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GLTER

Gold's long-term expected return

Contents

Gold's real return – greater than you thought

While gold's contribution to managing portfolio risk is well established, supported by a large body of work devoted to its hedging characteristics,[1] **its contribution to portfolio return is not.** Frameworks for estimating gold's long-term return exist but fall short of a robust approach that aligns with the capital market assumptions for other asset classes. This report sets out such a framework, accounting for gold's unique dual nature as a real good and a financial asset.

Publications tackling gold's expected return have generally concluded that gold's primary function is as a store of value, implying a long-run co-movement of gold with the general price level (CPI). Alternative approaches using risk premia estimations or bond-like structures with embedded options produce similar results.

And while existing research is rich in insight, two features frequently pop up that, in our view, mischaracterise gold and have led to biased conclusions:

- Using data from periods during the Gold Standard to analyse gold's performance paints a misleading relationship between gold and general prices[2]
- Viewing long-term price dynamics *exclusively* through the lens of demand from financial markets and ignoring other sources of demand, is a likely contributor to a systematic underweighting of gold in private portfolio allocations.

In most cases, existing research lands on an expected long-run *real return* ranging between 0% and 1%.[3]

We instead show that gold's long-run return has been well above inflation for over 50 years (Figure 1), more closely mirroring global gross domestic product (GDP), a proxy for the economic expansion driver used in our other gold pricing models.

1. For a discussion of this research see O'Connor (2015).
2. Prior to the closure of the gold window, gold was primarily a monetary asset that could only be bought and sold at its official price in most jurisdictions.
3. The most commonly applied deflator to achieve real returns is the US consumer price index.

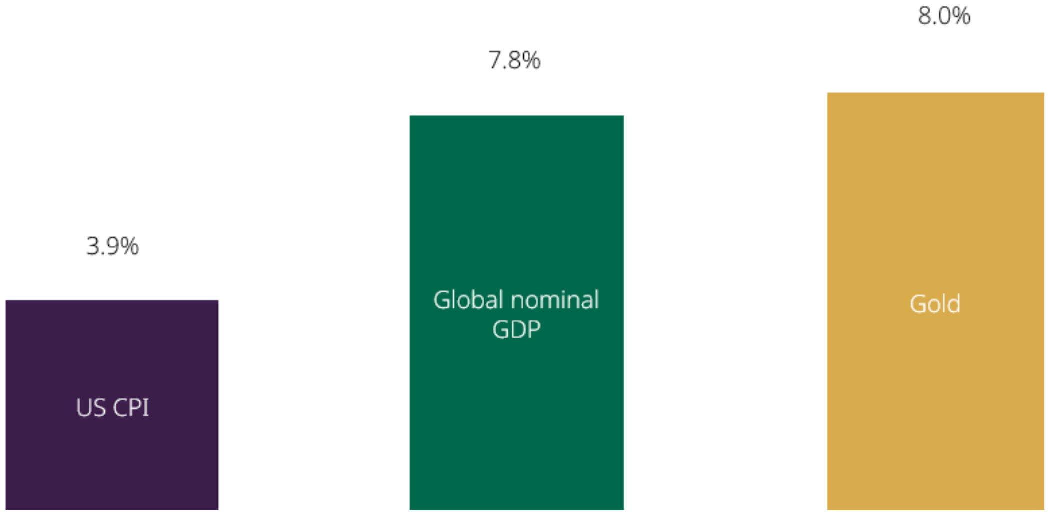
Our simple yet robust approach – which we refer to as Gold Long-Term Expected Return or GLTER – uses the distribution of above-ground gold stocks analysed via different demand categories as a foundation and starting point.

The drivers of gold buyers across various demand segments – jewellery and technology fabrication, central banks, financial investment, retail bars and coins[4] – are crucially broader and more important than existing theories suggest.[5] In addition, although financial market investors tend to dictate price formation in the short term, they are less dominant in the long term.[6]

We show that **the gold price over long horizons is mainly driven by *an economic component***, proxied by global nominal GDP, **coupled with a *financial component***, proxied by the capitalisation of global stock and bond markets, **that balances the overall relationship**. Third-party inputs are then used to estimate long-term expected returns for gold.[7]

Figure 1: Gold's return over the past 50 years has been in line with global GDP and well above inflation

Annual growth in US CPI, global nominal GDP and gold price (1971–2023)



Source: Bloomberg, Federal Reserve Bank of St Louis, LBMA Gold Price PM, World Gold Council

4. Defined as purchases of bars and coins less than 1kg in a retail setting. See Supply and Demand notes and definitions.
5. Further details of the data can be found here.
6. In reality, the delineation between short term and long term isn't easily done, suffice to say that supply chain buffers delay transmission to price from some demand sectors such as jewellery, retail bar and coin and technology.
7. This report does not purport to forecast the gold price or future performance of gold. This report sets out a proposed methodology and highlights the expected long-term returns for gold utilising third-party input assumptions. The World Gold Council does not make any recommendation or suggestion as to appropriateness of particular inputs into the model. Users can apply different inputs, which will generate different long-term expected returns for gold.

The challenge

Gold's dual nature, as both a real good and a financial asset, means that its value is not easily explained by traditional asset pricing models. This is further complicated by gold's continued use as a monetary asset within central bank reserves, despite the ending of the Gold Standard and the mandatory requirement to hold gold as reserves more than five decades ago.

