

REDUCING NATURAL GAS RISK THROUGH THE CREATION OF A BIVARIATE PORTFOLIO

SMANJENJE RIZIKA PRIRODNOG GASA KROZ KREIRANJE BIVARIJANTNOG PORTFOLIJA

Papić-Blagojević Nataša | Novi Sad School of Business, Novi Sad, Serbia | npapic.blagojevic@gmail.com | ORCID 0000-0002-1110-3414

Kuzman Boris | Institute of Agricultural Economics, Belgrade, Serbia | kuzmanboris@yahoo.com | ORCID 0000-0002-8661-2993

Subić Jonel | Institute of Agricultural Economics, Belgrade, Serbia | jonel.subic@gmail.com | ORCID 0000-0003-1342-1325

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Abstract

The subject of this research is the minimization of natural gas risk, a key global energy source that has experienced significant price fluctuations in recent years. This volatility exposes investors in gas to financial risk, and the goal is to reduce this risk by creating a bivariate portfolio using the Markowitz methodology. Gas is combined with four different auxiliary instruments: gold and wheat futures, as well as composite indices from the USA and China—the S&P 500 and SHCOMP. The constructed portfolio is referred to as the minimum variance portfolio, which has the lowest variance among all possible combinations of the two instruments. The analysis is based on eight years of daily data from January 2017 to December 2024, to identify the best auxiliary instrument that, when combined with gas, would result in the lowest risk. The results indicated that, among the four portfolios created, the combination with gold yielded the best outcomes. Additionally, the hedging efficiency index demonstrated that the portfolio with gold achieves the highest degree of gas risk reduction, at 98.55%. As far as we are aware, no previous research has examined the integration of these four assets with oil within a bivariate portfolio framework. This gap in the literature serves as the central rationale for conducting this study.

Sažetak

Predmet istraživanja rada je minimizacija rizika prirodnog gasa, kao ključnog globalnog energetskeg izvora koji je poslednjih godina doživeo značajne oscilacije cena. Ova volatilnost izlaže investitore finansijskom riziku, pa je cilj rada usmeren na smanjenje rizika kroz kreiranje bivarijantnog portfolija uz korišćenje Markovicove metodologije. Gas se kombinuje sa četiri različita pomoćna instrumenta: fjučersima na zlato i pšenicu, kao i kompozitnim indeksima iz SAD-a i Kine—S&P 500 i SHCOMP. Konstruisani portfolio naziva se portfolio minimalne varijanse jer ima najnižu varijansu među svim mogućim kombinacijama dva instrumenta. Analizom su obuhvaćeni dnevni podaci u periodu od januara 2017. do decembra 2024. godine, kako bi se identifikovao najbolji pomoćni instrument koji bi, u kombinaciji sa gasom, rezultirao najmanjim rizikom. Rezultati su pokazali da je, među četiri kreirana portfolija, kombinacija sa zlatom dala najbolje rezultate. Pored toga, indeks efikasnosti hedžinga pokazao je da portfolio sa zlatom postiže najviši stepen smanjenja rizika prirodnog gasa od 98,55%. Koliko je nama poznato, nijedno prethodno istraživanje nije ispitalo integraciju ova četiri sredstva sa naftom u okviru bivarijantnog portfelja. Ova praznina u literaturi predstavlja osnovni motiv za sprovođenje ovog istraživanja.

Keywords: portfolio, futures contract, variance, Sharpe ratio, natural gas, risk

Ključne reči: portfolio, fjučers ugovor, varijansa, Šarpov racio, prirodni gas, rizik

Introduction

Natural gas is a major energy resource worldwide and it plays an increasingly pivotal role in the world energy market [1]. It serves not only as a direct energy source for end users but also as a crucial feedstock and fuel for industrial processes and the power sector [2]. The increasing integration between energy markets reduces the diversification opportunities and increases the vulnerability of energy markets to local external shocks [3]. In the last twenty years, significant economic changes have occurred in the structure of primary energy consumption. Natural gas has experienced the highest consumption growth, with an increase of 70%, while oil consumption has grown by 33% and coal consumption by 46%. Among the three, natural gas is the cleanest burning fossil fuel, since it emits the least amount of carbon dioxide when combusted [4].

