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# On the diversification benefits of commodities from the perspective of euro investors

Julia Belousova[a], Gregor Dorfleitner[b,*]

[a] Allianz Investment Management SE, 80802 München, Germany
[b] Department of Finance, University of Regensburg, 93040 Regensburg, Germany

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ABSTRACT

This paper investigates the diversification contribution of several commodities to a portfolio of traditional assets from the perspective of a euro investor. The approach applied in our analysis has high informational content as it differentiates between the sources of the diversification benefits in a statistically significant way. The results indicate that the diversification contribution varies greatly amongst the different commodities. Industrial metals, agriculturals and livestock contribute to the reduction of risk, while energy and precious metals contribute to both the reduction of the level of risk and to the improvement of return. The differentiation between bull and bear markets reveals that investors can enhance the portfolio performance by changing exposure into individual commodities. Investors can benefit from the diversification gains through financial instruments as the diversification gains hold both in the sample of physical commodity and commodity futures. Overall, the results confirm that commodities are valuable investments from the perspective of diversification.



## 1. Introduction

The strong growth of commodity investments indicates an increasing interest of investors in commodity markets. According to Carpenter (2011), the total amount of commodity assets under management reached a record number of $412bn in March 2011. By analysing the reasons for the popularity of commodity investments, ETF Securities (2011) shows that commodities outperformed major asset classes in 2010, establishing their position as the best performing asset class over the past 10 years.

This paper investigates the diversification benefits of commodities for a euro investor when this asset class is incorporated into a portfolio of stocks and bonds. Prior research automatically assumed the perspective of a US investor or an investor in US dollar-denominated assets. However, considering the US dollar returns of all assets and adding the euro/dollar exchange rate as an additional benchmark asset would not model the euro investors' perspective precisely enough since the amount of US dollars to be transferred back into euro at the end of the investment period is ex ante stochastic. Due to the denomination of commodity prices in US dollars, exchange rate movements have a multiplicative impact on their prices and values expressed in other currencies. The possibility of depreciation or appreciation of the dollar imposes an additional risk and hence implies a generally different diversification contribution of commodities for a euro investor as compared to the diversification contribution for a US dollar investor.

An upturn in the volumes of trading reveals the increasing attraction of commodities as an asset class for European investors.[1] Hence, the results of the analysis are of high relevance to both private and institutional investors, which reflect on the incorporation of commodities in their investment portfolios.

We reinvestigate the added value of commodity investments by applying the much more precise methodology of spanning tests, which differentiates this analysis additionally from prior literature. Another contribution of this paper lies in the fact that the analysis is conducted at the level of 25 individual commodities, which are selected based on liquidity and economic significance, while prior research concentrated mainly on the investigation of commodity

* Corresponding author. Tel.: +49 941 943 2684; fax: +49 941 943 4608.
*E-mail addresses:* julia.belousova@allianz.com (J. Belousova), gregor.dorfleitner@wiwi.uni-regensburg.de (G. Dorfleitner).

[1] According to Maslakovic (2011), the trading volumes of commodity derivatives on major European exchanges more than tripled from about 97 million contracts in 2000 to 354 million in 2010. The segment of *exchange traded commodities* (ETCs), which is of special interest for private investors, has also experienced a huge upturn. The market leader ETF Securities reports an increase from 31 products and EUR 1.685bn assets under management in 2006 to 151 products and EUR 16.644bn assets under management in February 2012 regarding its euro denominated ETC products (source: ETF Securities, historical data published on http://www.etfsecurities.com).

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indices. Since commodity indices tend to overweight particular commodity sectors, they are not representative of the performance of individual commodities and commodity sectors.

Our paper examines both physical commodities *and* commodity futures to address the question of whether and how diversification gains can be achieved through the use of real-world financial instruments. The analysis is conducted over the entire sample period of 16 years and over the sub-periods of bull and bear equity markets to quantify the value of tactical commodity allocations linked to rising and falling equity markets.

Commodities are broadly accepted as a separate asset class. This implies that they possess similar investment attributes, distinguishing them from other asset classes. According to Adams et al. (2008) and Anson et al. (2011), the following properties of commodities are commonly reported as being typical. First, commodities offer an effective hedge against both expected and unexpected inflation. As commodities are real assets, they have an intrinsic value and reflect the changes in the price level. Second, commodity prices are determined by the current state of the economy and vary with the business cycle. Thus, periods of strong expansion coincide with rising commodity prices due to the increased demand and to the inflation-hedging properties of commodities. Third, commodity prices are predominantly denominated in US dollars. A general depreciation of the dollar contributes to an increase in commodity prices, while an appreciating dollar leads to a decrease in commodity prices. Finally, commodities are not income-producing assets as they do not yield an ongoing stream of cash flows. Therefore, commodity prices cannot be estimated through traditional valuation techniques. They depend on current economic conditions and are determined by the interaction of supply and demand.

Although all commodities have common investment attributes which establish them as a separate asset class, a high degree of heterogeneity among individual commodities exists. The classification of commodities is based on the differentiation between hard and soft commodities. Hard commodities include metals and energy, while soft commodities comprise livestock and the agricultural sectors. The latter is subdivided into grains/seeds and softs. This classification has established itself within the commodity industry and, as is seen in Table A1, is used as the basis for the calculation of commodity sub-indices.

Commodities are distinguishable from traditional assets through several characteristics, the most prominent one being their low correlation with stocks and bonds. However, commodity markets show strong market dynamics with a steady increase in the trading volumes and the total turnover. The growth of financial activity indicates the increased investors' awareness that commodities constitute a separate investment class. Consequently, even more investors consider the inclusion of commodities in their portfolios. The growing interest in commodities contributes to a higher liquidity and to an enhanced pricing efficiency. However, the increased capital inflows can lead to higher correlations of commodities with other financial assets, eliminating their diversification benefits. The latter argument is supported by Cao et al. (2010) and Daskalaki and Skiadopoulos (2011) and provides an additional motivation to reinvestigate investors' diversification benefits under the advanced methodology of spanning tests.

The remainder of the paper is organised as follows: Section 2 presents related literature, Section 3 describes the methodology of spanning tests and Section 4 reports the empirical results of our diversification analysis. Section 5 concludes.

## 2. Related literature

Previous literature has already addressed the question of commodity diversification. A clear differentiation can be made on the basis of the research outcomes. Although the bulk of empirical works detects the diversification potential of commodities, this evidence is not unanimous.

Satyanarayan and Varangis (1996) and Idzorek (2007) find diversification benefits, analysing the shift of the efficient frontier when the investment universe is extended to a commodity index. Georgiev (2001) and Gibson (2004) constitute portfolios with different commodity allocations and observe their improved risk-return characteristics in the mean–variance space. You and Daigler (2010) detect the diversification benefits of commodity futures by employing the mean–variance and Sharpe optimisation models.