As gold does not generate any cash flows, traditional discounted cash flow models are not applicable.[8] Generally, commodity pricing models also fall short given gold's unique and ever-growing above-ground stock that, among other things, diminishes primary production as marginal supply. Unlike most other commodities such as oil and wheat, gold cannot be consumed in the sense that its consumption makes it disappear.

Several theories suggest that gold's expected return should equal the inflation rate. These include the work of Hotelling.[9] His work on exhaustible resources proposes that commodity prices are linked to interest rates, implying an opportunity cost of production. Since interest rates and inflation rates co-move over longer horizons, price changes in commodities and the cost of production both move with interest rates (as proposed by Hotelling) and inflation rates (see Levin et al.).[10]

> Unlike most other commodities, e.g. oil and wheat, gold cannot be consumed in the sense that its consumption makes it disappear.

But focusing on inflation, interest rates or mining costs as the main driver of gold prices is too narrow for several reasons.

First, gold has significantly outperformed both inflation and the risk-free interest rate: its average annual compounded return (in US dollars) from 1971 to 2023 was 8% for gold vs 4% for US CPI and 4.4% for the US 3-month Treasury.[11] The probability that such excess returns are due to chance, rather than a characteristic of gold, is very low.

These returns also reject claims that the zero or low correlation of gold with the market, measured as a zero beta with respect to the market in a capital asset pricing model framework, implies that the return of gold is equal to the risk-free rate.[12] Gold returns are not a proxy for the risk-free rate theoretically and indeed are greater empirically.[13]

Second, some research suggests producers are marginal price setters by linking gold prices to mining costs.[14] However, it has been shown that miners react to higher gold prices by mining more costly deposits – driving mining costs up, and vice versa.[15] Thus, causality appears to work in the opposite direction to that suggested by such research.

Finally, the large above-ground stock of gold comprises an ever-growing source of supply ready to return to market, competing with primary production that contributes less than 2% to the stock each year. This makes the gold price not only less sensitive to production but also materially distinguishes gold from other commodities.

The cube

The bulk of existing research places financial investment at the forefront of price determination for gold but while the short-term impact of financial markets is undeniable, the long-term importance of other sources of buying is even more so.

The estimated above-ground stock of gold, at 212,582 tonnes, which we depict as a cube, is a balance sheet snapshot of gold ownership (**Figure 2,p.6**). It is remarkable for a number of reasons.

The cube illustrates how the total stock of this ubiquitous metal could occupy a physical space barely larger than three Olympic-sized swimming pools. In addition, it reveals how little financial investment – (referring here to physically backed gold ETFs and over-the-counter (OTC) physical holdings) has been amassed by market participants over the years in relation to other sources of demand – a misleading statistic given the vast volumes of gold that flow through financial centres every day.

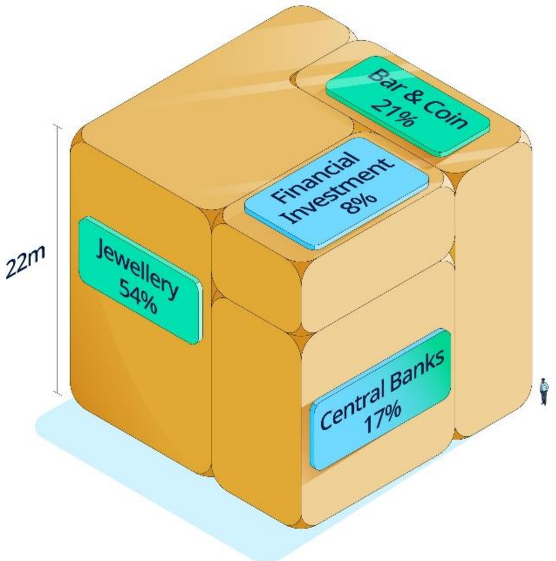
8. Gold is an asset, not a liability.
9. Hotelling (1931).
10. Levin, Abhyankar and Ghosh (1994).
11. A one-sided T-test of gold's excess return vs CPI and the risk-free rate gives a p-value of 0.04 and 0.05 respectively. An alternative way to express this is that the probability of observing such a return if the expected excess return is zero, is very low.
12. Baur and Lucey (2010).
13. He, O'Connor and Thijssen (2022).
14. Levin, Abyankhar and Ghosh (1994).
15. O'Connor, Lucey and Baur (2016).

That so much of this hypothetical cube is not owned via financial instruments implies that any explanation of its total distribution must consider factors beyond those solely linked to the day-to-day decisions of financial market participants.

The distribution of the cube also suggests that the price of gold has been driven by two distinct components: an *economic component* combined with a *financial component*.

