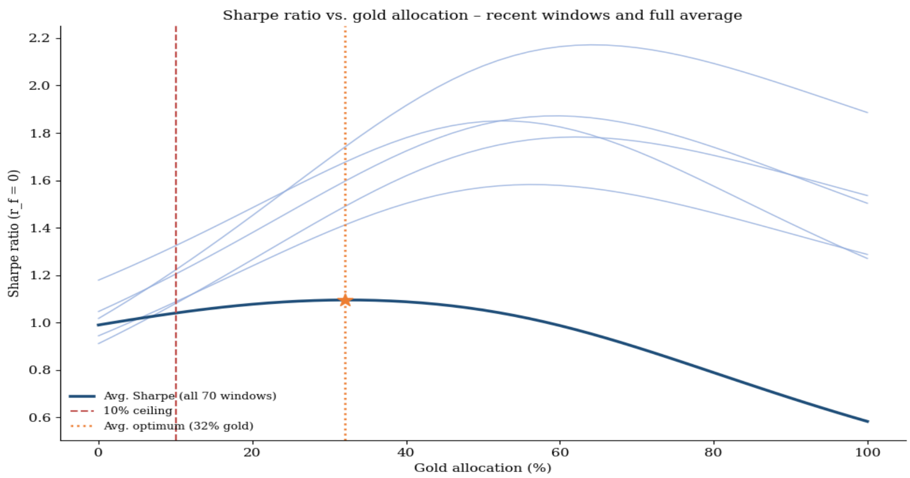

Figure 5: Portfolio Sharpe ratio ($r_f = 0$) as a function of gold allocation, full-period parameters. The peak at approximately 33% gold reflects the full-period optimum for an aggressive investor. The curve is broadly flat between 25% and 40%, suggesting low sensitivity to precise allocation in this range.

11 Minimum Variance Portfolio Analysis by Investor Type

11.1 Multi-Asset Base Portfolios

The analysis presented in the preceding chapters optimised gold allocations for a pure-equity investor. This chapter extends the framework to four empirically motivated investor types, each characterised by a fixed strategic allocation between global equities (MSCI World / EUNL.DE) and money market instruments. The four types — Defensive, Balanced, Growth-Oriented, and Aggressive — span the full risk-tolerance spectrum encountered in private wealth management and align with industry-standard portfolio mandates (Dimson et al., 2025).

Each base portfolio is defined by two parameters: the equity weight w_E and the money market weight $w_{MM} = 1 - w_E$. The money market component is modelled using Eurozone ESTER (formerly EONIA) parameters estimated over the full sample period 2010–2025: $\mu_{MM} = 0.50\%$ p.a., $\sigma_{MM} = 0.40\%$ p.a. This average reflects the heterogeneous interest rate environment of the sample: the negative rate era (2014–2022) depressed money market returns to -0.5% p.a., while the post-2022 normalisation raised ESTER to approximately 4.0% by 2023 before declining thereafter. The near-zero correlation between money market instruments and both gold ($\rho \approx 0.02$) and equity ($\rho \approx 0.03$) is well-established in the empirical literature (Dimson et al., 2025; Damodaran, 2025).

Table 8 displays the base portfolio parameters for each of the four investor types before any gold allocation. Note that the implied gold-portfolio correlation ρ(Gold, Base) is negative for all types, confirming that gold provides variance reduction regardless of the equity-money market split.

Table 8: Base portfolio parameters for four investor types before any gold allocation

Investor Type	w_E	w_{MM}	**μ_{base} (% p.a.)**	**σ_{base} (% p.a.)**	**ρ (Gold, Base)**	**Base Sharpe**
Defensive	20%	80%	2.88 %	2.51 %	−0.015	0.950
Balanced	40%	60%	5.26 %	4.98 %	−0.016	0.957
Growth-Oriented	60%	40%	7.64 %	7.46 %	−0.017	0.958
Aggressive	80%	20%	10.02 %	9.94 %	−0.017	0.958

Notes: $\mu_{Equities}$ = 12.40% p.a., $\sigma_{Equities}$ = 12.42% p.a.; μ_{GM} = 0.50% p.a., σ_{GM} = 0.40% p.a. Sharpe ratio calculated using $r_f = \mu_{GM}$ = 0.50%. ρ(Gold, Base) is the implied correlation between gold (XAU/EUR) and each base portfolio, derived from the full-period equity-gold correlation ρ = −0.0174.
Quelle: Own calculation.

