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Risk Return Structure of crystalline Osmium as a part of Investment Portfolios

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Abstract
Precious metals such as gold and silver have long been considered a stable form of investment and have proven to be effective diversification instruments within multi-asset portfolios in numerous empirical studies. With the increasing standardization and certification of crystalline osmium, the question arises as to whether this precious metal, which has been little researched to date, can also help optimize the risk-return profile.
This paper examines the risk-return structure of crystalline osmium compared to gold and silver, particularly with regard to its role as an addition to traditional equity investments. The focus is on an empirical analysis of rolling volatilities and correlations in the period from November 6, 2017, to March 20, 2025, based on daily returns. To assess the diversification potential, portfolio combinations of the three precious metals are formed with the S&P 500, the MSCI World Index, and the DAX. The focus is on the comparison between crystalline osmium and the established precious metals.
The aim of the paper is to examine whether crystalline osmium can be a valuable portfolio addition based on portfolio theory indicators, despite its limited market liquidity, due to its low correlation and stable volatility structure. The article thus closes a research gap in the field of alternative precious metal investments and makes a first empirical contribution to the portfolio-theoretical classification of crystalline osmium as a potential eighth precious metal in the investment context.

Keywords
Finance, precious metals, Osmium, Portfolio theory, portfolio performance, diversification

Introduction

Since the end of the Bretton Woods system in 1971, the role of precious metals as an asset class has changed considerably. In times of economic uncertainty – such as during the 2008 financial crisis or the COVID-19 pandemic – investors are increasingly looking for safe havens for their capital. Gold and silver have established themselves as proven instruments for diversification and hedging against inflation (Baur & McDermott, 2010; Hillier et al., 2006; Creti et al., 2013; Alqaralleh & Canepa, 2022; Lei et al., 2023; Talbi et al., 2021; Basher & Sadorsky, 2016). Studies show that adding precious metals such as gold and silver to a portfolio can lead to greater stability and risk diversification (Baur & Lucey, 2010; Uzik et al., 2023).

The integration of precious metals into investment portfolios is particularly recommended due to their low or negative correlation to traditional asset classes such as equities and bonds. Gold often has a low or even negative correlation with equity markets, making it an effective means of minimizing risk (Baur & McDermott, 2010; Sen & Chakrabarti, 2024; Echaust & Just, 2022; Hoang et al., 2015; Hood & Malik, 2013). Silver, although more volatile than gold, also offers diversification benefits, particularly in specific market phases (Lucey & Li, 2015; Ul Haq et al., 2024).

More recently, crystalline osmium, the eighth and rarest precious metal, has increasingly become the focus of scientific and investment-related considerations (Jakić, 2021). Due to its unique physical properties, such as the highest density of all stable elements (22.61 g/cm³), as well as its chemical inertness, crystalline osmium is being discussed as a potentially attractive alternative asset class. Unlike raw osmium in sponge form, which is considered toxic, crystalline osmium has been classified as non-toxic in scientific studies and as thermally stable up to over 600°C (Pelclova, 2022; Jehn, 1984).

The scientific literature on crystalline osmium as an investment is currently still limited. With the exception of a few publications – in particular by Jakić (2021), which only deals with crystalline osmium descriptively – there are currently no empirical studies on the crystalline osmium asset class within the framework of portfolio theory. However, initial indicative analyses suggest that, due to its low correlation with traditional markets and its stable volatility structure, crystalline osmium has the potential to contribute to both volatility reduction and return optimization.

Recent studies highlight the growing role of hybrid and multi-criteria decision support approaches in portfolio theory and investment risk management. Gavurova et al. (2025) emphasize the importance of hybrid decision models for evaluating socio-economic impacts in complex systems, combining statistical and expert-based reasoning. Similarly, Skare et al. (2024) demonstrate the efficiency of fuzzy multi-criteria models for balancing multiple performance indicators under uncertainty. Kelemen et al. (2022) further confirm that integrated hybrid frameworks enable a more holistic evaluation of risk and sustainability factors, which is directly applicable to diversified investment portfolios involving alternative assets, such as crystalline osmium.