Scherer and He (2008) regress commodity indices on a portfolio of traditional assets and conclude on the diversification impact of commodities on the basis of the *p*-values of regression estimates. Nijman and Swinkels (2008) indicate the improvement of asset-liability management of institutional investors, when commodities are included in the investment universe. Galvani and Plourde (2010) find that four energy futures contracts reduce the risk level of a portfolio of energy stocks in the period from 1990 to 2008. Huang and Zhong (2006) conclude that there is consistency in the diversification benefits of real estate investment trusts, treasury inflation-protected securities and commodities.

Also, the diversification contribution of commodities has been emphasised in the framework of tactical asset allocation strategies. Conover et al. (2010) extend the analysis to investigate the variation of the diversification benefits in sub-periods linked to the changes in the monetary policy of the Federal Reserve. They find the diversification benefits during both restrictive and expansive monetary policy. In contrast to this, Jensen et al. (2000, 2002) purport that the diversification benefits of commodity investments only exist during restrictive phases of the monetary cycle. In the same way, Woodard (2008) detects that the diversification benefits of commodities can be enhanced if investors incorporate tactical trading into their asset allocation decisions.

The diversification benefits of commodities have been stated from the perspective of expected utility, too. Anson (1999) finds that the utility of commodity investments increases with the investor's level of risk aversion. Ankrim and Hensel (1993) detect the performance improvement of optimal portfolios for any given risk tolerance coefficient.

While the majority of prior research agrees on the diversification benefits of commodities, there also exit contradictory results. The recent works of Daskalaki and Skiadopoulos (2011) and Cao et al. (2010) deny the diversification properties of commodities. Their findings are also in line with Domanski and Heath (2007), Tang and Xiong (2010) and Silvennoinen and Thorp (2010), who do not directly address the question of diversification, but provide proof of the *financialization* of commodity markets.

Daskalaki and Skiadopoulos (2011) combine utility analysis with regression techniques, investigating the diversification potential of commodity indices and five commodity futures over the time period from 1989 to 2009. They implement the approach of DeRoon et al. (1996), generalising the notion of spanning to non-mean–variance utility functions. As diversification benefits are not preserved in the out-of-sample framework, Daskalaki and Skiadopoulos (2011) conclude that commodities do not yield added value to investors. Cao et al. (2010) perform their analysis in the mean–variance framework. They conclude that there are no differences in the efficient frontiers with and without the inclusion of commodities.

Concerning the methodology, the majority of the literature does not evaluate the diversification properties of commodities within a statistical framework. Scherer and He (2008), Nijman and Swinkels (2008), Galvani and Plourde (2010), Huang and Zhong (2006) and Daskalaki and Skiadopoulos (2011) apply regression-based techniques. However, these works either do not follow the established methodology of spanning tests or conduct their analysis in another context.

The review of related literature also reveals that the major part of prior research has performed their analyses on the basis of commodity indices. Galvani and Plourde (2010) and Daskalaki and Skiadopoulos (2011) have so far been the sole researchers of the contribution of individual commodity futures under the regression approach. However, Galvani and Plourde (2010) perform their analysis in a different context, studying the diversification contribution of four energy commodities to a portfolio of energy stocks. Daskalaki and Skiadopoulos (2011) restrict their analysis to five individual commodities, under the assumption that they represent the performance of other commodities in the respective sectors. This approach does not consider the existence of within-sector commodity differences, which influences their diversification characteristics.

Hence, on the one hand, indications of financialisation in commodity markets exist. However, on the other hand, diversification benefits of commodities are analysed neither under the methodology of spanning tests nor on the level of individual commodities. This provides a motivation to reinvestigate investors' benefits through the inclusion of commodities in a portfolio of traditional assets.

## 3. Econometric framework

The bulk of previous literature evaluated the diversification impact of commodities in the mean–variance framework of Markowitz (1952). The regression-based approach has not yet found broad application in the field of commodities. Accordingly, the likelihood ratio (LR) test, initially proposed by Huberman and Kandel (1987), is not the most powerful invariant test of mean–variance spanning. For this reason, it is supplemented with the Wald (W) and the Lagrange multiplier (LM) tests. Generalised method of moments (GMMs) spanning tests are performed to control for the non-normality of returns and the heteroscedasticity of error terms. The GMM-based tests are accomplished under the regression approach as, following Kan and Zhou (2008), they perform better than the corresponding tests under the stochastic discount factor (SDF) approach. For the purpose of a comprehensive evaluation of the diversification benefits, traditional tests are supplemented by the step-down procedure, which differentiates between the sources of diversification gains, namely reduction of risk or enhancement of return. In this way, step-down tests establish the link to the notion of utility.

The method of mean–variance spanning, initially introduced by Huberman and Kandel (1987), statistically tests the impact that the introduction of additional $N$ risky assets, referred to as *test assets*, has on the efficient frontier of an investment opportunity set of $K$ *benchmark assets*. According to Merton (1972), the efficient frontier is spanned between the GMVP and the tangency portfolio. Thus, the objective of spanning tests is to analyse whether or not the augmented investment opportunity set of the $N+K$ assets leads to a significant improvement of the initial efficient frontier of $K$ benchmark assets and, respectively, to a significant improvement of the tangency and the GMVP portfolios.

If the initial and the augmented efficient frontiers fully coincide, we have the case of *spanning*. This implies that no mean–variance investor can benefit from extending their investment universe to benchmark assets irrespective of the level of the risk-free rate. The difference between the efficient frontiers is not statistically significant. Consequently, the initial investment set of $K$ assets generates the same risk-return profile as the $N+K$ assets. In the following, the diversification benefits of commodities are evaluated with spanning tests, the notation and treatment of which is based on the approach of Kan and Zhou (2008).