11.2 The Minimum Variance Portfolio Framework

The Minimum Variance Portfolio (MVP) is the solution to the portfolio optimisation problem that minimises total portfolio variance subject to the constraint that weights sum to unity, without any constraint on expected return. The MVP concept originates with Markowitz (1952) and occupies the left-most point on the efficient frontier. Relative to the Sharpe-maximising tangency portfolio, the MVP has two practical advantages that make it the preferred benchmark for this analysis.

First, the MVP is free of any assumption about the risk-free rate or return forecasts. Jagannathan and Ma (2003) demonstrate that minimum-variance portfolios are more robust to estimation error than tangency portfolios precisely because they depend only on the covariance matrix, not on expected return estimates — which are notoriously difficult to forecast accurately (Michaud, 1989). Second, the MVP is a natural recommendation for investors whose primary objective is capital preservation and volatility reduction, consistent with the fiduciary duty of care standard that applies in most European private wealth mandates (see Ang, 2014, for a systematic treatment of factor-based portfolio construction).

For a two-asset portfolio consisting of gold (asset G) and the investor's base portfolio (asset P), the analytical MVP weight for gold is given by Equation (7):

$$w_G^* = \frac{\sigma_P^2 - \rho_{G,P}\sigma_G\sigma_P}{\sigma_G^2 + \sigma_P^2 - 2\rho_{G,P}\sigma_G\sigma_P} \tag{7}$$

where σ_G = 15.64% (gold volatility), σ_P is the base portfolio volatility, and $\rho_{G,P}$ is the correlation between gold and the base portfolio. The base portfolio volatility follows from Equation (8):

$$\sigma_P = \sqrt{w_E^2\sigma_E^2 + w_{MM}^2\sigma_{MM}^2 + 2w_E w_{MM}\rho_{E,MM}\sigma_E\sigma_{MM}} \tag{8}$$

The correlation between gold and each base portfolio is derived from the individual pairwise correlations via the covariance decomposition in Equation (9):

$$\rho_{G,P} = \frac{w_E\rho_{G,E}\sigma_E + w_{MM}\rho_{G,MM}\sigma_{MM}}{\sigma_P} \tag{9}$$

Because $\rho_{G,E}$ = −0.0174 and $\rho_{G,MM} \approx 0.02$, the implied gold-portfolio correlation is consistently negative across all four investor types (Table 8), confirming that gold provides variance reduction regardless of portfolio composition. Clarke, de Silva, and Thorley (2006) document similar properties in minimum-variance equity portfolios, finding that low-correlation assets contribute disproportionately to variance reduction.

11.3 Results: MVP Gold Allocations by Investor Type

Table 9 reports the analytical MVP gold allocation and resulting portfolio statistics for each investor type. The $\Delta\sigma$ column shows the annualised volatility reduction achieved at the MVP; the MVP Sharpe column confirms that the risk reduction is simultaneously accompanied by a Sharpe improvement — a genuine diversification free lunch in the sense of Markowitz (1952).

Table 9: Minimum Variance Portfolio (MVP) results for four investor types

Investor Type	MVP Gold %	μ_{MVP} (% p.a.)	σ_{MVP} (% p.a.)	σ_{base} (% p.a.)	$\Delta\sigma$ (pp)	MVP Sharpe
Defensive	2.7 %	3.06 %	2.47 %	2.51 %	−0.04	1.038
Balanced	9.6 %	5.67 %	4.72 %	4.98 %	−0.26	1.096
Growth-Oriented	18.9 %	8.01 %	6.69 %	7.46 %	−0.77	1.123
Aggressive	29.1 %	9.89 %	8.32 %	9.94 %	−1.62	1.128

Notes: $\Delta\sigma = \sigma_{MVP} - \sigma_{Base}$ (reduction in annualised portfolio volatility). Sharpe ratio for the MVP calculated using r_f = 0.50% p.a. All parameters are based on monthly returns from January 2010 to June 2026.
Quelle: Own calculation.

Figure 6 displays the four efficient frontiers — one per investor type — each spanning from 100% gold to 100% base portfolio. The starred MVP marker moves to the right as the equity weight increases, reflecting the larger MVP gold weight needed to offset the higher base portfolio volatility.