This paper aims to systematically examine the risk-return structure of crystalline osmium in comparison to gold and silver, as well as to leading stock indices (S&P 500, MSCI World, DAX). The focus is on multi-asset portfolio combinations of crystalline osmium, silver, and gold with the indices mentioned. This should clarify whether crystalline osmium is suitable as a separate, supplementary asset class for improving portfolio efficiency.

Material and Methods

For this study, the period from November 6, 2017, to March 20, 2025 was selected. The start date corresponds to the first documented market price for crystalline osmium in certified form, which means that the analysis includes the entire price history of this asset class that is available to date. The observation period allows for a well-founded empirical analysis across several market cycles and thus creates the basis for a reliable portfolio-theoretical classification. The analysis included a total of six asset classes, which can be divided into two groups: firstly, the group of precious metals consisting of gold, silver, and crystalline osmium, and secondly, the group of stock market indices consisting of the S&P 500 Composite Index, the MSCI World Index, and the DAX Performance Index. The aim is to compare crystalline osmium with established precious metals and traditional market benchmarks in terms of its risk-adjusted performance and its suitability for diversification in multi-asset portfolios. The price data for crystalline osmium was taken from the website www.osmium-preis.com, which provides daily updated spot prices in euros per gram for certified crystalline osmium. For gold and silver, historical prices were obtained from the platform www.westmetall.com, which provides daily published precious metal prices in US dollars per troy ounce. The prices of the stock indices S&P 500, MSCI World, and DAX were extracted using the professional financial database Refinitiv EIKON. To calculate the daily returns, continuous returns were used for all asset classes, which were calculated using the natural logarithm function according to the following formula:

$$r_{i,t} = ln\left(\frac{K_{i,t}}{K_{i,t-1}}\right). \quad (1)$$

In this context, $K_{i,t}$ denotes the price of the respective asset class i at time t. This method of logarithmic returns allows for an additive aggregation over time and is particularly suitable for higher-frequency time series with low volatility. Volatility and correlation were calculated based on 260-day windows, corresponding to the average number of trading days per year. In order to map dynamic developments over time, both key figures were calculated on a rolling basis, i.e., for each new date, a moving window was placed over the previous 260 return values. This made it possible to track the temporal change of the risk and correlation structures between the asset classes in detail. This methodological approach allows for the evaluation of crystalline osmium both in cross-section (compared to other asset classes) and over time, and provides the basis for further portfolio calculations and the examination of diversification effects within mixed asset allocations.

Two scientific questions are posed. These are intended to examine whether, on the one hand, portfolios with crystalline osmium achieve a higher average return than the reference portfolios without crystalline osmium and, on the other hand, whether the portfolios with crystalline osmium lead to lower volatility than the corresponding reference portfolios. Thus, the following hypotheses are tested:

- (H_{01}): The average return of the portfolio with crystalline osmium does not differ significantly from the return of the reference portfolio without osmium.
- (H_{02}): The volatility of the portfolio with crystalline osmium does not differ significantly from the volatility of the reference portfolio without osmium.

The test for these two hypotheses is carried out using a two-sample t-test. The respective reference portfolios are compared with the benchmark portfolio. The MSCI World Index is defined as the benchmark portfolio. The risk-return structures of the three precious metals —silver, gold, and crystalline osmium —and the two multi-asset portfolios are then compared with the benchmark portfolio.

Two multi-asset portfolios are constructed from the three precious metals silver, gold, and crystalline osmium, and the three indices DAX, S&P500, and MSCI-World. The first multi-asset portfolio considers all six assets equally. The second step involves performing a portfolio optimization, where the weighting results in a minimum-variance portfolio based on the available data.

According to modern portfolio theory, as developed by Markowitz (1952), the two central parameters for evaluating portfolios are the expected return and the associated volatility (risk). Both parameters can be precisely described mathematically for a portfolio consisting of nnn different asset classes.

The portfolio return is the weighted arithmetic mean of the expected individual returns. Mathematically, the expected return of a portfolio r_{PF} is calculated from the scalar product of the weighting vector **x** and the return vector **r**:

$$r_{PF} = \boldsymbol{x}^T \times \boldsymbol{r} \,. \tag{2}$$

The portfolio volatility (standard deviation of portfolio returns) is derived from the variance-covariance matrix of the returns on the individual assets and their respective weightings in the portfolio.