The significant fluctuations in natural gas prices during the Russia-Ukraine conflict that began in 2022 have caused considerable global concern. Therefore, how to hedge these unprecedented market risks in the natural gas market becomes more and more urgent for policy makers, and natural gas market investors [5]. Several reasons justify why to hedge natural gas prices. First, hedging protects against sudden price spikes or drops due to geopolitical events, weather patterns, or supply chain disruptions. Second, for companies that rely on natural gas as a raw material, hedging can shield them from rising costs. Third, reduces exposure to market volatility and unpredictable price swings. Fourth, some industries are required to hedge to meet risk management standards.

Implemented hedging strategies have demonstrated that crude oil is the most effective asset for hedging natural gas, with gold and ECO being the next best options [6]. Górká and Kuziak [7] found that it is possible to achieve risk diversification across renewable, clean and green energy sources, natural gas, and crude oil, but hedging opportunities with oil and gas are quite limited. Živkov, Balaban, and Simić [8] sought to reduce the extreme risks linked to gas by developing multi-scale portfolios comprising six assets, which included gas alongside both developed and BRICS stock indices. Their research revealed that portfolios featuring BRICS indices had a slight edge, possibly because these countries exhibit a lower degree of market integration. Ghoddusi and Emamzadehfard [9] examined different dimensions of futures hedging within the U.S. natural gas market and concluded that incorporating cointegration and fluctuating prices over time has little impact on the hedge ratio and the effectiveness of hedging across most physical price points. Chiou-Wei et al. [10] examined the relationship between spot and futures returns and volatilities, linking them to key market fundamentals such as weather conditions, underground gas storage levels, oil prices, and macroeconomic news. Their findings indicate that most of these factors have a significant influence on gas prices. Additionally, empirical evidence reveals that the optimal hedge ratio was not stable but varied considerably throughout the sample period. A separate study [11] applied generalized autoregressive score-driven (GAS) models to futures hedging in crude oil and natural gas markets. For both commodities, GAS models demonstrate superior hedging effectiveness compared to alternative strategies, especially in the case of natural gas.

In recent years, electricity consumption patterns have undergone significant shifts, marked by a rising reliance on natural gas and oil, alongside an increasing emphasis on environmental sustainability and efficiency. To mitigate the risks associated with natural gas as a crucial global energy source, this study constructs a bivariate portfolio by pairing natural gas with SHCOMP, S&P 500, gold, and wheat. Given that the energy crisis remains one of the most pressing global challenges, the values of these key parameters exhibit considerable volatility and fluctuation.

The study's findings indicate substantial risk reduction when incorporating gold, wheat, S&P 500, and SHCOMP into investment portfolios. Also, in terms of the risk-return tradeoff (Sharpe ratio), portfolios that integrate these assets with natural gas demonstrate higher returns and lower risk than investing in natural gas alone. Depending on their risk tolerance, investors should consider including these assets in their portfolios. Moreover, raising the allocation of these assets within the portfolio results in an additional decrease in total risk.

This paper intentionally combines four different assets with natural gas, as they differ significantly in terms of their nature, underlying drivers, and volatility. This approach allows us to evaluate which auxiliary asset contributes most to the risk reduction of natural gas. To the best of our knowledge, this is the first study to combine these four assets with oil in a bivariate portfolio, providing the primary motivation for this research.

Materials and methods

Portfolio managers utilize a range of strategies in the construction of a securities portfolio, aiming to achieve the efficiency frontier and select an appropriate portfolio. When developing a portfolio strategy, managers have to analyze three dimensions: the past, present, and future. Harry M. Markowitz developed one of the most well-known portfolio strategies, introducing a mathematical model that supports effective portfolio diversification [12]. This model allows for the calculation of expected rates of return for various securities, while also minimizing portfolio risk through diversification. Due to the risk reduction potential of diversification, portfolio investment risk, measured as its variance, depends upon both individual assets' return variances as well as the correlation between portfolio assets [13] [14].