Figure 2: The cube of above-ground gold stocks shows gold's ownership across sectors of demand

Estimated above-ground gold holdings by category*



*Data as of Q1 2024. Financial investment includes OTC and gold ETF.
Source: World Gold Council, Metals Focus, Refinitiv GFMS

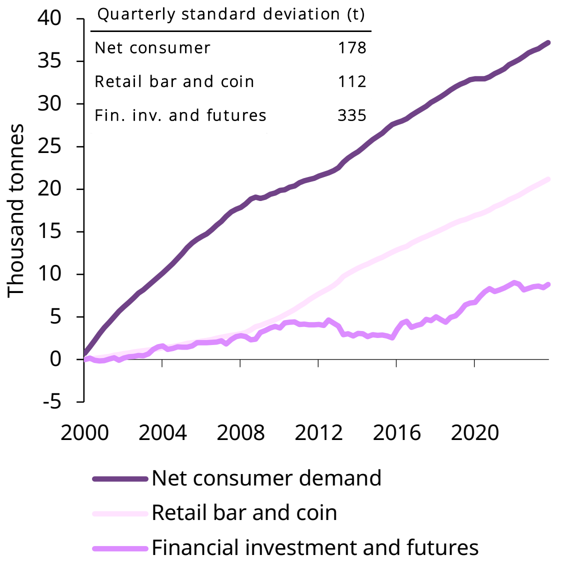
We illustrate an example of these dynamics in **Chart** 1 using quarterly data from 2000, adding COMEX futures net positions to the mix to capture derivatives activity.[16] This compares the cumulative net consumer flows (jewellery plus technology minus recycling) to flows relating to gold financial instruments (gold ETFs, plus OTC net buying and net long futures positions). The volume from gold accumulated through financial instruments is more than twice as volatile as net consumption, yet accumulates at a much lower rate.

It is this accumulation – whether for individuals, the reserves of select central banks or even investment for long-term savings – that we attribute to an *economic component*. The *financial component* represents, more tactical considerations, such as hedging demand, whether from individual or institutional investors.[17]

These components closely match the drivers we have outlined in our other pricing models, GRAM and Qaurum. Additional drivers, including risk and uncertainty and momentum, are less relevant in the long run but feature heavily in the short run (see Focus 1,p.6).

Chart 1: Financial investment is more volatile and accumulates more slowly than consumer and retail bar and coin demand

Cumulative gold demand since 2000 across categories*



*Data as of Q4 2023. Consumption represents jewellery and technology less recycling. Retail bar and coin follows our standard definition as reflected in Supply and demand notes and definitions. Financial investment and futures captures OTC, ETF and COMEX futures demand.
Source: Bloomberg, Metals Focus, Refinitiv GFMS, World Gold Council

> The cube illustrates how the total stock of gold could occupy a physical space barely larger than three Olympic-sized swimming pools.

16. Although COMEX futures ownership, and indeed that on other futures exchanges, does not explicitly exist in the cube, eligible and registered stocks do, and some positions in the futures market are hedged using physical gold. More importantly, we add futures to the mix as they play an important role in price discovery in the short term and add to short-term turnover in markets.

17. The dual nature of gold drivers was covered extensively by Goldman Sachs as part of its Fear and Wealth framework; see Appendix D: GDP as a driver of demand for our analysis. In addition, the model developed by Barsky et al. (2021) employs real GDP as a significant driving factor behind the price.

Focus 1: Gold's key drivers

Gold's performance responds to the interaction of its roles as a consumer good and as an investment asset. It draws not only from investment flows but also from fabrication and central bank demand.

In this context, we focus on four key drivers to understand its behaviour across periods:

- Economic expansion: periods of growth are supportive of jewellery, technology and long-term savings
- Risk and uncertainty: market downturns, inflation and geopolitical risk often boost investment demand for gold as a safe haven
- Opportunity cost: the price of competing assets, including bonds and currencies, influences investor attitudes towards gold
- Momentum: capital flows, positioning and price trends can boost or dampen gold's performance.

For more, see GRAM and Qaurum.

Money no more

There is a common pitfall in establishing an expected return for gold when using historical data to test a theory empirically. Generally, more history is preferable to less, as more observations increase one's confidence in the analysis. Capital market assumptions for long-term stock and bond returns commonly use data from 1900 or earlier.[18] Replicating this for gold creates one glaring issue: for the best part of the 20th century gold prices were determined by the conversion rate established by central banks and governments. This means that gold was money, linked to the US dollar at a fixed price that was only adjusted sporadically. As such, investors were not always able to use it in practice as an inflation hedge or an equity market hedge. And in the US, citizens were barred from acquiring gold as an investment from 1933 to 1974.

For gold, while its historical performance during Gold Standard periods is an interesting reference, it is truly its market structure and behaviour post-1971 that matters most (see Appendix C: Why 1971?).

By way of an example, to value a company and assess its expected return, one needs to apply the analysis to the business it will be rather than to the business it has been. If the two are materially different, then past is not prologue. Take Finnish company Nokia, established as a manufacturer of rubber cable and boots until the early 1990s when it morphed into one of the global leaders in the telecoms industry. Applying valuation metrics to Nokia as a boot maker in the early 1990s would have been as fallible as valuing gold in 2024 based on its performance as money during the first half of the 20th century.

> For gold, while its historical performance during Gold Standard periods is an interesting reference, it is truly its market structure and behaviour post-1971 that matters most.

The long-term system

We proxy the economic and financial components using real-world economic and financial variables. Our economic component proxy is global nominal GDP in US dollars. Nominal GDP comprises real GDP, an inflation component (the GDP deflator) and a currency component – used to convert local GDP to US dollars. This captures the flow of capital from income to gold.

Our financial component is proxied using the capitalisation of global equity and bond markets – the global portfolio – in US dollars. It captures the investments available for investors to reallocate income and wealth. It is important to note that we are looking at market capitalisation, accounting for both quantity of float and issuance, not just prices.[19]

We assess the influence of each of these variables using regression analysis. The analysis reveals that GDP is the primary driver of the gold price in the long run.