σ_{PF}: standard deviation of the portfolio (volatility)
x: vector of portfolio weights (column vector)
Σ: covariance matrix of asset returns

$$\boldsymbol{x} = \begin{bmatrix} x_1 \\ x_2 \\ \vdots \\ x_n \end{bmatrix}. \tag{3}$$

$$\sum = \begin{bmatrix} \sigma_1^2 & Cov(1,2) & \cdots & Cov(1,n) \\ Cov(2,1) & \sigma_2^2 & \cdots & Cov(2,n) \\ \vdots & \vdots & \ddots & \vdots \\ Cov(n,1) & Cov(n,2) & \cdots & \sigma_n^2 \end{bmatrix}. \tag{4}$$

Results

In the observed period from November 6, 2017, to March 20, 2025, a performance analysis was carried out for eight precious metals, including gold, silver, and crystalline osmium, on the basis of daily returns using the

Laspeyres index. The index development shows that gold has recently reached new all-time highs several times, but that the other precious metals have also been in focus.

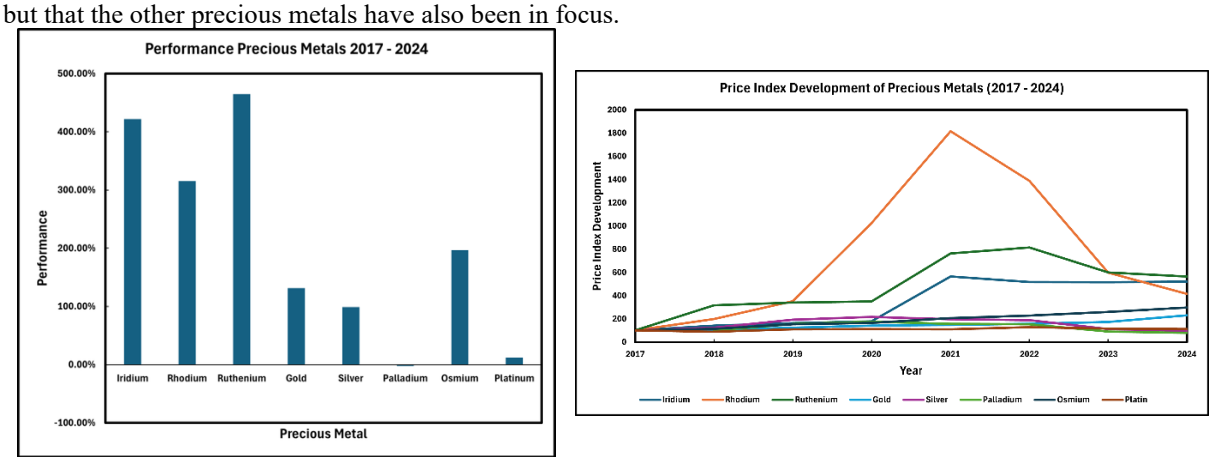

Fig. 1. Index development and overall performance of precious metals 2017-2024.

During the period under review, the crystalline osmium managed to outperform the established precious metals silver and gold. The calculations of volatilities and correlations once again bring crystalline osmium into focus. Crystalline osmium proved to be particularly interesting in terms of its correlation to the stock indices examined (DAX, S&P 500, MSCI World): the correlations are very low overall and are even negative for crystalline osmium in some cases. From a portfolio theory perspective, this suggests that osmium can be an effective addition to existing investments in order to reduce overall risk.

Tab. 1. Rolling volatility and correlation.