### 3.1. Spanning tests

As mentioned above, spanning tests are used to evaluate the statistical significance of the improvement of the augmented efficient frontier of the $N+K$ assets relative to the initial frontier of $K$ benchmark assets. The covariance matrix of the $N+K$ assets' returns is given by $V$. Spanning tests are based on the regression of $N$ test assets on $K$ benchmark assets, which is given by

$$R_{com} = XB + E, \tag{3.1}$$

If $N = 1$, $R_{com}$ is the vector of returns of the test asset at the instants of time $1,\ldots,T$ . If $N > 1$, $R_{com}$ is a $T \times N$ matrix of returns. Since this setting is only applied as a side aspect of our empirical investigation below, namely only when we analyse portfolios of commodities, we restrict to our main application case $N = 1$ for the rest of the section.[2] Then $X$ is a $T \times (K+1)$ matrix with

$$X = \begin{pmatrix} 1 & R_{1,1} & \ldots & R_{1,K} \\ \vdots & \vdots & \ddots & \vdots \\ 1 & R_{T,1} & \ldots & R_{T,K} \end{pmatrix},$$

where $R_{t,k}$ is the return of the benchmark asset $k$ at time $t$, $B$ is the $K+1$ dimensional coefficients vector $[\alpha,\beta]'$, where $\beta = (\beta_1,\ldots,\beta_K)$ and $E$ is the error term vector $(\varepsilon_1, \ldots, \varepsilon_T)'$. The matrix $V$ can be written as

$$V = \begin{pmatrix} V_{11} & V_{12} \\ V_{21} & V_{22} \end{pmatrix},$$

where $V_{11}$ is the variance of the test asset, $V_{22}$ the covariance matrix of the benchmark assets, and $V_{21}$, $V_{12}$ the column and row vector, both representing the covariances of the benchmark assets with the test asset. From Huberman and Kandel (1987), who treat the general setting with arbitrary $N$, we can derive the null hypothesis for spanning as

$$H_0 : \alpha = 0, \delta = 1 - \beta 1 = 0. \tag{3.2}$$

If the condition for spanning in (3.2) holds, the test assets do not improve the tangency portfolio (the test of $\alpha = 0$) and the GMVP (the test of $\delta = 0$) in a statistically significant way. Note that (3.2) is a joint hypothesis. This implies that the addition of test assets to the portfolio of benchmark assets does not shift the efficient frontier. Respectively, the rejection of $H_0$ indicates the benefits of diversification, which result from the enlargement of the investment set.

The LR, W and LM spanning tests are based on the regression in (3.1). These tests are estimated with maximum likelihood estimators (MLEs), relying on the normal distribution assumption. Thus, $\widehat{B}$ is an unconstrained MLE of $\hat{\alpha}$ and $\hat{\beta}$ from regression (3.1) and $\widehat{\Sigma}$ is the estimator of the covariance matrix of error terms. The null hypothesis in (3.2) can be rewritten as

$$\Theta = [\alpha, \delta]' = AB + C = 0_2, \tag{3.3}$$

where

$$A = \begin{bmatrix} 0 & 0'_K \\ 1 & -1'_K \end{bmatrix} \quad \text{and } C = \begin{bmatrix} 0 \\ 1 \end{bmatrix}.$$

The derivation of test statistics requires the definition of the following estimator matrices:

$$\widehat{G} = TA(X'X)^{-1}A' \quad \text{and } \widehat{H} = \Theta\hat{\Sigma}^{-1}\Theta', \tag{3.4}$$

where $\widehat{\Theta}$ is the MLE of $\Theta$ and $\widehat{\Sigma}$ the MLE of $\Sigma := V - V_{21}V_{11}^{-1}V_{12}$. If $\lambda_1$ and $\lambda_2$ denote the eigenvalues of the matrix $\widehat{H}\widehat{G}^{-1}$, where $\lambda_1 \geqslant \lambda_2 \geqslant 0$, then the LR, W and LM test statistics are given by

[2] We refer the reader to Kan and Zhou (2008) for a detailed description of the general case.

$$\mathrm{LR} = T\sum_{i=1}^{2}\ln(1+\lambda_i)\overset{A}{\sim}\chi_2^2, \tag{3.5}$$

$$\mathrm{W} = T(\lambda_1+\lambda_2)\overset{A}{\sim}\chi_2^2, \tag{3.6}$$

$$\mathrm{LM} = T\sum_{i=1}^{2}\left(\frac{\lambda_i}{1+\lambda_i}\right)\overset{A}{\sim}\chi_2^2. \tag{3.7}$$

As is seen in the Eqs. (3.5)–(3.7), the distributions of the LR, W and LM tests are asymptotically chi-squared with degrees of freedom equal to the number of restrictions under $H_0$. Despite equal asymptotic distributions and similarities of test statistics, Berndt and Savin (1977) and Breusch (1979) show that W $\geqslant$ LR $\geqslant$ LM. Thus, under asymptotic distributions the tests provide conflicting results with the W test favoring rejection and the LM test favoring acceptance. As none of the tests solely embodies the best predictive power, it is important to perform all three tests in order to achieve reliable results.

### 3.2. Spanning tests under non-normality of returns

The main limitation of MLE-based tests is the assumption that the returns are normally distributed and that the error terms in (3.1) are homoscedastic. The non-normality does not influence the sample distribution to a large extent in the case of conditional homoscedasticity.[3] If error terms exhibit conditional heteroscedasticity, the LR, W and LM are not asymptotically chi-squared distributed under $H_0$, implying that test statistics do not provide reliable results. As the multivariate ARCH-LM test shows some evidence of conditional heteroscedasticity in the sample, the GMM, introduced by Hansen (1982), is used as an alternative to the MLE.

GMM-based spanning tests can be implemented either under the regression approach, used by Ferson et al. (1993), or under the SDF approach, proposed by DeSantis (1993), Ferson (1995) and Bekaert and Urias (1996). Kan and Zhou (2008) show that the regression-based GMM tests have more power, compared with the SDF-based GMM tests. Therefore, the analysis focuses on the regression approach, in particular on the $W_{GMM}$ test. The $W_{GMM}$ test statistic is calculated identically to that of the W test in (3.6). The only difference is that the $W_{GMM}$ is based on the GMM estimation. For more details see Kan and Zhou (2008, pp. 21–23).

### 3.3. Step-down tests

As is seen in (3.2), spanning tests are joint tests, which measure the statistical significance of the shift of the tangency portfolio ($\alpha = 0$) and the GMVP ($\delta = 0$). Kan and Zhou (2008) report that spanning tests put more emphasis on $\hat{\delta}$. The reason is that $\hat{\delta}$ can be estimated in a statistically more accurate way, compared with $\hat{\alpha}$. As a result, spanning tests have good power for assets that reduce the variance of the GMVP, but low power for assets that improve the tangency portfolio.

To overcome this problem, the so-called step-down procedure can be implemented, which involves two sequential $F$-tests: the test of $\alpha = 0$ ($F_1$-test) and subsequently of $\delta = 0$ under the condition of $\alpha = 0$ ($F_2$-test). The step-down procedure supplements spanning tests as it allows the detection of the sources of the rejection of $H_0$. A rejection in the $F_1$ test indicates the statistical difference in the tangency portfolios, while a rejection in the $F_2$ test refers to the difference in the GMVPs. The test statistic of $F_1$ is given by

$$F_1 = (T-K-1)\left(\frac{\bar{\Sigma}}{\hat{\Sigma}}-1\right), \tag{3.9}$$

where $\hat{\Sigma}$ is the unconstrained and $\bar{\Sigma}$ is the constrained estimate of $\Sigma$ under the constraint of $\alpha = 0$. Under $H_0$, the $F_1$ follows an $F$-distribution with 1 and $T-K-1$ degrees of freedom. The $F_2$-test is defined by

$$F_2 = (T-K)\left(\frac{\tilde{\Sigma}}{\bar{\Sigma}}-1\right), \tag{3.10}$$

where $\tilde{\Sigma}$ is the constrained estimate of $\Sigma$ under the constraints of $\alpha = 0$ and $\delta = 0$. The $F_2$ follows an $F$-distribution with 1 and $T-K$ degrees of freedom.