18. Global Investment Returns Yearbook 2024 | UBS Global. Long-Term Capital Market Assumptions | J.P. Morgan Asset Management (jpmorgan.com).
19. As such these variables are a composite of prices and issuance. The marginal negative coefficient for bonds in particular may reflect that issuance must often be absorbed regardless of yield, as we saw in Europe after the Global Financial Crisis, which might crowd out investments in alternatives such as gold.

The analysis reveals that GDP is the primary driver of the gold price in the long run.

Table 1 presents the regression results for two different specifications. Model (1) is a simple regression to examine the co-movement of gold prices with only GDP. This model yields a positive and statistically significant relationship with 79% (R^2) of the variation of gold prices explained by GDP. However, the insignificance of the Phillips-Perron unit-root test result suggests that this simple system does not satisfactorily explain long-run gold prices.

Table 1: Gold's long run behaviour is explained by global GDP and global portfolio capitalisation

Gold long-term price model (1971-2023)

Dependent variable:	Log gold price, US$/ oz	
	Model (1)	Model (2)
Log global nominal GDP	0.821***	2.837***
Log global portfolio		-1.079 **
Observations	53	53
Adjusted R^2	79%	92%
Phillips-Perron unit-root test p-value	0.116	0.039***

Note: ***,**,* represent statistical significance at the 1%, 5% and 10% levels respectively. Data from 1971 to 2023.
Source: Bloomberg, BIS, Federal Reserve Bank of St Louis, LBMA Gold Price PM, WFE, World Gold Council. See **Appendix A**: Data for data descriptions.

Model (2), which we have labelled Gold Long-Term Expected Return or GLTER, uses both components to create a stable long-run system with an R^2 of 92%. A relatively larger coefficient for GDP estimated at 2.8 means that, all else being equal, a 1 unit rise in GDP is associated with a 2.8 unit rise in gold. As we log both sides, these can be interpreted as percentage changes. The negative coefficient for the global portfolio (-1.07) moderates this relationship, as gold is competing for a share of savings, with a one-unit rise in the capitalisation of equity and bond markets associated with a one-unit reduction in gold prices. Once growth as the primary driver of gold prices has been accounted for, we are left with this substitution effect between gold and the global portfolio.

Importantly, the negative coefficient on the global portfolio does not mean that it lowers the price of gold, but that it makes it appreciate at a lower rate.

In this case both the Phillips-Perron test and a Johansen cointegration test[20] clearly indicate that there is a long-run relationship and equilibrium between gold prices and the two components.

Once growth as the primary driver of gold prices has been accounted for, we are left with this substitution effect between gold and the global portfolio.

Additional regressions show that individually stocks and bonds each have a negative coefficient when included with GDP in a two-variable system, adding credence to the above finding. See Appendix **B** for a full discussion.

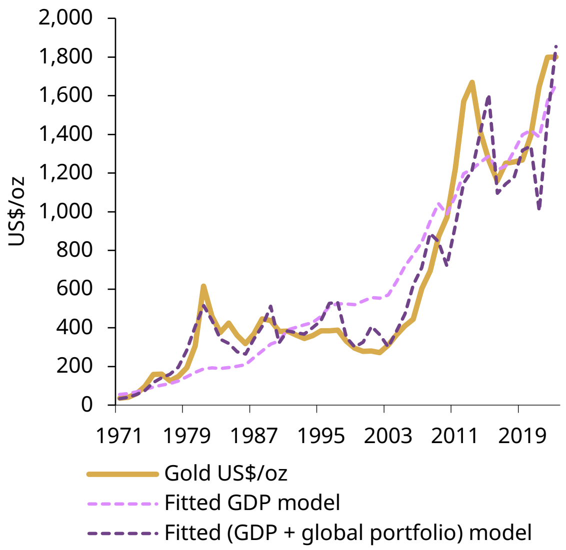
Chart 2, p.9 presents the results of these regressions. The purple dashed line shows the modelled gold price using GDP only, with the errors being particularly pronounced in the 1980s and the 2000s. The graph also displays the fitted line of the full model (black dashed) using both global nominal GDP and global portfolio capitalisation. The use of two variables rather than one yields a better fit with the price of gold. While it is not surprising that two variables provide a better fit than one, it is notable that the financial variable significantly reduces the deviations from the long-term relationship.

Crucially, using only an economic component to explain gold prices produces a model with rather prolonged periods of disequilibrium (see **Table 3** in Appendix B: Robustness tests of OLS regressions for these results). Accounting for gold's *dual nature* makes for a much more nuanced explanation of gold's long-run price path.

20. A long-run relationship, or more technically cointegration, implies that two variables co-move in the long run and that any short-run deviation from the long-run path is corrected or reversed.

Chart 2: Gold is influenced by GDP and the global portfolio in the long run

Actual and modelled gold prices*



*Data from 1971 to 2023.
Source: Bloomberg, BIS, Federal Reserve Bank of St Louis, LBMA Gold Price PM, WFE, World Gold Council. See **Appendix A**: Data for data descriptions.

A building block approach for expected gold returns

We convert our findings into a framework that is perhaps more accessible to investors: the building block approach used widely by practitioners assessing long-term capital market assumptions.