	Korrelation (rolling) 260d					*Korrelation (rolling) 260d*					
Date	*Osmium -Gold*	*Osmium -DAX*	*Osmium - S&P500*	*Osmium -MSCI World*	*Osmium -Silver*	*Gold-DAX*	*Silver-DAX*	*Gold-S&P500*	*Silver-S&P500*	*Gold-MSCI World*	*Silver-MSCI World*
20.03.2025	*-0.03*	*-0.31*	*-0.18*	*-0.23*	*-0.07*	*-0.01*	*0.06*	*0.06*	*0.07*	*0.10*	*0.11*
31.12.2024	*-0.02*	*-0.18*	*-0.16*	*-0.18*	*-0.05*	*0.02*	*0.07*	*0.02*	*0.05*	*0.07*	*0.09*
29.12.2023	*0.08*	*-0.13*	*-0.09*	*-0.09*	*0.08*	*0.10*	*0.08*	*0.09*	*0.11*	*0.13*	*0.12*
30.12.2022	*-0.08*	*-0.06*	*0.05*	*0.01*	*-0.08*	*0.02*	*0.08*	*-0.01*	*0.04*	*0.04*	*0.08*
31.12.2021	*0.05*	*0.13*	*0.02*	*0.06*	*0.05*	*0.10*	*0.13*	*0.08*	*0.11*	*0.15*	*0.19*
31.12.2020	*-0.02*	*-0.03*	*-0.03*	*-0.02*	*-0.08*	*0.15*	*0.25*	*0.19*	*0.27*	*0.21*	*0.30*
30.12.2019	*0.03*	*-0.08*	*-0.11*	*-0.11*	*0.02*	*-0.08*	*-0.03*	*0.09*	*0.15*	*0.06*	*0.11*
31.12.2018	*-0.16*	*0.01*	*-0.01*	*-0.03*	*-0.09*	*-0.03*	*0.06*	*0.10*	*0.14*	*0.13*	*0.14*
Average 2018-2025	*-0.02*	*-0.08*	*-0.06*	*-0.07*	*-0.03*	*0.03*	*0.09*	*0.08*	*0.12*	*0.11*	*0.14*

The results of the calculations show that crystalline osmium has a largely independent risk structure compared to gold and silver. Based on the same data, multi-asset portfolios were then compiled, consisting of gold, silver, crystalline osmium, and the three stock indices. On the one hand, an equal-weight portfolio was created from all six asset classes, and on the other hand, a minimum variance portfolio was generated using portfolio optimization.

Tab. 2. Weighting of the minimum variance portfolio.

Portfolio Asset	Weights
Osmium	52.11%
Gold Fixing London	27.76%
DAX	8.06%
S&P 500	0.00%
MSCI World Index	12.07%
Silber	0.00%
Volume	100.00%

The calculation of the minimum variance portfolio based on daily logarithmic returns and a rolling 260-day volatility showed a clear dominance of crystalline osmium in the portfolio. With a share of 52.11%, osmium is the main component. Gold follows with 27.76%, while the MSCI World Index accounts for 12.07%. The DAX was weighted at 8.06%, while silver and the S&P 500 were not included in the optimal risk minimization model. This result highlights the central role of osmium in a portfolio with minimal risk, even though it is rarely traded on established financial markets.

To visualize performance, all portfolios were mapped using a Laspeyres index, with 2017 serving as the base year (index = 100). Compared to the MSCI World Index, the minimum variance portfolio showed a significantly more stable performance with lower volatility. Particularly during volatile market phases (for instance, pandemic or geopolitical crises), the portfolio with a high osmium share proved to be less volatile than the benchmark.