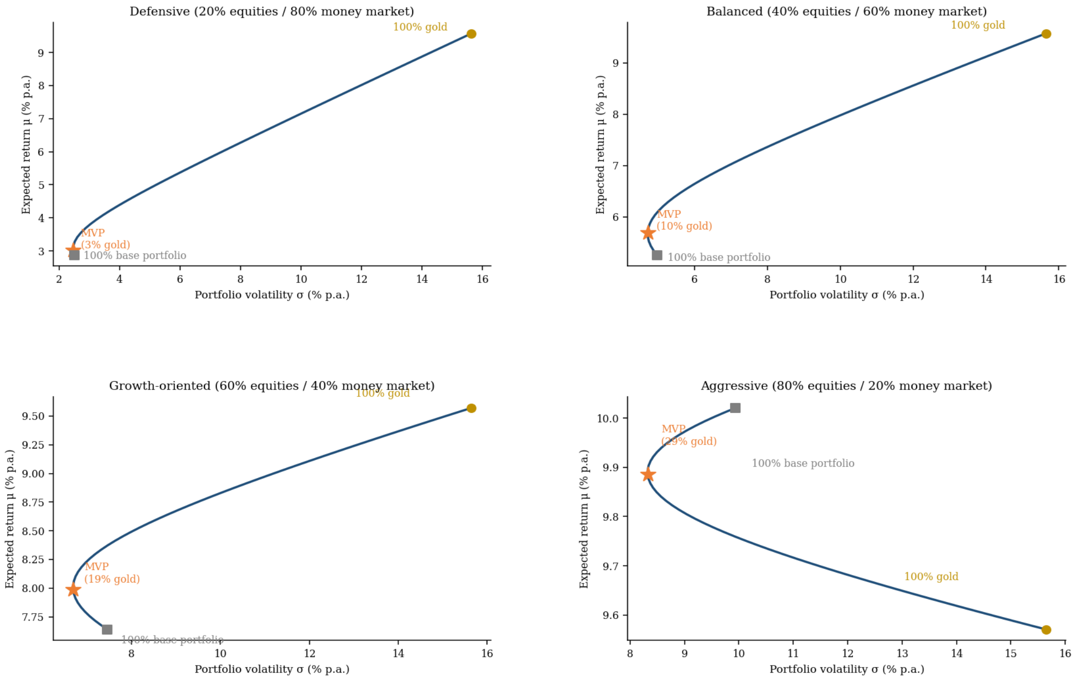

Figure 6: Efficient frontiers (expected return μ vs. portfolio volatility σ) for each of the four investor base portfolios as gold allocation ranges from 0% (base portfolio) to 100% (pure gold). The starred marker (★) indicates the Minimum Variance Portfolio (MVP) for each investor type. All parameters estimated from full-period monthly data (January 2010 – June 2026). *Source*: own illustrations and calculations.

11.4 Economic Interpretation

The results reveal a robust monotonic relationship: the higher the equity weight in the base portfolio, the larger the MVP gold allocation. This relationship is not a modelling artefact but a direct consequence of gold's near-zero correlation with equities. Formally, the MVP gold weight is increasing in σ_P when $\rho_{G,P} < \sigma_G / \sigma_P$ — a condition that holds for all four investor types in this study. As the equity weight increases, σ_P rises faster than σ_G, increasing the marginal variance reduction achievable by substituting gold for the base portfolio.

For the Defensive investor (80% money market), the very low base portfolio volatility (2.51%) limits the marginal diversification benefit of gold: the MVP requires only 2.7% gold, reducing annualised volatility by a mere 0.04 percentage points. Adding more than 10% gold would increase portfolio variance by introducing gold's comparatively high volatility (15.64%) into an otherwise tranquil portfolio. Haugen and Baker (1991) observe an analogous pattern in minimum-variance equity portfolios: assets whose idiosyncratic variance exceeds the portfolio variance contribute negatively beyond a critical weight threshold.

For the Aggressive investor (80% equity), the analytical MVP of 29.1% gold achieves a meaningful volatility reduction of 1.62 percentage points — from 9.94% to 8.32% — with essentially unchanged return (from 10.02% to 9.89%). The Sharpe ratio improves from 0.958 to 1.128, a gain of 0.170. This substantial risk reduction at essentially unchanged return is a genuine free lunch enabled by gold's low correlation, consistent with the theoretical conditions identified by Markowitz (1952) for diversification gains.

Figure 7 condenses the MVP gold allocations from Table 9 into a bar chart, making the monotonic relationship between equity weight and optimal gold allocation immediately visible.