Gold's price relationship with GDP and the global portfolio can be extended to represent a relationship in return terms. This converts and simplifies these level components into the following relationship:

$$r_g = \beta_1 * GDP\ Growth - \beta_2 * global\ portfolio\ growth$$

where r_g are annual gold returns, GDP growth is annual global nominal GDP growth and global portfolio growth reflects the growth in market capitalisation of equities and bonds, both in US dollars.

> Our analysis suggests that gold's long-term expected returns are explained by three parts global nominal GDP growth less one-part global portfolio growth.

In **Table 2** we use the results of Model (2) to predict an 8.6% annual average return for the period 1971–2024, versus an actual return of 8% over that period. Using external forward estimates for GDP growth and the global portfolio, the model predicts an annual average return of 5.2% for the next 15 years.

Table 2: Gold's return will be influenced by future expected growth

Historical and modelled gold annualised returns*

Variable:	Nominal GDP	Global portfolio	Modelled gold return	Actual return
Coefficient	2.837	-1.079	_	_
1971-2023	7.00%	10.40%	= 8.6%	= 8%
2025-2040	5.24%	8.98%	= 5.2%	_

*Data from 1971 to 2023. Modelled return as described in **Table 1**. CPI forecast from J.P. Morgan LTCMA 2024. Assuming forecast horizon of 10-15 years. Expected GDP growth from Oxford Economics Global Scenario service baseline forecast. Equity and bond returns from J.P. Morgan LTCMA 2024 using AC World equities and World Government bonds respectively. Growth in outstanding shares and bonds calculated using 5-year average issuance.
Source: Bloomberg, BIS, Federal Reserve Bank of St Louis, LBMA Gold Price PM, WFE, World Gold Council. See **Appendix A**: Data for data descriptions.

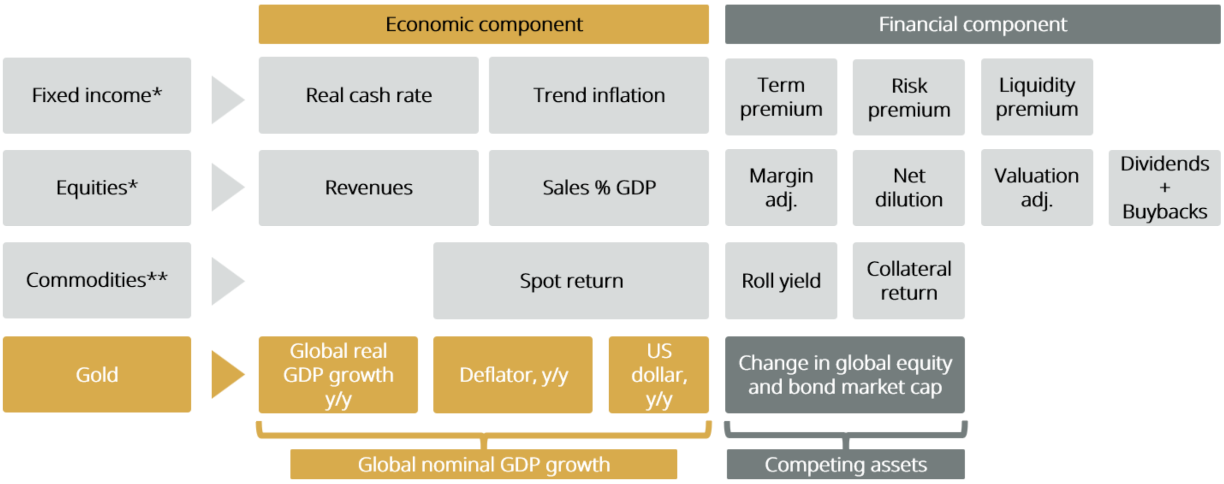
The estimated average gold return over the 2025-2040 period in excess of 5% per year is well above that produced by most other models (**Figure** 3,**p.10**). Specifically, the estimate exceeds common long-term return assumptions such as a zero real return (2.5% nominal in line with expected CPI inflation) over the next 15 years,[21] or a gold return equivalent to the risk-free rate (2.9% for short-term US Treasury bills).

This is lower than the historical return we've observed, largely down to a lower expected growth in global GDP. However, all asset returns are likely to be impacted. For example, estimates for intermediate US Treasury bonds and World government bonds over the same period are 3.9% and 4.8%, respectively (see Appendix E). And US large cap stocks are expected to grow at a 7% annual rate – below their 20-year return.

> This is lower than the historical return we've observed, largely down to lower expected growth in global GDP. However, all asset returns are likely to be impacted.

21. J.P. Morgan LTCMA 2024.

Figure 3: Asset class building blocks



Source: J.P. Morgan, Morgan Stanley, World Gold Council. See **Appendix A**: Data for data descriptions.

Conclusion

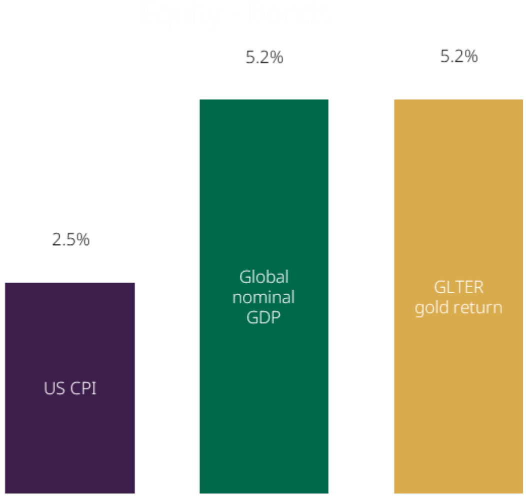
In our view, any model that fails to account for economic growth alongside financial factors will prove insufficient in establishing gold's long-term expected return.