This paper constructs optimal portfolios by targeting minimum variance. To measure portfolio risk, it is essential to know not only the variance of the securities that constitute the portfolio but also the correlation of their expected returns risk [15]. This includes understanding the degree and direction of alignment between the expected returns of each pair of securities in the portfolio. A rational, risk-averse investor will seek returns with the lowest correlation, aiming for a minimum risk portfolio. Generally, the weaker the correlation among the securities, the greater the impact of diversification on reducing variability [16]. The correlation coefficient, which can be either positive or negative, is calculated using the following formula:

$$\rho = \frac{COV(r_a r_b)}{\sigma_A \sigma_B} \quad (1)$$

where ρ is the coefficient of correlation, $COV(r_a r_b)$ covariance of securities A and B, and $\sigma_A \sigma_B$ standard deviation of securities (A and B).

When choosing a portfolio to invest in, investors place significant importance on the risk level, measured by the portfolio's standard deviation. They also closely consider the expected return of the portfolio, as this represents their earnings. Typically, higher risk is associated with higher returns, and vice-versa. However, these two quantities are not perfectly correlated, meaning that among two instruments with the same return, one may carry a higher risk than the other. Both factors are considered by a financial metric known as the Sharpe ratio, which is calculated using the following formula [17]:

$$Sharpe \text{ ratio} = \frac{r_p - r_f}{\sigma_p} \quad (2)$$

where r_p is the portfolio return, r_f is the risk-free interest rate, and σ_p is the portfolio standard deviation.

The Sharpe ratio allows investors to determine whether portfolio returns are the result of taking on significant additional risk or stem from a sound investment strategy and superior security selection. This ratio measures the performance of an investment fund based on the relationship between reward and risk taken over a given period.

This paper focuses on a portfolio consisting of only two instruments. This approach to portfolio construction is easier to calculate because it does not involve traditional portfolio optimization; instead, it relies on the equation proposed by Kroner and Ng [18]. Constructing a portfolio with more instruments could provide better hedging results, but this methodology is significantly more complex as it involves optimization. This is the limitation of the applied model, but it is beyond the scope of the present paper and is left for future research. The Kroner and Ng [18] equation is presented in the following expression:

$$W_s = \frac{\sigma_p^2 - \text{COV}_{p,s}}{\sigma_p^2 + \sigma_s^2 - 2 * \text{COV}_{p,s}} \quad (3)$$

$$W_p = 1 - W_s \quad (4)$$

where W_s represents the share of the secondary instrument (s) in a portfolio of two instruments, W_p represents the share of the primary instrument (p), σ_p^2 is the variance of the primary instrument, σ_s^2 is the variance of the secondary instrument, and $\text{COV}_{p,s}$ is the covariance between the two instruments.

This equation calculates the share of the secondary instrument in a two-instrument portfolio that minimizes variance, thereby reducing the portfolio's overall risk and creating a minimum variance portfolio (MVP). A key assumption in this formula is that the primary instrument (in our case natural gas) is riskier than the secondary one. In portfolio management, the risk-reduction performance is assessed in terms of hedge effectiveness index (HEI), which is measured as in equation (5):

$$HEI = \frac{\sigma^2_{unhedged} - \sigma^2_{hedged}}{\sigma^2_{unhedged}} \quad (5)$$

The hedge effectiveness index (HEI) measures how well a hedging strategy reduces investment risk. It compares the variance of an unhedged investment, where only the primary instrument is used, to the variance of a hedged portfolio that includes both instruments. A HEI value close to one signifies a highly effective hedge, as it reflects a significant decrease in risk. Conversely, a HEI near zero indicates minimal risk reduction, while a negative value suggests that investing solely in the primary instrument is more advantageous than holding the portfolio. Notably, the HEI cannot exceed one. When determining the proportion of the secondary instrument in the portfolio, selecting a less risky secondary instrument is essential.