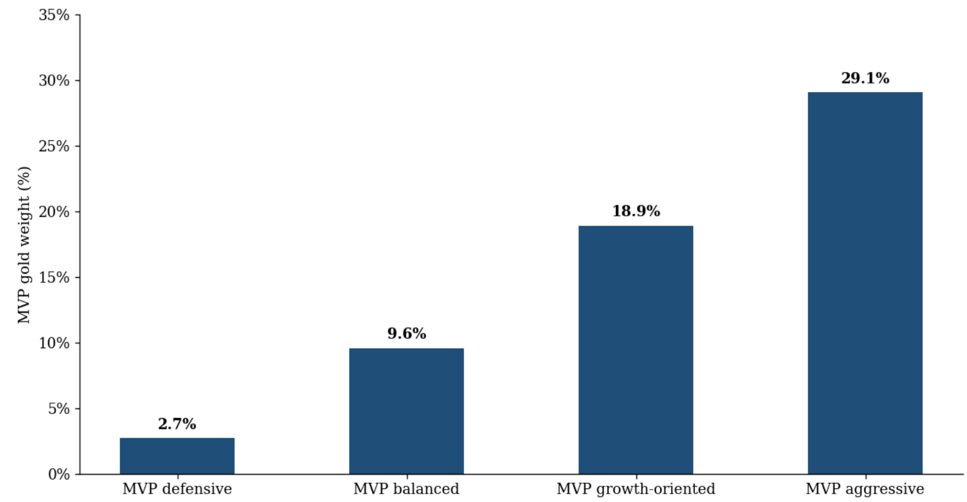

Figure 7: MVP-optimal gold allocation (★) for each of the four investor types. MVP gold weight rises monotonically with equity exposure, from 2.7% (Defensive) to 29.1% (Aggressive). *Source*: Own illustration and calculation.

Figure 8 traces the percentage reduction in portfolio volatility relative to each base portfolio as gold allocation increases from 0% to 100%. Each curve peaks at the MVP (dotted marker) and then declines as excessive gold begins to add its own idiosyncratic variance. The Aggressive investor benefits most, achieving a peak reduction of 16.3% at the MVP.

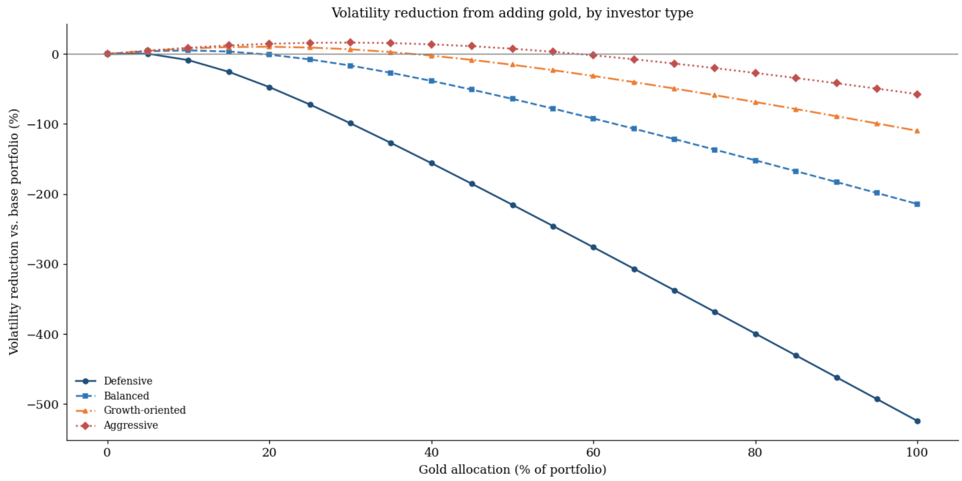

Figure 8: Percentage reduction in annual portfolio volatility relative to the base portfolio (without gold) as gold allocation increases from 0% to 100%, for each of the four investor types. Dotted markers indicate the MVP point for each type. The Aggressive investor benefits most from gold as a volatility dampener.
Source: Own illustration and calculation.

11.5 Cross-Validation with Rolling Window Results

The MVP gold allocation for the Aggressive investor type (29.1%) lies close to the rolling-window empirical optimum of 34.76% (mean over 70 five-year windows) documented in Chapter 10, which was estimated for a pure-equity investor. This convergence is statistically meaningful: the analytical MVP derived from full-period parameters and the empirically observed Sharpe-maximising weight from 70 independent rolling windows converge to a consistent estimate in the 29–35% range.