Our novel contribution highlights the theoretical and empirical importance of *economic growth* and gold's role in *global portfolios* in driving gold prices in the long run.

GLTER complements our other gold pricing models, GRAM and Qaurum, where economic expansion is present but not a central driver given their short- and medium-term focus. And it explains why gold's long-term return has been, and will likely remain, well above inflation.[22]

Figure 4: Gold's return over the coming decade will be influenced by expected global economic growth

Expected annual growth in US CPI, global nominal GDP and modelled gold price using GLTER (2025-2040)*



*CPI forecast from J.P. Morgan LTCMA 2024. Assuming forecast horizon of 10-15 years. Expected GDP growth from Oxford Economics Global Scenario service baseline forecast. Equity and bond returns from J.P. Morgan LTCMA 2024 using AC World equities and World Government bonds respectively. Growth in outstanding shares and bonds calculated using 5-year average issuance. Modelled GLTER gold return as described in Table 1.
Source: J.P. Morgan, Oxford Economics, World Gold Council. See **Appendix A**: Data for data descriptions.

22. Using J.P. Morgan long-term capital market assumptions, GLTER suggests that gold return between 2025-2040 is expected to be above that of US Intermediate US Treasury bonds and World government bonds. For more, see Appendix E: Long-term capital market assumptions.

Appendix

Appendix A: Data

The data used in our analyses comes from various sources.

- For gold price data, we use the LBMA London PM spot price from January 1971, sourced from Bloomberg
- Nominal global GDP is sourced from the Federal Reserve Bank of St Louis FRED database
- Annual world equity market capitalisation from 1975 to 2022 is sourced from the World Federation of Exchanges and is backdated to 1971 using Wilshire 5000 index returns from Bloomberg
- Annual bond market capitalisation, represented by total global non-financial debt outstanding, is sourced from the BIS
- Data on the supply and demand categories is sourced from Metals Focus, and prior to 2010, from Refinitiv GFMS
- The stock of gold is sourced from Goldhub, via Metals Focus, and historical values are generated by subtracting from respective categories
- Forecasts of global nominal GDP in US dollars come from Oxford Economics, and equity and bond returns forecasts come from the J.P. Morgan Long-Term Capital Market Assumptions 2024 (LTCMA, 28th Edition). Additional building blocks sourced from Morgan Stanley's LTCMA 2023 for illustration.

Appendix B: Robustness tests of OLS regressions

The initial econometric specification, for estimating gold's long-run expected return is presented in **Table 1, p.8**. In **Table 3** we show some alternative specifications and discuss them relative to Model (2) above, which is our preferred model.

Regardless of specification GDP always has a positive coefficient. The coefficient on global portfolio is positive if GDP is not included in the equation. This switching of the sign is a marginal effect as discussed above and is consistent with GDP being the stronger effect on gold returns, as is sometimes seen in microeconomic studies where the income effect dominates the substitution effect, causing the sign on substitutes to flip when a measure of income is included.

Table 3: Alternative model specifications

Dependent variable:	Log gold price, US$/oz		
	Model (4)	Model (5)	Model (6)
Log global nominal GDP		3.089***	1.869**
Log equity market cap			-0.548**
Log debt market cap		-1.225***	
Log global portfolio	0.4003***		
Observations	53	53	5
Adjusted R^2	0.67	0.95	0.8
Phillips-Perron unit-root test (p-value)	0.063*	0.030**	0.11

Note: ***,**,* represent statistical significance at the 1%, 5% and 10% levels respectively. Annual data from 1971 to 2023.

Source: Bloomberg, BIS, Federal Reserve Bank of St Louis, LBMA Gold Price PM, WFE, World Gold Council. See **Appendix A**: Data for data descriptions.

Using alternatives for the financial component, such as equity or debt market caps, gives the same intuition as for global market cap where the sign is consistently negative when paired in a regression with GDP as the other independent variable. The marginal negative coefficient for debt in particular may reflect that issuance often must be absorbed regardless of yield, as we saw in Europe after the Global Financial Crisis, which might crowd out investments in alternatives such as gold.

While some specifications do show evidence of cointegration when only growth or financial factors are included in univariate regressions, it is clear from the Philips-Perron tests that the best examples of cointegration, and therefore long-run equilibrium systems, are found when both are included.

But there are two challenges with these specifications. The first is the presence of multicollinearity among the independent variables. Multicollinearity exists when there is a strong correlation among the independent variables that can give rise to several issues:

- Unreliable coefficient estimates from the standard errors are inflated making them less precise
- Instability in coefficient estimates with small changes have potentially large impacts on parameter estimates
- Model overfitting, which can lead to fitting more noise than the actual theoretical relationships

Multicollinearity can be tested by the variance inflation factor (VIF). The VIF assesses how much the variance of an estimated regression coefficient is "inflated" by the presence of multicollinearity. When VIF values are high, it indicates that a predictor variable can be accurately predicted by other variables in the model, suggesting redundancy or high correlation. VIF values above 10 are often considered a concern, indicating potentially problematic multicollinearity. The VIF values for the estimated OLS equation are shown in Table 4.