In the context of hedging risks in the gas market, this study creates bivariate portfolios by combining gas return time-series with those of supplementary assets such as gold, wheat, the S&P 500, and the SHCOMP index. Each of the selected assets plays a distinct role and responds differently to macroeconomic shocks, making them valuable for diversification when combined wisely. In other words, gold is a defensive, macro-driven asset; wheat is a volatile, supply-sensitive commodity with a role in the global food market; the S&P 500 is a core global equity benchmark reflecting U.S. economic strength; and the SHCOMP reflects the economy of the largest emerging market and one of the world's largest energy consumers. All time-series are collected from the investing.com website. The sample spans from January 2017 to December 2024, comprising the COVID-19 pandemic and the war in Ukraine. Table 1 presents a summary of the descriptive statistics for these return time series.

Table 1. Descriptive statistics

	Mean	Variance	Skew.	Kurt.	DF-GLS
Natural gas	0.001	1.869	0.262	10.957	-49.864
Gold	0.017	0.372	-0.368	6.219	-44.975
Wheat	0.008	1.009	0.705	19.367	-48.178
S&P 500	0.021	0.511	-0.861	19.295	-20.405
SHCOMP	0.001	0.462	-0.347	9.764	-43.361

Note: The critical values for the DF-GLS test with 5 lags, assuming only a constant, are -2.566 at the 1% significance level and -1.941 at the 5% significance level.

Source: Authors' calculation

Based on the mean values, our findings indicate that the S&P 500 provides the greatest average return, with gold, wheat, SHCOMP, and natural gas following in that order. This indicates that, on average, the S&P 500 index experienced the highest growth during the observed period. The average daily growth rate of natural gas is nearly zero, meaning that despite periods of high price increases, the average growth rate of natural gas is around zero in the observed period. This means that natural gas experienced significant price increases

and decreases in the observed period, indicating high volatility in this energy asset. This can be clearly seen in the left and right plots of Figure 1.

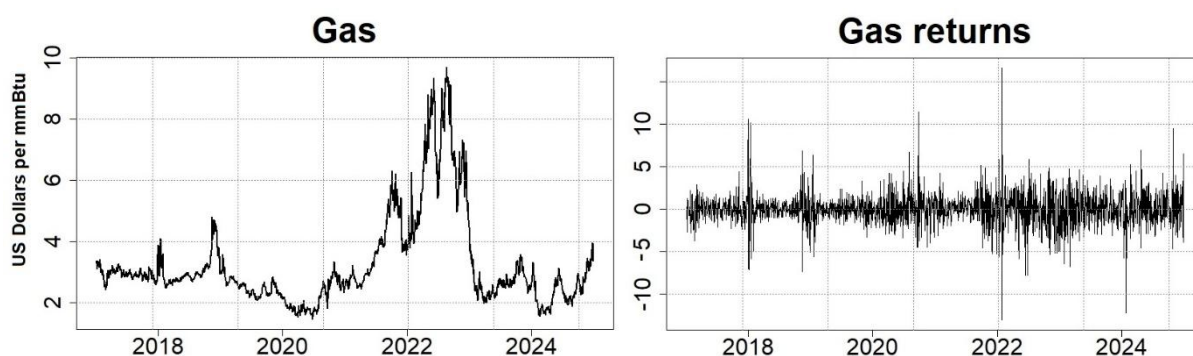


Figure 1. Dynamics of gas price and returns

Note: mmBtu indicates Million Metric British Thermal Unit.

Source: Authors' calculation

Variance measures the dispersion of values around the mean and is considered an indicator of reliability, or more specifically, a measure of risk. The variance results indicate that natural gas carries the highest risk (1.869). In contrast, all auxiliary instruments exhibit significantly lower risk levels. Among them, wheat has the highest risk (1.009), followed by the S&P 500 (0.511), while gold has the lowest risk (0.372). This indicates that all the supplementary assets are appropriate for combining with natural gas, as their risk profiles are significantly lower than that of gas.

Gold, the S&P 500, and SHCOMP exhibit negative skewness, while wheat and natural gas have positive skewness. Skewness describes the asymmetry of return distributions relative to the mean. A negative skew indicates that more negative returns are concentrated on the left side of the mean, whereas a positive skew indicates that returns are more concentrated on the right side. Kurtosis measures the presence of extreme values within a distribution. The highest daily deviations are observed in the S&P 500 and wheat indices, indicating that stock markets reacted more intensely to global events such as the COVID-19 pandemic and the conflict in Ukraine compared to commodity markets like gas, gold, and SHCOMP.