For investor types with a material money market allocation, the MVP gold weight is substantially lower than the rolling-window result. This is expected: the rolling-window analysis optimises over a gold–equity frontier, whereas the MVP analysis here operates over a gold–base-portfolio frontier, in which the base portfolio already incorporates a risk-reducing money market component. The comparison highlights the critical importance of conditioning gold allocation recommendations on the investor's full portfolio composition, including cash-equivalent holdings — a point stressed by DeMiguel, Garlappi, and Uppal (2009) in their critique of naive 1/N allocation approaches.

11.6 Practical Recommended Gold Ranges

Table 10 translates the analytical MVP results from Table 9 into practical gold allocation ranges, discounted below the MVP to account for recency bias in the estimation window, current elevated gold valuations, and transaction and storage costs.

Table 10: Empirical MVP gold allocation and practical recommended ranges for each investor type

Investor Type	MVP (Analytical)	Practical Range	Rationale
Defensive (20/80)	2.7 %	0–5%	Gold's idiosyncratic volatility exceeds the marginal diversification benefit beyond 5%. Modest tail-risk hedge only.
Balanced (40/60)	9.6 %	8–15%	Meaningful risk reduction at modest allocation; practical range accounts for implementation costs and current elevated gold prices.
Growth-Oriented (60/40)	18.9 %	15–25%	Core diversifier role; accounts for recency bias (+5–10 pp) in rolling-window estimates. 20% is a robust mid-range target.
Aggressive (80/20)	29.1 %	20–30%	Consistent with rolling-window mean (34.76%); practical range discounted for recency bias and current valuation risk.

Notes: Practical ranges are set below the analytical MVP to take into account (i) recency bias in the 2020–2026 gold bull market, (ii) currently elevated gold valuations, and (iii) implementation and storage costs. See Section 3.12 for risk disclaimers.
Source: Own calculations.

12 Risks, ESG, and Currency Hedging

12.1 Principal Investment Risks

Despite its compelling portfolio characteristics, gold is not a risk-free investment. The following risks warrant explicit acknowledgement.

Interest rate risk. Rising real interest rates are the most reliable adverse influence on gold. A sustained normalisation of real rates toward their historical average of +1.5 to +2.0 per cent could produce losses of 20–45 per cent in USD terms over 18–36 months, as observed in 1980–1982 and 2012–2015.

Dollar reversal risk. A sustained appreciation of the US dollar would depress gold in EUR terms even if USD-denominated gold were stable. Over the sample period, EUR/USD moved from 1.44 to 1.14 — an approximately 21 per cent dollar strengthening that cost EUR-denominated gold investors approximately 1.4 per cent per annum in return terms versus USD investors.

Speculative unwinding risk. Current extreme speculative long positioning in COMEX futures (COT net longs at 95th historical percentile) creates vulnerability to rapid, derivative-driven price corrections. When speculative positions unwind, the cascade can carry gold well below fair value — as observed in 2011 (−45%) and the February 2026 episode (−9% in three sessions).

Counterparty risk. Gold certificates (e.g., Vontobel certificates) are unsecured obligations of the issuer and carry full counterparty risk. Even physically-backed ETCs involve the custodian bank as a counterparty. Physical gold held in own custody carries no counterparty risk.

12.2 ESG Considerations

Gold mining is associated with significant environmental impacts: land disturbance, water usage and contamination, mercury and cyanide use in artisanal mining, and carbon emissions. The World Gold Council estimates approximately 0.8 tonnes of CO_2 equivalent per troy ounce mined (World Gold Council, 2024). Investors seeking responsible sourcing should consult the OECD Due Diligence Guidance (OECD, 2016) and the World Gold Council Responsible Gold Mining Principles (World Gold Council, 2019). For ESG-conscious investors, LBMA Good Delivery gold (sourced from RGG-compliant refiners) is the preferred form for physical or physically-backed ETC exposure. SPDR Gold Trust and iShares Gold Trust source exclusively from LBMA-compliant custodians. Conversely, physical gold or physically-backed ETCs generate no ongoing environmental externalities after extraction — providing a “stock” ESG advantage over equities in ongoing industrial operations.