The statistical significance of spanning tests does not necessarily correspond to the economic significance. Consequently, an economically significant difference in the tangency portfolios is difficult to detect statistically, while an economically insignificant difference in the GMVPs may lead to a rejection of the null hypothesis. To account for the economic significance, step-down tests allow the adjustment of the significance levels of $F_1$ and $F_2$, given by $\alpha_1$ and $\alpha_2$, respectively. As it is difficult to detect the statistical difference of the tangency portfolios, it is advisable to set $\alpha_1$ at a higher and $\alpha_2$ at a lower significance level.

Hence, the step-down procedure is indispensable in the context of spanning tests: it increases the informational content of the joint spanning tests by identifying the sources of rejection and it provides flexibility to account for the economic significance by adjusting the significance levels of statistical tests.

## 4. Empirical analysis

Our empirical analysis is structured as follows. It starts with the introduction of the dataset which is used to perform spanning tests and an overview of the descriptive characteristics of commodities. The next sub-section presents key findings for the diversification benefits of commodities in the portfolio of traditional assets. Afterwards, the analysis is repeated with commodity futures, also during periods of bull and bear markets.

### 4.1. The dataset

The dataset consists of monthly prices of benchmark and test assets, which are provided by the Datastream database. It covers the time period from January 1st 1995 until December 1st 2010, so that each time series consists of 191 observations. To analyse the diversification effects of commodities from the perspective of a euro investor, all prices of commodities and those benchmark assets that are denominated in US dollars are converted into euros. Thus, the calculation is based on simple returns based on euro prices.[4] Benchmark assets, which describe the current investment opportunity set, are represented by the total return equity and bond indices. It is assumed that a European investor holds a diversified stock portfolio, which is approximated by the MSCI index family. Therefore, the European equity market is represented by the MSCI Europe, the US equity market by the MSCI US, the Asia–Pacific market by the MSCI Pacific and the exposure to emerging markets is gained through the MSCI EM. The performance of European debt markets is approximated by the J.P. Morgan EMU government bond index, which includes fixed-income securities of all maturities in the

[3] Conditional homoscedasticity means that error terms are independently and identically distributed, conditional on $x_t$.

[4] The question concerning the correct return definition (simple or logarithmic) is not irrelevant in the framework of spanning tests. According to Dorfleitner (2002), simple returns are preferable when portfolio aspects are the topic of analysis, while log returns are favourable only for time series models. Since we consider the portfolio aspect as the major concern in our analysis, our calculations are based on simple returns.

Euro-zone. To consider money markets as an investment opportunity, spanning tests are performed on the basis of excess returns over the risk-free rate, which is approximated with EURIBOR.[5] Note that the euro investor already has exposure to the euro/dollar exchange rate because of his investment in the MSCI US and, to an extent, in the MSCI EM. Therefore, the main contribution of the commodities investment does not lie in providing such exposure. However, due to the euro/dollar exchange rate the investor may face a different diversification behaviour as compared to a US dollar investor. When adding the euro/dollar exchange rate as benchmark asset, as discussed above, the diversification results are not the same as for the euro investor.

The choice of commodities relies on the composition of the Dow Jones-UBS Commodity Index (DJ-UBSCI) and the S&P Goldman Sachs Commodity Index (S&P GSCI). The S&P GSCI is a production-based index, which reflects the economic significance of constituent commodities. This explains the strong overweighting of the energy sector. As is seen in Table A1, the energy sector has the weight of 70%, while the precious metals group is weighted with 3%. The weighting of the DJ-UBSCI relies primarily on the amount of trading activity. Thus, liquidity has twice as much influence as production measures in determining the index composition. The DJ-UBSCI imposes weight limits to provide sufficient diversification: the weights of individual commodities vary between 2% and 15%, while the sector exposure is capped at 33%. Diversification limits assure that the index reflects the movements of the commodity market as a whole.

Stoll and Whaley (2011) and Tang and Xiong (2010) highlight the dominant position of the DJ-UBSCI and the S&P GSCI in commodity markets. This evidence is supported by the fact that the largest index funds track the performance of both indices: 85% of assets under management (AUM) of commodity index funds are invested in the DJ-UBSCI, followed by the S&P GSCI with 10%.[6]

The sample includes 25 commodities, covering the compositions of both indices: 24 constituents of the S&P GSCI index, 18 of which are also included in the DJ-UBSCI.[7] The sample is extended by platinum, which is not a direct constituent of both indices. However, this serves the purpose of extending the precious metals sector, which is the smallest one, to ensure the comparability of the diversification potential across sectors. Platinum is chosen due to its important position among precious metals, which has been recognised in the recent discussions concerning its performance characteristics.[8]

Table C1 in the Appendix shows the exact composition of the sample. The energy sector is composed of six commodities, namely Brent crude oil, WTI crude oil, gas oil, heating oil, natural gas and unleaded gasoline; softs and grains include four commodities each: cocoa, coffee, cotton and sugar (softs); corn, soybeans, Chicago wheat and Kansas wheat (grains); industrial metals contain five commodities: aluminium, copper, lead, nickel and zinc; there are three commodities in the precious metals group: gold, platinum and silver; the livestock sector consists of three commodities: feeder cattle, live steers and pork bellies.

### 4.2. Descriptive statistics

The descriptive statistics provide an insight into the investment properties of different commodity sectors and allow the evaluation of their risk-return characteristics in comparison to equity and fixed-income securities. As is seen in Table C2 in the Appendix, the key statistics vary strongly across commodity classes. This supports the findings of Erb and Harvey (2006) and Kat and Oomen (2007), which claim that commodities form a heterogeneous asset class. Energy is characterised by high returns, while other commodity sectors generally display returns in the range of equity returns. Almost all commodities exhibit considerably higher standard deviations than stocks. This explains why the Sharpe ratios of commodities are lower than those of traditional assets. Energy and precious metals make an exception insofar as their Sharpe ratios are comparable to equity.