However, high kurtosis values do not influence the construction of bivariate portfolios. This is because equation (5) relies solely on the risk measures of the primary and secondary instruments, along with their covariances. As a result, the third and fourth moments of the distribution do not impact on the allocation of the secondary instrument within the portfolio.

Results and Discussion

The results of the constructed bivariate portfolios, designed to minimize gas risk, are presented in the following tables. Table 2 displays the allocation of the primary and secondary instruments within each portfolio, where natural gas serves as the primary instrument, while gold, wheat, the S&P 500, and SHCOMP act as auxiliary instruments.

As shown in Table 2, the proportion of gas in the portfolios varies between 21% and 37%, with the smallest allocation occurring in the portfolio containing S&P 500 at 21.47%, while the highest is in the portfolio with wheat at 37.26%. The lower share of gas in the gas–gold portfolio (21%) suggests that gold provides strong diversification benefits to natural gas. Gold likely acts as a safer or more effective hedge, reducing the need to hold a large proportion of gas. Conversely, the higher share of gas in the gas–wheat portfolio (37%) indicates that wheat offers less diversification or hedging benefit relative to gold. From the aspect of hedging, investors may find gold more effective, allowing for a smaller exposure to gas. On the other hand, portfolios including wheat require a larger natural gas share, potentially implying higher portfolio volatility or less efficient diversification. It is evident from Table 2 that in every

portfolio, the auxiliary instruments hold a significantly larger share than gas. This outcome is expected, as all auxiliary instruments exhibit considerably lower risk compared to gas, as shown in Table 1.

Table 2. Average weight of instruments in the portfolio in percentage

	Gas vs gold	Gas vs wheat	Gas vs S&P 500	Gas vs SCHOMP
Gas	21.60	37.26	21.47	23.31
Auxiliary instrument	78.40	62.74	78.53	76.69
Σ	100	100	100	100

Source: Authors' calculation

After constructing the four bivariate portfolios, the next step is to evaluate their performance based on the first four moments. Table 3 presents the descriptive statistics of these portfolios, along with the statistics for natural gas, allowing for a direct comparison between the gas time series and the constructed portfolios. As shown in Table 3, all portfolios exhibit significantly lower variance than gas. Additionally, their variance is lower than that of the empirical series of auxiliary instruments. This confirms the effectiveness of diversification, demonstrating that the risk associated with gas is substantially reduced when combined with any of the four auxiliary instruments.

Table 3. Descriptive statistics of the constructed portfolios

	Mean	Variance	Skew.	Kurt.
Natural gas	0.001	1.869	0.262	10.957
Gas vs gold	0.012	0.225	-0.041	11.099
Gas vs wheat	0.003	0.527	-0.175	40.449
Gas vs S&P 500	0.015	0.304	-0.433	14.905
Gas vs SHCOMP	0.005	0.270	0.326	13.185

Source: Authors' calculation

Among the four portfolios, the combination with gold produces the best results, as it has the lowest variance at 0.225. Compared to the empirical risk of gas, which stands at 1.869, the gas-gold portfolio achieves an eightfold reduction in variance. The second most effective combination is with the Chinese SHCOMP index, which has a variance of 0.270, reducing gas risk by a factor of seven, further demonstrating the portfolio's effectiveness.

The third-best portfolio pairs gas with the American S&P 500 index, resulting in a variance of 0.304, which lowers risk by six times. The least effective portfolio among the four is the gas-wheat combination, with the highest variance of 0.527. Despite this, it still reduces gas risk by 3.5 times. These results demonstrate that all four portfolios significantly mitigate gas risk, confirming the effectiveness of the formula (3) used in their construction.