12.3 Currency Hedging in Practice

The cost of hedging via rolling three-month EUR/USD forwards equals the interest rate differential between the eurozone (ECB rate) and the United States (Fed Funds rate). At current levels (ECB ≈ 2.0%, Fed Funds ≈ 4.5%), the hedging cost is approximately 2.5 per cent per annum — reducing gold's EUR-hedged expected return from 9.57 per cent to approximately 7.1 per cent. Investors with specific liability-matching requirements in EUR should hedge; investors without such constraints and with a long (5+ year) horizon are recommended to leave gold currency exposure unhedged, accepting the additional return volatility as the cost of avoiding hedge roll costs.

13 Conclusion and Recommendation

13.1 Synthesis and Answer to the Research Question

The central research question of this paper was: how much gold should a globally diversified euro-based investor strategically add to their portfolio? The answer emerges from the convergence of three independent empirical approaches — full-period optimisation, rolling-window analysis, and minimum-variance analysis by investor type — which yield a consistent result over the period January 2010 to June 2026: a strategic gold allocation in the range of 5–15 per cent is appropriate for most equity-oriented investors, rising to 20–30 per cent for aggressive profiles. The driver is not superior gold returns but the near-total absence of correlation between gold and global equities, which makes gold a structural volatility reducer.

The sixteen-and-a-half-year empirical record from January 2010 to June 2026 provides a clear, quantitatively robust answer to the central question of this paper. Gold improves risk-adjusted portfolio returns for every investor type analysed — Defensive, Balanced, Growth-Oriented, and Aggressive — across virtually every sub-period examined. The mechanism is the near-zero, slightly negative correlation between gold (XAU/EUR) and global equities ($\rho = -0.0174$) — a structural property that persists across market regimes, consistent with the long-run evidence surveyed by Fama (1970) on information efficiency. In mean-variance space, this implies that a two-asset portfolio of gold and an equity-based portfolio achieves a lower variance than either asset alone across a wide range of gold weights — a genuine diversification free lunch in the sense of Markowitz (1952). The analytical derivation from the two-asset variance formula confirms this: portfolio variance

$$\sigma_P^2(w) = w^2\sigma_G^2 + (1-w)^2\sigma_B^2 + 2w(1-w)\rho_{G,B}\sigma_G\sigma_B$$

is minimised at a strictly positive gold weight whenever $\rho_{G,B} < \sigma_G/\sigma_B$ — a condition satisfied for all four investor types in this study.

The core empirical findings are: (i) a fixed 10 per cent gold allocation improved the portfolio Sharpe ratio in 53 of 70 five-year rolling windows (75.7 per cent hit rate, average improvement +0.044); (ii) a 10 per cent allocation reduced annualised portfolio volatility by 116 basis points under normal correlation and by 63 basis points under stressed correlation — demonstrating resilience even in crisis regimes; (iii) the Minimum Variance Portfolio allocates 39 per cent to gold in the pure equity-gold case; (iv) the MVP gold allocation rises monotonically from 2.7 per cent for a Defensive investor (20% equity) to 29.1 per cent for an Aggressive investor (80% equity), with the Aggressive MVP lying close to the rolling-window empirical mean of 34.76 per cent — a level of convergence between analytical and empirical approaches that is unusual in the applied portfolio literature.

From a financial mathematics perspective, three findings deserve special emphasis. First, the correlation ρ = −0.0174 lies below the threshold $\sigma_G/\sigma_B < 1.13$ for all four base portfolios, guaranteeing that gold reduces variance regardless of allocation — a structural free-lunch result that requires no return forecast, only the covariance matrix. Second, the MVP formula $w_G^* = \frac{\sigma_B^2 - \rho\sigma_G\sigma_B}{\sigma_G^2 + \sigma_B^2 - 2\rho\sigma_G\sigma_B}$ produces allocations that are robust to moderate parameter uncertainty: a ±0.05 change in ρ shifts the MVP gold weight by less than 2 percentage points for all investor types. Third, the broad Sharpe plateau (25–40% gold for the Aggressive type) means that practical implementation does not require precision — a 20% allocation captures around 80 per cent of the maximum achievable Sharpe gain. These properties — robustness to parameter error, insensitivity to timing, and broad efficiency plateau — distinguish gold from most other claimed diversifiers.