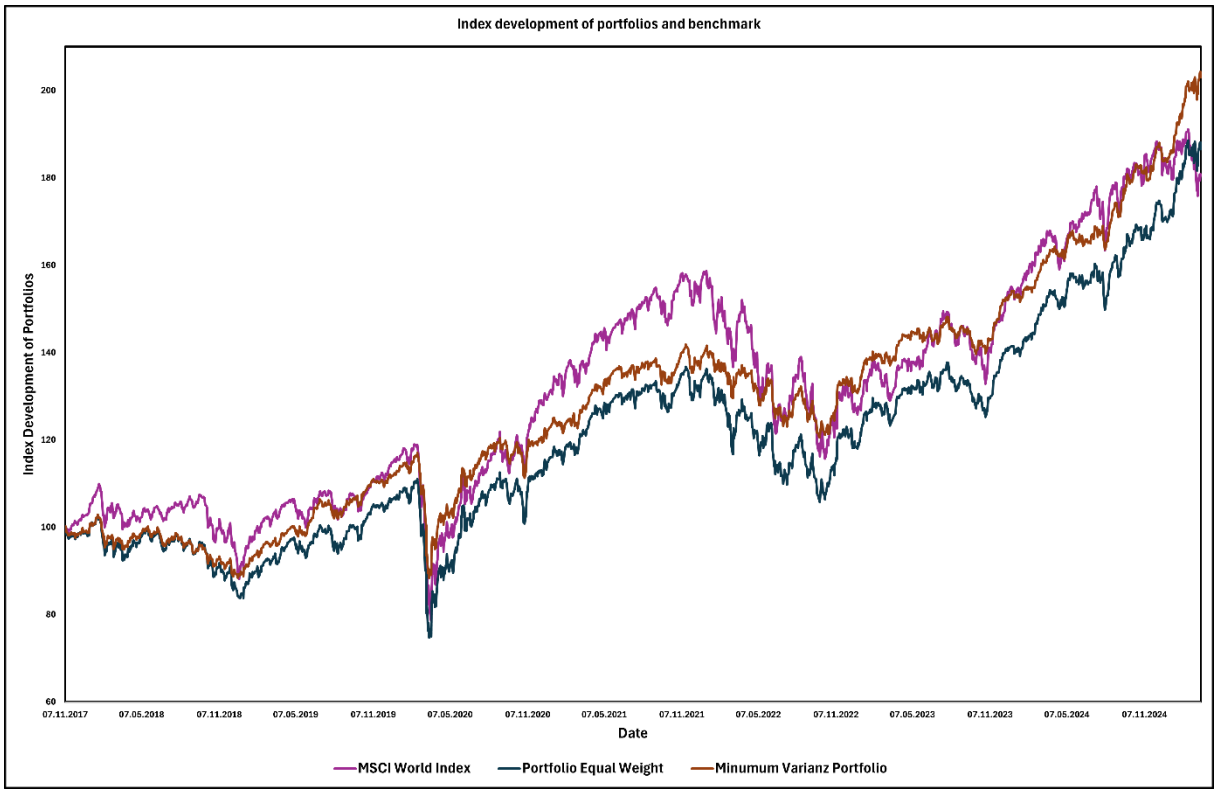

Fig. 2. Index development of portfolios and benchmark (MSCI World Index) 2017-2024.

The analysis of correlations reveals that crystalline osmium exhibits a very low, and sometimes even negative, correlation to all major stock indices (MSCI World, S&P 500, DAX) throughout the entire period. On average, the correlation of crystalline osmium to the indices was between –0.06 and –0.08, which indicates considerable diversification potential from a portfolio theory perspective. Osmium also has an independent risk structure compared to gold and silver, with an average correlation of –0.02 to gold and –0.03 to silver.

Tab. 3. Correlation matrix

Correlations

		MSCI World Index Return	Osmium Return	Gold Fixing London Return	DAX Return	S&P 500 Return	Silver Return	Portfolio Equal Weight Return	Minumum Varianz Portfolio Return
MSCI World Index Return	Pearson Correlation	1	-0.028	.125**	.700**	.967**	.179**	.857**	.766**
	Sig. (2-tailed)		0.238	0.000	0.000	0.000	0.000	0.000	0.000
	N	1842	1842	1842	1842	1842	1842	1842	1842
Osmium Return	Pearson Correlation	-0.028	1	-0.015	-0.041	-0.018	-0.019	-0.011	.157**
	Sig. (2-tailed)	0.238		0.508	0.080	0.434	0.410	0.651	0.000
	N	1842	1842	1842	1842	1842	1842	1842	1842
	Pearson Correlation	.125**	-0.015	1	.059*	.092**	.678**	.182**	.319**