Like stocks and bonds, almost all commodities have positive excess kurtosis. This implies a leptokurtic return distribution, which has fatter tails with the higher probability for extreme events compared with normally distributed returns. Contrarily to stocks and bonds, the majority of commodities are positively skewed. This feature is beneficial to investors, because it indicates the lower downside risk and the upward return bias of an investment portfolio.

Table C3 in the Appendix displays the correlation coefficients of the individual commodities and the benchmark assets. The correlation analysis suggests that the introduction of commodities into a portfolio of stocks and bonds can reduce portfolio volatility substantially: almost all commodities are negatively correlated with fixed-income securities and money markets; correlations with equity markets are also either negative or only weakly positive. The evidence of low correlations of commodities with traditional assets is explained by the fact that commodities establish a separate asset class. This implies that commodities are influenced by different economic fundamentals when compared to traditional assets, giving rise to the expectation of low correlations. Commodities of the same category are characterised by a certain degree of homogeneity, which explains high within-sector correlations, as shown in Table C3.

Overall, the descriptive statistics suggest that commodities are not superior to traditional assets as stand-alone investments; they are more volatile and have lower Sharpe ratios. However, low positive or negative correlations with stocks and bonds indicate that commodities are valuable due to their diversification potential for investors who hold a portfolio of traditional assets. Therefore, the next section analyses the diversification properties of commodities from the perspective of statistical significance, differentiating between the sources of diversification benefits.

### 4.3. Diversification potential of physical commodities

The diversification potential of commodities is evaluated with spanning tests as described in Section 3. Thus, the LR, W and LM tests are supplemented by the $W_{GMM}$ and the step-down procedure for the purpose of a comprehensive analysis of the diversification properties of commodities. Relying on the dataset described above, the following regression specification is used:

$$R_{com} = \alpha + \beta_{MSCIEU}R_{MSCIEU} + \beta_{MSCIUS}R_{MSCIUS} + \beta_{MSCIPAC}R_{MSCIPAC} + \beta_{MSCIEM}R_{MSCIEM} + \beta_{bond}R_{bond} + \varepsilon, \quad (4.1)$$

where $R_{com}$ denotes the return of the commodity under consideration. The analysis of the diversification effects of the commodity sectors is accomplished by regressing a sub-portfolio of commodities in a given sector on the benchmark assets[9]. As specified above, all returns are defined as excess returns over EURIBOR 1-month.

[5] As the data for EURIBOR has only been available since the introduction of the euro, the German interbank 1-month rate (FIBOR 1-month) is used as a risk-free rate until 1999. The comparison of interbank rates over the time period from 1995 to 1999 does not reveal any substantial differences among EU member states. This justifies the usage of FIBOR 1-month as the risk-free rate for the Euro-zone.

[6] See Bank of America/Merrill Lynch (2010).

[7] Soybean oil is an oil product and can be classified neither as softs nor as grains. Therefore, it is excluded from the sample to prevent the distortion of the diversification properties of commodity sectors. As is seen in Table A1, soybean oil is low-weighted in the DJ-UBSCI, so that its exclusion does not distort the principle of relying on the composition of indices to a large extent.

[8] Cf. Hammoudeh et al. (2011), Helman (2010), and Seeking alpha (2009).

[9] In this case, $R_{com}$ corresponds to a $T \times N$ matrix of commodity returns. See Kan and Zhou (2008) for details.

Table 1 shows the test statistics and respective p-values, which are given in parentheses, for 25 commodities over the time period from January 1st 1995 to December 1st 2010. The extent of the portfolio improvement is assessed on the basis of the *p*-value: the lower the *p*-value, the higher the diversification benefits. Relying on Section 3.3, the interpretation of the step-down results requires caution. According to Kan and Zhou (2008), $\alpha_1$ should be set to a higher significance level than $\alpha_2$ due to the difficulties of detecting the significance of $F_1$. Consequently, the *p*-values of $F_1$, which slightly exceed a 10% significance level, can still be interpreted as the improvement of the tangency portfolio.

As is seen in Table A1, the null hypothesis of spanning is rejected for almost all commodities. This indicates that commodities have the diversification contribution to the portfolio of traditional investments from the perspective of statistical significance. In the energy sector, all commodities, except for natural gas, contribute to the reduction of portfolio risk and to the improvement of return: both $F_1$ and $F_2$ of the step-down analysis are rejected at a 10% significance level. The weaker diversification impact of natural gas is explained by its extreme volatility, as shown in Table C2.

These outcomes do not coincide with Galvani and Plourde (2010), who find that energy commodities decrease portfolio risk but fail to improve return. As already mentioned, Galvani and Plourde (2010) investigate the impact of energy commodities on a portfolio of energy stocks. Therefore, the differences in benchmark portfolios and investigation questions explain the varying results.

Precious metals also have strong diversification properties, regarding the fact that they simultaneously enhance portfolio return and decrease the level of risk. Platinum has a *p*-value for $F_1$ which is higher than that of gold and silver, which is explained by its slightly lower Sharpe ratio and its higher correlations with equity markets. The ability of energy and precious metals to improve the expected portfolio return is supported by the descriptive statistics: energy and precious metals have the highest Sharpe ratios among the commodity sectors.

In other sectors, the diversification benefits of commodities are attributable only to the reduction of the level of risk. Within the group of industrial metals, the spanning hypothesis cannot be rejected for lead, nickel and zinc. However, the diversification potential is detected for aluminium and copper, which can be explained by their lower correlations with traditional assets. In the softs sector, the diversification impact is found for cocoa and sugar, which is again supported by the correlation analysis. In the category of grains the commodities corn, soybeans and Kansas wheat decrease the portfolio volatility. In the livestock sector, the diversification properties are detected for live steers and feeder cattle. As in the case of natural gas, the excessive volatility of pork bellies eliminates their diversification potential. White sugar, live steers and feeder cattle have the lowest p-values, which indicates that their ability to reduce risk is particularly strong.

Summarising, we can state that the diversification gains of commodities are sector-dependent. Energy and precious metals enhance the portfolio performance in terms of both risk and return. The inclusion of agricultural commodities and livestock is primarily beneficial to risk-averse investors, who hold portfolios on the part of the efficient frontier close to the GMVP and who are interested in the reduction of portfolio risk.

The outcomes of spanning tests indicate strong diversification properties of commodities. Only 6 out of the sample of 25 commodities show no evidence of diversification effects: cotton, Chicago wheat, lead, nickel, zinc and pork bellies. This implies that the investment, even in a single commodity, contributes to the performance improvement of the portfolio of traditional investments.

### 4.4. Diversification potential of commodity futures

Due to the difficulties of direct investment in physical commodities, most investors seek their exposure to commodities through financial markets. As is seen in Tables C4 and C5 in the Appendix, the roll return leads to the differences in the descriptive characteristics and correlations of the commodity futures, compared with physical commodities, due to contangoed and backwardated futures markets. Therefore, the point of investigation is to find out whether the roll return has an impact on the diversification potential of commodities.