Table 4: Variance inflation factors (OLS)

Variance inflation factors		
Sample: 1971-2023		
Included observations: 52		
	Coefficient	
Variable	Variance	Centred
		VIF
Log global nominal GDP	0.049	
Log global portfolio	0.013	392
C	3.365	392

Source: Bloomberg, BIS, Federal Reserve Bank of St Louis, LBMA Gold Price PM, WFE, World Gold Council. See **Appendix A**: Data for data descriptions.

A common method of dealing with multicollinearity would be to remove one or more of the independent variables. For this study, it is critical to include all three variables. Ridge regression is an extension of OLS that is designed to address multicollinearity.

Ridge regression modifies the ordinary least squares by adding a penalty term or shrinkage parameter to the regression equation. This penalty term is based on the sum of the squares of the coefficients (also known as L2 regularisation), effectively constraining the coefficients and preventing them from reaching extreme values. It does so by shrinking the coefficients towards zero, particularly those of highly correlated predictors, without eliminating them entirely. This helps to reduce the variance of the coefficient estimates, making them more reliable and less sensitive to small changes in the data.

The model was estimated using ridge regression and the results are shown in Table 5.

The estimated coefficients from the ridge regression are smaller in absolute value than the OLS model, but well within a range that allows one to conclude that the underlying theoretical relationships have not changed meaningfully. This approach helps to address the presence of highly correlated independent variables and would help reduce the variance in the model but it does not address the second challenge with the original OLS model: attempting to estimate a cointegrating relationship among the variables.

Cointegration is a statistical concept that describes a long-term equilibrium relationship between two or more non-stationary time series variables. In simpler terms, cointegration reflects a situation where multiple variables are linked in such a way that even though, individually, they might wander away from each other in the short run, they tend to move together in the long run.

Table 5: Ridge regression

Dependent variable: Log gold price			
Method: Elastic net regularisation			
Sample: 1971-2023			
Included observations: 53			
Penalty type: Elastic Net (alpha = 1)			
	(Minimum)	(+ 1 SE)	(+ 2 SE)
Variable		Coefficients	
Log global nominal GDP	2.661	2.154	1.834
Log global portfolio	-0.987	-0.721	-0.554
C	-22.457	-18.335	-15.739

Source: Bloomberg, BIS, Federal Reserve Bank of St Louis, LBMA Gold Price PM, WFE, World Gold Council. See **Appendix A**: Data for data descriptions.

This study was designed to better understand the long-run expected return of nominal gold prices. The independent variables were chosen based on their theoretical relationship with gold over the long run. Therefore, estimating the most precise cointegrating equation possible is a stronger concern than dealing with multicollinearity.

OLS estimation of a single equation cointegrating model has been widely used since Engle and Granger introduced the two-step procedure in 1987. OLS is commonly used in this framework due to its computational efficiency and ease of interpretation. There are, however, some disadvantages:

- Inefficient parameter estimates resulting from the violation of the OLS assumption of strictly exogenous independent variables
- The presence of serial correlation potentially leads to biased standard errors and/or incorrect inference
- The lack of an error-correction mechanism means that both short and long term effects are estimated.

Phillips and Hansen introduced fully modified least squares (FM-OLS) to address these issues and improve the coefficient estimates in a cointegrating framework. The advantages of FM-OLS over OLS include:

- Correcting for endogeneity leads to less biased and more consistent coefficient estimates
- Correcting for the possible presence of serial correlation leads to possibly more efficient estimates
- Some of the stricter OLS assumptions can be relaxed.

The model was estimated using FM-OLS. The results are shown in Table 6.

Table 6: Fully modified (FM-OLS)

Dependent variable: Log gold price				
Method: Fully modified least squares (FM-OLS)				
Sample (adjusted): 1972-2023				
Included observations: 52 after adjustments				
Cointegrating equation deterministics: C				
Long-run covariance estimate (Bartlett kernel, Newey-West fixed bandwidth = 4.0000)				
Variable	Coefficient	Std. error	t-Statistic	Prob.
Log GDP	3.065	0.384	7.989	0.000
Log global portfolio	-1.198	0.199	-6.025	0.000
C	-25.761	3.237	-7.959	0.000
R^2	0.912		Mean dep var	6.190
Adjusted R^2	0.909		Std. dep var	0.827
S.E. of regression	0.250		Sum squared resid	3.055
Long-run variance	0.149			

Source: Bloomberg, BIS, Federal Reserve Bank of St Louis, LBMA Gold Price PM, WFE, World Gold Council. See **Appendix A**: Data for data descriptions.

The model fit in both the FM-OLS and OLS is similar, with a 91% adjusted R^2. The coefficient estimates are also similar in size and magnitude.

This Appendix addresses the estimation challenges of both multicollinearity and cointegration. There is no clear method that allows both issues to be addressed simultaneously and there is a trade-off when addressing one over the other. The ridge regression was estimated to demonstrate the effect on coefficient estimates to address multicollinearity. The FM-OLS model was estimated to address cointegration. Both additional models resulted in similar coefficient estimates, providing support to the original OLS coefficient estimates and the theoretical relationships discussed in this report.