Regarding the third moment, or skewness, three out of the four portfolios: gas-gold, gas-wheat, and gas-S&P 500, exhibit negative skewness. This might be considered as a disadvantage, as it indicates a higher concentration of negative returns compared to positive ones. Additionally, the kurtosis values of all four portfolios are relatively high and exceed the kurtosis of gas. This suggests that the portfolios contain extreme values, which may be undesirable for investors. However, the equation proposed by [18] does not account for the third and fourth moments when determining the share of the secondary instrument. Instead, it focuses solely on the second moment (variance), where it can be seen that all portfolio variances are significantly lower compared to the gas counterpart.

As a result, skewness and kurtosis are effectively disregarded, meaning these portfolios are primarily suited for investors seeking to minimize risk or variance. Incorporating the third and fourth moments into the calculation would be complex and fall outside the scope of this study. If skewness and kurtosis were considered, the portfolio with gold would yield the most favorable results. Among the three negatively skewed portfolios, gas-gold has the least negative skewness. Furthermore, its kurtosis is the lowest among all four portfolios, at 11.099, making it the most attractive option from this perspective.

In addition to Table 3, which outlines the characteristics of the portfolios, Figure 2 provides a visual comparison of the time series for the created portfolios and natural gas.

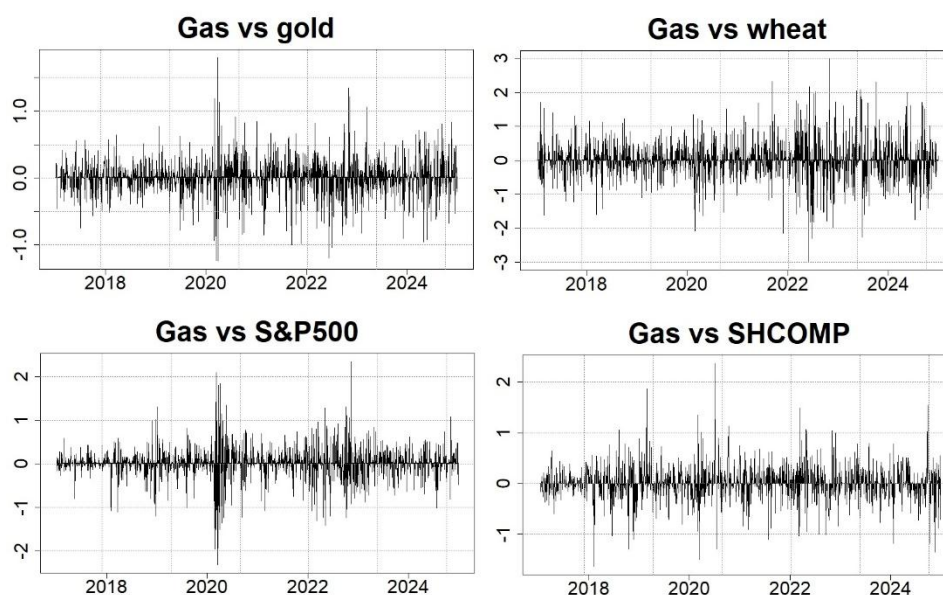


Figure 2. Graphical representation of portfolio returns

Source: Authors' calculation

This figure illustrates the movement of daily returns, clearly showing that all portfolios experience significantly smaller fluctuations in daily returns compared to the gas time series (see Figure 1). This visual comparison indicates that the risk of all portfolios is substantially lower than that of gas. Specifically, while the maximum positive and negative values for gas fluctuate around ± 10 , the extreme values for the individual portfolios rarely exceed ± 2 . Looking at the plots in Figure 2, it is evident that higher volatility is recorded in the gold and S&P 500 portfolios during the pandemic, while in the wheat portfolio, this occurs during the war in Ukraine. This is expected because conflicts, wars, global diseases, and political instability create uncertainty about supply chains, production, and trade flows. From a portfolio perspective, this results in increased volatility, leading to larger drawdowns and wider fluctuations in returns.

The extended portfolio analysis involves calculating the Sharpe ratio for each portfolio and comparing it to that of the unhedged asset, which in this case is natural gas. Table 4 displays the Sharpe ratio values for both gas and the portfolios, as the ratio for gas fluctuates due to the synchronization of time series. Specifically, the Sharpe ratio is calculated for each minimum variance portfolio, although the main focus is not on determining the optimal portfolio with the highest Sharpe ratio.