For this purpose, spanning tests are repeated with 25 S&P GSCI excess return sub-indices on respective commodities. Index providers calculate the spot return, excess return and total return types of commodity indices. In contrast to the spot return index, both excess and total return indices include the roll return component in the index calculation. The difference between the excess and total return indices refers to the collateralisation of commodity investment: the excess return index corresponds to an uncollateralised, while the total return index to a fully cash-collateralised commodity futures position. As a result of the collateral interest yield, the total return index can have positive returns when the underlying commodity prices decline and returns from direct investments in physical commodities are negative.

Since the excess return index does not include the return on the collateral, it corresponds to short-term futures contracts and represents the exposure to commodity markets better than total return or spot return indices. Therefore, the analysis is based on the S&P GSCI excess return type of the index.[10]

As can be seen in Table 2, the results of spanning tests for commodity futures coincide with the results for the sample of physical commodities. Thus, investors benefit from the inclusion of commodity futures in their investment portfolio to the same extent as from the inclusion of physical commodities. Accordingly, energy and precious metals contribute to the improvement of both the GMVP and the tangency portfolio. Thus, they enhance the performance of traditional investments on the level of both risk and return. Commodities in other sectors primarily benefit risk-averse investors, who are interested in hedging the portfolio risk.

There are no material differences on the level of individual commodities, either. To be precise, however, slight differences can be detected for Brent crude oil, natural gas, platinum and Chicago wheat. Natural gas shows only weak diversification potential in the sample of physical commodities, which is no longer found for commodity futures. In the sample of commodity futures, the evidence of diversification is somewhat weaker for Brent crude oil, but stronger for platinum and Chicago wheat.

In summary, the diversification properties of physical commodities hold in futures markets. Therefore, investors can realise the diversification benefits by investing in short-term futures contracts or in financial instruments which are priced off futures contracts.

### 4.5. Analysis of sub-periods

Next, we address the question concerning whether commodities preserve their investment benefits over short-term periods. In particular, the diversification potential of commodities is investigated in sub-periods linked to the price movements in traditional markets.

[10] Under the constraint of data availability, spanning tests are conducted for Brent crude oil, gas oil, Kansas wheat since 01.02.1999 and for feeder cattle since 01.02.2002. Due to the varying lengths of the time series, these commodities cannot be regressed on benchmark assets simultaneously with other commodities. For this reason, they are excluded from the set of dependent variables in a multiple regression.

**Table 1**
Results of spanning tests for physical commodities.

| Commodities | LR | Wald | LM | GMM-Wald | F1 | F2 |
|---|---|---|---|---|---|---|
| Energy | | | | | | |
| Crude oil (Brent) | 8.8486 | 9.0567 | 8.6467 | 9.5898 | 3.7812 | 4.9175 |
| | (0.0119) | (0.0108) | (0.0133) | (0.0083) | (0.0533) | (0.0278) |
| Crude oil (WTI) | 9.7955 | 10.0511 | 9.5486 | 10.5590 | 3.7733 | 5.8745 |
| | (0.0075) | (0.0066) | (0.0084) | (0.0051) | (0.0536) | (0.0163) |
| Gas oil | 7.2984 | 7.4397 | 7.1607 | 8.3588 | 3.4992 | 3.6576 |
| | (0.0260) | (0.0242) | (0.0279) | (0.0153) | (0.0630) | (0.0574) |
| Heating oil | 13.3353 | 13.8119 | 12.8804 | 14.0300 | 3.7455 | 9.4923 |
| | (0.0013) | (0.0010) | (0.0016) | (0.0009) | (0.0545) | (0.0024) |