Gold Fixing London Return	Sig. (2-tailed)	0.000	0.508		0.012	0.000	0.000	0.000	0.000
	N	1842	1842	1842	1842	1842	1842	1842	1842
DAX Return	Pearson Correlation	.700**	-0.041	.059*	1	.571**	.137**	.958**	.932**
	Sig. (2-tailed)	0.000	0.080	0.012		0.000	0.000	0.000	0.000
	N	1842	1842	1842	1842	1842	1842	1842	1842
S&P 500 Return	Pearson Correlation	.967**	-0.018	.092**	.571**	1	.147**	.759**	.651**
	Sig. (2-tailed)	0.000	0.434	0.000	0.000		0.000	0.000	0.000
	N	1842	1842	1842	1842	1842	1842	1842	1842
Silver Return	Pearson Correlation	.179**	-0.019	.678**	.137**	.147**	1	.254**	.310**
	Sig. (2-tailed)	0.000	0.410	0.000	0.000	0.000		0.000	0.000
	N	1842	1842	1842	1842	1842	1842	1842	1842
Portfolio Equal Weight Return	Pearson Correlation	.857**	-0.011	.182**	.958**	.759**	.254**	1	.966**
	Sig. (2-tailed)	0.000	0.651	0.000	0.000	0.000	0.000		0.000
	N	1842	1842	1842	1842	1842	1842	1842	1842
Minumum Varianz Portfolio Return	Pearson Correlation	.766**	.157**	.319**	.932**	.651**	.310**	.966**	1
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	
	N	1842	1842	1842	1842	1842	1842	1842	1842

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Two separate t-tests were carried out to test the hypotheses formulated at the beginning:

Volatility (H_{02}): The two-sample t-test showed that crystalline osmium, the equal-weight portfolio, and the minimum variance portfolio each had significantly lower volatility than the MSCI World Index (all *p*-values < 0.01). Thus, the null hypothesis H_{02} could be rejected at the 1% significance level in all cases. The integration of crystalline osmium into a portfolio thus contributes significantly to volatility reduction.

Tab. 4. Two-sample t-test for difference in volatility.

Paired Samples Test									
		Paired Differences							
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper	t	df	Sig. (2-tailed)
Pair 1	Osmium Vola rol 260d - MSCI World Index Vola rol 260d	-0.004	0.004	0.000	-0.004	-0.003	-34.428	1582	0.000
Pair 2	Gold Fixing London Vola rol 260d - MSCI World Index Vola rol 260d	-0.001	0.003	0.000	-0.002	-0.001	-20.851	1582	0.000
Pair 3	Silver Vola rol 260d - MSCI World Index Vola rol 260d	0.006	0.004	0.000	0.006	0.006	65.187	1582	0.000
Pair 4	Portfolio Equal Weight rol 260d - MSCI World Index Vola rol 260d	-0.001	0.001	0.000	-0.001	-0.001	-49.778	1582	0.000

Pair 5	Minumum Varianz Portfolio rol 260d - MSCI World Index Vola rol 260d	-0.003	0.002	0.000	-0.004	-0.003	-75.574	1582	0.000

The evaluation of the two hypotheses provides a differentiated picture regarding the effect of crystalline osmium on the risk-return structure of mixed portfolios.

The first hypothesis (H_{01}), according to which the average returns of the mixed portfolios with osmium do not differ significantly from those of the reference portfolios without osmium, could not be rejected in the t-test performed. The analysis showed that the integration of crystalline osmium into the portfolio structure does not generate significantly higher or lower returns compared to existing benchmark portfolios. This suggests a return-neutral effect, which in turn is advantageous if other effects – such as a reduction in volatility – make a positive contribution to portfolio stability.

Tab. 5. Two-sample t-test for difference in return.

Paired Samples Test									
		Paired Differences							
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper	t	df	Sig. (2-tailed)
Pair 1	Osmium Return - MSCI World Index Return	0.000	0.013	0.000	0.000	0.001	0.991	1841	0.322
Pair 2	Gold Fixing London Return - MSCI World Index Return	0.000	0.013	0.000	0.000	0.001	0.504	1841	0.614
Pair 3	Silver Return - MSCI World Index Return	0.000	0.018	0.000	-0.001	0.001	0.202	1841	0.840
Pair 4	Portfolio Equal Weight Return - MSCI World Index Return	0.000	0.005	0.000	0.000	0.000	0.141	1841	0.888
Pair 5	Minimum Varianz Portfolio Return - MSCI World Index Return	0.000	0.007	0.000	0.000	0.000	0.402	1841	0.688

By contrast, the second hypothesis (H_{02}), which assumes no significant difference in volatility between mixed and reference portfolios, was rejected with statistical significance. The corresponding two-sample t-test showed that portfolios with osmium exhibit significantly lower volatility. This proves that osmium has a risk-minimizing effect on the portfolios under consideration – especially in comparison to traditional allocations without osmium.