Table 4. Sharpe ratio of natural gas and the created portfolios

	Gas vs gold	Gas vs wheat	Gas vs S&P 500	Gas vs SHCOMP
Sharpe ratio of gas	0.0004	-0.0004	0.0004	0.0002
Sharpe ratio of portfolio	0.2365	0.0114	0.1653	0.0747

Source: Authors' calculation

According to the results in Table 4, all portfolios exhibit a significantly higher Sharpe ratio compared to natural gas, demonstrating that the Kroner and Ng equation also effectively enhances the return-to-risk relationship. In other words, while the Sharpe ratio of gas hovers around ± 0.0004 , all the constructed portfolios demonstrate higher Sharpe ratios, suggesting that each one not only mitigates risk but also enhances returns.

Among the portfolios, the gas-gold combination stands out with the highest Sharpe ratio of 0.2365, followed by the gas-S&P 500 portfolio at 0.1653. The strong performance of the gas-gold portfolio can be attributed to gold's very low risk, whereas the gas-S&P 500 portfolio benefits from the high returns of the S&P 500 index. The gas-wheat portfolio shows the lowest Sharpe ratio at 0.0114, though it still outperforms the Sharpe ratio of gas on its own. These findings suggest that the gas-gold combination is the most favorable in terms of minimizing risk while maintaining a strong return-to-risk ratio. Therefore, investors looking to invest in gas should consider pairing it with gold, as this combination offers the best balance of risk reduction and return enhancement.

Finally, the results of gas hedging efficiency across all four portfolios are presented, with Table 5 displaying the hedge effectiveness index (HEI) values.

Table 5. HEI results

	Gas vs gold	Gas vs wheat	Gas vs S&P 500	Gas vs SHCOMP
HEI	98.55	92.03	97.36	97.93

Source: Authors' calculation

According to these results, all portfolios significantly reduce gas risk, demonstrating their high effectiveness. However, as previously mentioned, the portfolio with gold achieves the greatest reduction in gas risk at 98.55%. The second-most effective portfolio is the combination with the Chinese SHCOMP index, which reduces risk by 97.93%, followed by the gas-S&P 500 portfolio at 97.36%. The least effective combination is gas and wheat, with a reduction of 92.03%, which is still remarkably high.

Conclusion

The world has faced two major crises since 2020. The first was triggered by the COVID-19 pandemic, which severely disrupted economies worldwide. The second began in February 2022 with the outbreak of the conflict between Russia and Ukraine. Now entering its fourth year, this conflict has led to a sharp increase in global gas prices, significantly heightening market risk.

Considering this, the study explores risk reduction strategies by combining natural gas with four different assets in a bivariate portfolio. To achieve this, two composite stock indices—the S&P 500 (USA) and SHCOMP (China)—along with two globally significant commodities, wheat and gold, were used as auxiliary instruments in combination with gas.

The findings indicate that natural gas, as measured by variance, carries significantly higher risk compared to auxiliary instruments. This justifies the inclusion of less risky auxiliary instruments alongside highly volatile gas. The results show that gas is between 3.5 and 8 times riskier than auxiliary instruments.

Furthermore, the construction of four portfolios led to the conclusion that the gas-gold combination delivers the best results, as it has the lowest variance at 0.225. The hedge effectiveness index further confirms this, revealing that the gas-gold portfolio achieves the highest risk reduction at 98.55%.

Finally, the Sharpe ratio calculation reveals that the gas-gold portfolio offers the best performance in terms of return for the level of risk involved, with a Sharpe ratio of 0.2365, while the gas-wheat portfolio has the lowest Sharpe ratio at 0.0114. These results indicate that the gas-gold combination is the most favorable, not only in terms of minimizing risk but also in optimizing the return-to-risk ratio.

Overall, the findings suggest that pairing gas with gold yields the most favorable outcomes from both a risk management and return perspective. Therefore, this study provides valuable insights for investors looking to hedge against excessive gas market risk.

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