| Natural gas | 3.7472 | 3.7842 | 3.7107 | 2.5268 | 0.8804 | 2.7867 |
| | (0.1536) | (0.1508) | (0.1564) | (0.2827) | (0.3493) | (0.0967) |
| Unleaded gasoline | 6.8897 | 7.0154 | 6.7669 | 7.6007 | 3.6744 | 3.0764 |
| | (0.0319) | (0.0300) | (0.0339) | (0.0224) | (0.0568) | (0.0811) |
| *Portfolio energy* | 22.8916 | 23.9490 | 21.9019 | 20.3250 | 0.9409 | 2.8069 |
| | (0.0287) | (0.0207) | (0.0386) | (0.0612) | (0.4671) | (0.0123) |
| Industrial metals | | | | | | |
| Aluminium | 10.9092 | 11.2268 | 10.6035 | 11.4380 | 0.0151 | 10.9168 |
| | (0.0043) | (0.0036) | (0.0050) | (0.0033) | (0.9023) | (0.0011) |
| Copper | 5.1186 | 5.1878 | 5.0506 | 4.7610 | 0.7103 | 4.3213 |
| | (0.0774) | (0.0747) | (0.0800) | (0.0925) | (0.4004) | (0.0390) |
| Lead | 0.1823 | 0.1824 | 0.1822 | 0.1657 | 0.1191 | 0.0578 |
| | (0.9129) | (0.9128) | (0.9129) | (0.9205) | (0.7304) | (0.8103) |
| Nickel | 0.9676 | 0.9700 | 0.9651 | 1.0547 | 0.3512 | 0.5904 |
| | (0.6164) | (0.6157) | (0.6172) | (0.5902) | (0.5542) | (0.4432) |
| Zinc | 0.5084 | 0.5091 | 0.5077 | 0.6126 | 0.0002 | 0.4956 |
| | (0.7755) | (0.7753) | (0.7758) | (0.7362) | (0.9896) | (0.4823) |
| *Portfolio industrial metals* | 16.0325 | 16.6309 | 15.4641 | 17.8500 | 0.2515 | 2.9142 |
| | (0.0987) | (0.0829) | (0.1160) | (0.0576) | (0.9386) | (0.0148) |
| Precious metals | | | | | | |
| Gold | 12.9021 | 13.3478 | 12.4759 | 9.9759 | 3.6256 | 9.1734 |
| | (0.0016) | (0.0013) | (0.0020) | (0.0068) | (0.0585) | (0.0028) |
| Platinum | 9.3115 | 9.5422 | 9.0882 | 10.0660 | 2.5035 | 6.6849 |
| | (0.0095) | (0.0085) | (0.0106) | (0.0065) | (0.1153) | (0.0105) |
| Silver | 11.0036 | 11.3268 | 10.6927 | 8.1884 | 3.9297 | 6.9321 |
| | (0.0041) | (0.0035) | (0.0048) | (0.0167) | (0.0489) | (0.0092) |
| *Portfolio precious metals* | 16.6030 | 17.3337 | 15.9130 | 13.5570 | 1.6669 | 3.7905 |
| | (0.0109) | (0.0081) | (0.0142) | (0.0350) | (0.1757) | (0.0114) |
| Softs | | | | | | |
| Cocoa | 11.5863 | 11.9450 | 11.2419 | 10.7840 | 1.1260 | 10.4367 |
| | (0.0030) | (0.0025) | (0.0036) | (0.0046) | (0.2900) | (0.0015) |
| Coffee | 2.7018 | 2.7210 | 2.6828 | 2.1746 | 0.0194 | 2.6300 |
| | (0.2590) | (0.2565) | (0.2615) | (0.3371) | (0.8894) | (0.1066) |
| Cotton | 1.5557 | 1.5621 | 1.5494 | 1.7482 | 0.0356 | 1.4851 |
| | (0.4594) | (0.4579) | (0.4608) | (0.4172) | (0.8506) | (0.2245) |
| Sugar | 12.9052 | 13.3511 | 12.4788 | 15.2740 | 1.1785 | 11.7420 |
| | (0.0016) | (0.0013) | (0.0020) | (0.0005) | (0.2791) | (0.0008) |
| *Portfolio softs* | 23.4153 | 24.8904 | 22.0551 | 24.5880 | 0.5507 | 5.3484 |
| | (0.0029) | (0.0016) | (0.0048) | (0.0018) | (0.6987) | (0.0004) |
| Grains | | | | | | |
| Corn | 7.3408 | 7.4836 | 7.2015 | 8.5777 | 0.9765 | 6.2729 |
| | (0.0255) | (0.0237) | (0.0273) | (0.0137) | (0.3244) | (0.0131) |
| Soybeans | 7.8953 | 8.0608 | 7.7344 | 6.7433 | 1.4157 | 6.3776 |
| | (0.0193) | (0.0178) | (0.0209) | (0.0343) | (0.2356) | (0.0124) |
| Wheat (Chicago) | 1.4357 | 1.4411 | 1.4303 | 1.4389 | 0.3326 | 1.0671 |
| | (0.4878) | (0.4865) | (0.4891) | (0.4870) | (0.5648) | (0.3029) |
| Wheat (Kansas) | 3.8182 | 3.8566 | 3.7803 | 4.4405 | 0.3195 | 3.4285 |
| | (0.1482) | (0.1454) | (0.1510) | (0.1086) | (0.5726) | (0.0657) |
| *Portfolio grains* | 11.6566 | 12.0056 | 11.3212 | 11.8930 | 0.3776 | 2.4788 |
| | (0.1672) | (0.1510) | (0.1842) | (0.1561) | (0.8244) | (0.0456) |
| Livestock | | | | | | |
| Feeder cattle | 20.4138 | 21.5446 | 19.3607 | 25.1320 | 0.3225 | 20.6205 |
| | (0.0000) | (0.0000) | (0.0001) | (0.0000) | (0.5708) | (0.0000) |
| Live steers | 11.5636 | 11.9208 | 11.2205 | 12.7830 | 0.0836 | 11.5195 |
| | (0.0031) | (0.0026) | (0.0037) | (0.0017) | (0.7728) | (0.0008) |
| Pork bellies | 1.4491 | 1.4546 | 1.4436 | 1.4425 | 1.2429 | 0.1658 |
| | (0.4846) | (0.4832) | (0.4859) | (0.4862) | (0.2664) | (0.6844) |
| *Portfolio livestock* | 23.4227 | 24.7502 | 22.1932 | 27.6660 | 0.4851 | 7.4550 |
| | (0.0007) | (0.0004) | (0.0011) | (0.0001) | (0.6931) | (0.0001) |