Table 7: Phillips-Perron unit-root test of residuals

Null hypothesis: FM-OLS residuals have a unit root			
Exogenous: Constant			
Bandwidth: 1 (Newey-West automatic) using Bartlett kernel			
		Adj. t-Stat	Prob.*
Phillips-Perron test statistic		-3.407	0.002
Test critical values:	1% level	-3.565	
	5% level	-2.920	
	10% level	-2.598	

*MacKinnon (1996) one-sided p-values.

Source: Bloomberg, BIS, Federal Reserve Bank of St Louis, LBMA Gold Price PM, WFE, World Gold Council. See **Appendix A**: Data for data descriptions.

Appendix C: Why 1971?

Our analysis starts in 1971, rather than 1968 or any other important turning points in the gold market that have been used elsewhere.

If we used a point for our analysis that started before the failure of the gold pool in 1968,[23] we would need to include data where the price did not adjust to market pressures: at that time it was set by central banks and governments. There were brief periods of free gold prices on the London market in the 1920s, and again in the 1930s, but these were seen as interim periods between the officially desired Gold Standard, rather than permanent changes.[24] Additionally, gold was a different asset during the Bretton Woods era, acting as money rather than a financial asset. The same logic applies to start dates in the 1800s.

April 1968 is often used as a starting point for analysis as this was the time when a free-floating gold price re-emerged in the London gold market.[25] But there remained an "official" market for gold running in parallel until 1971, as it was widely expected that a form of Gold Standard would make an imminent return.

When the gold window was closed in 1971, suspending convertibility of gold into US dollars at a fixed price, only a free market for gold remained. Price movements, while at times driven by the possibility of a return to a Gold Standard, were not constrained by official actions to limit price and gold became more of an investment asset, remaining so to the present day.

Another often used date is the end of 1974, when US citizens were legally allowed to buy gold for the first time since 1933. However, a number of reasons make this a less important date for a change in the gold market than the idea might suggest. Gold prices reached a peak the day before the liberalisation of the market, in expectation of a surge of pent-up US demand. These record prices resulted in a lack of demand in the US for newly available gold futures or physical gold products. Demand was also lower than expected as, despite restrictions, some Americans already owned gold, which they held abroad, and others had only memories of gold investment that involved the confiscation of their holdings in 1933 – a further deterrent.[26]

Appendix D: GDP as a driver of demand

Here we replicate and update some of the results from the Goldman Sachs document 'Precious Metals Primer: Fear and Wealth' (2017), in particular Exhibit 13.

We explore the drivers of demand in world, emerging and developed markets, in **Table 8**.

Table 8: Sensitivity of jewellery and bar and coin to economic growth

	World	World	EM	EM	DM	DM
Panel A: Jewellery						
Log gold price	-0.86***	-0.59**	-1.96***	-0.64	-1.05***	-1.05
Log global nominal GDP	1.25***	1.06***	2.12***	1.18***	1.22***	1.22
Log fear*		0.001		0.001		0.001
Panel B: Retail bar and coin						
Log gold price	0.69***	0.87***	0.56***	0.99**	1.05***	5.17***
Log savings	0.12**	0.04	0.25**	-0.05	-0.13	-1.97**
Log fear*		0.001		0.001		0.000
Years	1980-2023	2007-2023	1995-2023	2007-2023	1995-2023	2007-2023

* Fear variable is the difference between the flows to bonds vs equities.
***, **, * show significance at the 1%, 5% and 10% levels.
Source: Fear and Wealth (Goldman Sachs Research, 2017), World Gold Council

23. See, for example, Barro, R.J. and Misra, S. (2016) 'Gold returns' The Economic Journal, 126(594), pp. 1293-317.
24. See O'Connor and Lucey (forthcoming) for a full discussion of these markets.
25. Green, T. (2007) 'The Ages of Gold', Gold Fields Minerals Services Ltd., London.
26. O'Connor, F. (2024) 'A Tale of Two Launches: Gold Futures 1974 and Bitcoin ETFs 2024', *The Alchemist*, 113, p. 8.

In Panel A we can see that jewellery's income elasticity of demand – measured through GDP – is greater than 1 in all cases. A 1% rise in GDP sees a 1% average increase in demand across the globe, and a reaction twice as large in EM markets – indicating the importance of growth for physical gold markets.

Panel A shows a clear negative price elasticity for jewellery demand regardless of whether we look at world, DM or EM. This reflects the sensitivity of jewellery buyers to the price of gold, with a 1% price rise in EM markets resulting in a nearly 2% fall in tonnage demand for jewellery.

Equally, retail bar and coin demand is significantly impacted by a rise in savings – a more concentrated proxy for wealth – but fear (investment flows into bonds less equities) has dominated over the last decade and a half, likely driven by the impact of the Global Financial Crisis.

Appendix E: Long-term capital market assumptions

Here's an excerpt of J.P. Morgan 2024 Long-Term Capital Market Assumptions.

Table 9: Expected performance of reference assets

Category	10-15 year compounded return
US inflation	2.5%
US cash	2.9%
US intermediate Treasuries	3.9%
World government bonds	4.8%
US large cap equity	7.0%
All country world equity	7.8%

Source: J.P. Morgan 2024 LTCMA

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