Overall, the results confirm that osmium in its certified, crystalline form fulfills a valuable function as a diversification component without reducing the return potential of the overall portfolio.

The results show that crystalline osmium does not significantly improve returns in a multi-asset portfolio, but it does achieve a statistically significant reduction in volatility. Osmium thus fulfills the requirements of an effective diversification tool and should be considered in future portfolio considerations, despite the still limited market depth.

Discussion

The empirical analysis shows that crystalline osmium has an independent risk structure that differs significantly from established precious metals such as gold and silver, as well as from broad stock market indices. In particular, the extremely low to negative correlation with stock indices such as the DAX, the S&P 500, and the MSCI World confirms the assumption of a substantial diversification effect. This property is of particular importance for modern portfolio theory according to Markowitz (1952), as it can contribute to an increase in efficiency – i.e., to a shift in the efficient frontier while maintaining the expected level of returns. While the risk-reducing effect of crystalline osmium is statistically significant in both empirical analyses, there are no significant differences in terms of the average return compared to benchmark portfolios. This underlines the fact that the diversification effect mainly occurs along the volatility axis – a finding that is comparable to the existing literature

on gold. Baur & McDermott (2010) and Hillier et al. (2006) show that gold can act as a safe haven, particularly in phases of heightened uncertainty, without systematically generating higher returns. Similarly, the results of this paper show that osmium fulfills a risk-optimizing function, but does not provide return-alpha. Another key difference between crystalline osmium and traditional precious metals lies in its market structure: While gold and silver have liquid, globally accessible markets, crystalline osmium is traded exclusively through certified distribution partners. This results in limited liquidity and potentially higher trading margins. Nevertheless, this structure also offers advantages, for example, in terms of protection against counterfeiting (through the Osmium Identification Code) and regulatory clarity, for example, under the EU Chemicals Regulation (see Pelclova, 2022). It is particularly noteworthy that crystalline osmium is given significantly higher weightings than gold or silver in the minimum variance portfolio, without significantly reducing the average portfolio return. This suggests that osmium can play a substantial role in the context of risk-averse investment strategies – an effect that has rarely been empirically demonstrated in the alternative investments literature. Despite these advantages, methodological and structural limitations must also be taken into account: the historical data basis for crystalline osmium is still short compared to traditional precious metals, which limits long-term statements. Furthermore, secondary trading is limited, which restricts the flexibility of institutional investors. Nevertheless, the present results expand the existing literature on the role of precious metals in multi-asset portfolios (Creti et al., 2013; Alqaralleh & Canepa, 2022; Lei et al., 2023; Talbi et al., 2021) by an innovative component with clear diversification potential.

In summary, it can be said that crystalline osmium represents a new precious metal component that has been largely neglected so far. Due to its unique combination of chemical inertness, structural anti-counterfeiting features, regulatory clarity, and market-independent pricing structure, it can be a valuable stability anchor in certain portfolio contexts. The results thus provide an empirical basis for a differentiated assessment of crystalline osmium in the context of strategic allocation decisions.

Conclusions

The study provides two key insights into the role of crystalline osmium in multi-asset portfolios. Firstly, thanks to its low or sometimes negative correlation to traditional stock indices and other precious metals, osmium can be a useful addition to a portfolio for risk diversification. This is reflected in significantly reduced portfolio volatility, as evidenced by the results for both the equal-weight portfolio and the minimum-variance portfolio. Second, no statistically significant return advantage over portfolios without osmium could be determined in the period under review. Consequently, the diversification benefits are primarily rooted in risk reduction. These findings support the potential importance of crystalline osmium as the eighth precious metal for investors seeking to hedge their portfolios against market fluctuations. At the same time, they make it clear that, based on the available data, it is not yet possible to increase return expectations in the current market environment unequivocally. Future research should complement the results obtained here with longer time series that include further market developments in order to enable even more robust statements about the return prospects of osmium. In addition, the analysis of additional market phases (especially crisis and stress situations) could provide further insights into the behavior of osmium as a portfolio building block.

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