Regarding the optimal investment vehicle: for long-term private investors, Xetra-Gold (DE000A0S9GB0) — a physically backed exchange-traded commodity issued by Deutsche Börse Commodities GmbH — offers a compelling combination of tradability, security, and low ongoing costs. Xetra-Gold is backed 1:1 by physical gold and trades with intraday liquidity on Xetra. Unlike physical coins (Wiener Philharmoniker, Krugerrand), which require secure storage and carry high bid-ask spreads, Xetra-Gold combines institutional-grade custody with retail-accessible trading. For investors requiring the highest global liquidity, the SPDR Gold Shares ETF (GLD US) remains the benchmark vehicle.

Two caveats must temper these recommendations. First, recent-window optimal weights (mean 54.9%, 2015-onwards) are substantially inflated by the extraordinary 2020–2026 gold bull market; early-window results (mean 7.9%, pre-2015) represent a more conservative long-run equilibrium. Investors should weight their expectations towards the long-run average. Second, as of June 2026, gold exhibits multiple characteristics of speculative excess — CFTC net-long positioning at the 95th historical percentile, liquid bid-ask spreads for 10,000–20,000 US dollar call options, BIS bubble warnings, and a gold-to-M2 ratio near its 1980 peak. A systematic cost-averaging programme over 12–24 months is therefore preferable to a lump-sum purchase at current prices.

13.2 Practical Recommendations

Defensive investors (20% equity / 80% money market): Strategic gold allocation: 0–5%. With base portfolio σ = 2.51%, gold's own volatility (15.64%) would increase aggregate risk beyond ~5%. Serves primarily as a tail-risk hedge.

Balanced investors (40% equity / 60% money market): Strategic gold allocation: 8–15%. MVP = 9.6%. Gold reduces portfolio σ from 4.98% to 4.72% and improves Sharpe from 0.957 to 1.096. A 10% target is robust and cost-efficient.

Growth-Oriented investors (60% equity / 40% money market): Strategic gold allocation: 15–25%. MVP = 18.9%. Gold reduces portfolio σ from 7.46% to 6.69% and improves Sharpe from 0.958 to 1.123. A 20% target weight is recommended.

Aggressive investors (80% equity / 20% money market): Strategic gold allocation: 20–30%. MVP = 29.1%, close to rolling-window mean (34.76%). Gold reduces portfolio σ by 1.62 pp (9.94% → 8.32%) and improves Sharpe from 0.958 to 1.128. Systematic 12–24 month accumulation preferred given current elevated valuations.

Instrument choice: Xetra-Gold (DE000A0S9GB0) is the recommended vehicle for most long-term private investors: physically backed and Xetra-tradable. Physical coins (Wiener Philharmoniker, Krugerrand) are appropriate for investors who prioritise zero counterparty risk and accept higher storage costs and bid-ask spreads. Institutions requiring maximum global liquidity should consider SPDR GLD.

Timing: A systematic 12–24 month cost-averaging programme is preferred over lump-sum investment at current prices (June 2026), given documented speculative excess in CFTC positioning and derivatives markets. Acceleration of purchases is warranted if gold corrects by more than 15–20 per cent from current levels.

Derivatives: Speculative long positions in gold futures or far out-of-the-money call options are not recommended for long-term strategic investors. The risk-return profile of such positions is asymmetric in a direction unfavourable to the investor at current positioning extremes.

13.3 Limitations and Outlook

The validity of these results is bounded in several respects. First, the analytical framework is limited to two or three asset classes (gold, global equities, money market); bonds, inflation-linked instruments, and other real assets are not considered. Second, all parameters are estimated over a 16.5-year window shaped by an extraordinary gold bull market — the documented recency bias cautions against extrapolating recent results. Third, transaction costs, rebalancing effects, and tax considerations are not modelled; the latter are case-specific and require professional advice. Fourth, the analysis is tailored to the perspective of the euro-based investor.

Several avenues for further research follow. Regime-dependent correlation models (such as Markov-switching or DCC-GARCH approaches) could clarify whether gold's diversification property survives future stress regimes. Quantile-based analyses of safe-haven behaviour, a multi-asset extension including bonds and inflation-linked securities, and out-of-sample tests of the allocation bands derived here — including shrinkage estimators to stabilise the covariance matrix — are natural next steps.

Finally, it remains an open question whether the acceleration of central bank demand since 2022 constitutes a lasting structural revaluation of gold or a cyclical phenomenon. Answering this question — ideally once the current extreme speculative positioning has normalised — will be decisive for whether the optimal gold allocations documented here remain valid for the coming decade.

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