The table presents test statistics and the respective *p*-values (in parentheses) for the null hypothesis that physical commodities span a portfolio of stocks and bonds for different commodities. The portfolio of each sub-class includes all commodities belonging to the sub-class. The analysis is based on monthly excess returns over the risk-free rate during the period from January 1995 to December 2010. The first three columns report the results for the Likelihood Ratio (LR), Wald (W) and Lagrange Multiplier (LM) tests. The fourth column presents the results for the Wald test based on the GMM-estimation to control for the heteroscedasticity. The last two columns show the results of the step-down procedure, which allow for the differentiation of the diversification gains: $F_1$ tests the ability of commodities to improve return, while $F_2$ tests the ability to reduce the level of risk.

**Table 2**
Results of spanning tests for commodity futures.

| Commodities | LR | Wald | LM | GMM-Wald | $F_1$ | $F_2$ |
|---|---|---|---|---|---|---|
| Energy | | | | | | |
| S&P GSCI-crude oil (Brent) | 9.9253 | 10.2804 | 9.5864 | 9.4308 | 2.4559 | 7.3124 |
| | (0.0070) | (0.0059) | (0.0083) | (0.0090) | (0.1194) | (0.0077) |
| S&P GSCI-crude oil (WTI) | 7.2820 | 7.4226 | 7.1450 | 7.5628 | 3.1687 | 3.9744 |
| | (0.0262) | (0.0244) | (0.0281) | (0.0228) | (0.0767) | (0.0477) |
| S&P GSCI-gas oil | 8.8631 | 9.1455 | 8.5922 | 9.7610 | 3.3050 | 5.3639 |
| | (0.0119) | (0.0103) | (0.0136) | (0.0076) | (0.0713) | (0.0220) |
| S&P GSCI-heating oil | 6.9725 | 7.1013 | 6.8468 | 7.1447 | 2.8192 | 4.0197 |
| | (0.0306) | (0.0287) | (0.0326) | (0.0281) | (0.0948) | (0.0464) |
| S&P GSCI-natural gas | 1.2065 | 1.2104 | 1.2027 | 1.1611 | 0.8999 | 0.2726 |
| | (0.5470) | (0.5460) | (0.5481) | (0.5596) | (0.3440) | (0.6022) |
| S&P GSCI-unleaded gasoline | 10.0447 | 10.3135 | 9.7851 | 10.5320 | 5.6392 | 4.2445 |
| | (0.0066) | (0.0058) | (0.0075) | (0.0052) | (0.0186) | (0.0408) |
| *Portfolio energy* | 15.2631 | 15.7937 | 14.7575 | 16.8220 | 2.5432 | 1.1827 |
| | (0.0542) | (0.0454) | (0.0640) | (0.0320) | (0.0412) | (0.3199) |
| Industrial metals | | | | | | |
| S&P GSCI-aluminium | 9.8073 | 10.0635 | 9.5598 | 9.0607 | 0.4264 | 9.3498 |
| | (0.0074) | (0.0065) | (0.0084) | (0.0108) | (0.5146) | (0.0026) |
| S&P GSCI-copper | 5.7012 | 5.7872 | 5.6170 | 4.8817 | 2.5419 | 3.0383 |
| | (0.0578) | (0.0554) | (0.0603) | (0.0871) | (0.1126) | (0.0830) |
| S&P GSCI-lead | 0.2289 | 0.2291 | 0.2288 | 0.2162 | 0.2116 | 0.0103 |
| | (0.8919) | (0.8918) | (0.8919) | (0.8975) | (0.6461) | (0.9192) |
| S&P GSCI-nickel | 1.4831 | 1.4889 | 1.4774 | 1.5623 | 0.9272 | 0.5151 |
| | (0.4764) | (0.4750) | (0.4777) | (0.4579) | (0.3368) | (0.4738) |
| S&P GSCI-zinc | 0.9933 | 0.9958 | 0.9907 | 1.3596 | 0.1371 | 0.8313 |
| | (0.6086) | (0.6078) | (0.6094) | (0.5067) | (0.7116) | (0.3631) |
| *Portfolio industrial metals* | 20.1654 | 20.7385 | 19.6142 | 19.4740 | 1.8596 | 2.0767 |
| | (0.0277) | (0.0230) | (0.0331) | (0.0346) | (0.1035) | (0.0703) |
| Precious metals | | | | | | |
| S&P GSCI-gold | 10.6357 | 10.9374 | 10.3450 | 8.7372 | 2.9612 | 7.5530 |
| | (0.0049) | (0.0042) | (0.0057) | (0.0127) | (0.0870) | (0.0066) |
| S&P GSCI-platinum | 9.7291 | 9.9812 | 9.4855 | 10.2160 | 5.2732 | 4.2957 |
| | (0.0077) | (0.0068) | (0.0087) | (0.0060) | (0.0228) | (0.0396) |
| S&P GSCI-silver | 8.0528 | 8.2250 | 7.8854 | 6.1242 | 3.0490 | 4.8640 |
| | (0.0178) | (0.0164) | (0.0194) | (0.0468) | (0.0824) | (0.0286) |
| *Portfolio precious metals* | 15.0167 | 15.5690 | 14.4913 | 13.0590 | 2.0487 | 2.8607 |
| | (0.0201) | (0.0163) | (0.0246) | (0.0421) | (0.1086) | (0.0382) |
| Softs | | | | | | |
| S&P GSCI-cocoa | 9.4491 | 9.6867 | 9.2192 | 9.1049 | 0.1739 | 9.2497 |
| | (0.0089) | (0.0079) | (0.0100) | (0.0105) | (0.6772) | (0.0027) |
| S&P GSCI-coffee | 2.3845 | 2.3995 | 2.3697 | 2.1235 | 0.0625 | 2.2731 |
| | (0.3035) | (0.3013) | (0.3058) | (0.3459) | (0.8029) | (0.1333) |
| S&P GSCI-cotton | 3.1045 | 3.1298 | 3.0794 | 3.2891 | 1.0639 | 1.9670 |
| | (0.2118) | (0.2091) | (0.2144) | (0.1931) | (0.3037) | (0.1624) |
| S&P GSCI-sugar | 11.2221 | 11.5583 | 10.8988 | 11.5840 | 1.4008 | 9.7733 |
| | (0.0037) | (0.0031) | (0.0043) | (0.0031) | (0.2381) | (0.0021) |
| *Portfolio softs* | 21.3313 | 22.3168 | 20.4079 | 21.1930 | 0.7648 | 4.5600 |
| | (0.0063) | (0.0044) | (0.0089) | (0.0067) | (0.5494) | (0.0016) |
| Grains | | | | | | |
| S&P GSCI-corn | 9.6292 | 9.8761 | 9.3905 | 9.8548 | 0.4220 | 9.1723 |
| | (0.0081) | (0.0072) | (0.0091) | (0.0072) | (0.5167) | (0.0028) |
| S&P GSCI-soybeans | 7.2366 | 7.3754 | 7.1012 | 5.5594 | 2.0143 | 5.1016 |
| | (0.0268) | (0.0250) | (0.0287) | (0.0621) | (0.1575) | (0.0251) |
| S&P GSCI-wheat (Chicago) | 6.1787 | 6.2797 | 6.0798 | 5.7635 | 1.4881 | 4.5823 |
| | (0.0455) | (0.0433) | (0.0478) | (0.0560) | (0.2241) | (0.0336) |
| S&P GSCI-wheat (Kansas) | 3.5260 | 3.5702 | 3.4826 | 3.8171 | 0.0306 | 3.4128 |
| | (0.1715) | (0.1678) | (0.1753) | (0.1483) | (0.8613) | (0.0668) |
| *Portfolio grains* | 18.3332 | 18.7995 | 17.8828 | 15.3880 | 2.8698 | 3.1454 |
| | (0.0055) | (0.0045) | (0.0065) | (0.0175) | (0.0378) | (0.0264) |
| Livestock | | | | | | |
| S&P GSCI-feeder cattle | 6.2830 | 6.4729 | 6.1004 | 6.2803 | 0.9884 | 5.1187 |
| | (0.0432) | (0.0393) | (0.0473) | (0.0433) | (0.3225) | (0.0258) |
| S&P GSCI-live cattle | 30.8639 | 33.4975 | 28.4993 | 33.5950 | 0.0003 | 32.6203 |
| | (0.0000) | (0.0000) | (0.0000) | (0.0000) | (0.9860) | (0.0000) |
| S&P GSCI-lean hogs | 3.9375 | 3.9784 | 3.8972 | 3.9498 | 2.7173 | 1.1258 |
| | (0.1396) | (0.1368) | (0.1425) | (0.1388) | (0.1010) | (0.2901) |
| *Portfolio livestock* | 36.6186 | 39.7530 | 33.8270 | 37.5620 | 1.6700 | 17.5505 |
| | (0.0000) | (0.0000) | (0.0000) | (0.0000) | (0.1911) | (0.0000) |

The table presents test statistics and the respective *p*-values (in parentheses) for the null hypothesis that commodity futures, approximated by the S&P GSCI sub-indices, span a portfolio of stocks and bonds. The portfolio of each sub-class includes all futures belonging to the sub-class. The analysis is based on monthly excess returns over the risk-free rate during the period from January 1995 to December 2010. The first three columns report the results for the Likelihood Ratio (LR), Wald (W) and Lagrange Multiplier (LM) tests. The fourth column presents the results for the Wald test based on the GMM-estimation to control for the heteroscedasticity. The last two columns show the results of the step-down procedure, which allow for the differentiation of the diversification gains: $F_1$ tests the ability of commodities to improve return, while $F_2$ tests the ability to reduce the level of risk.

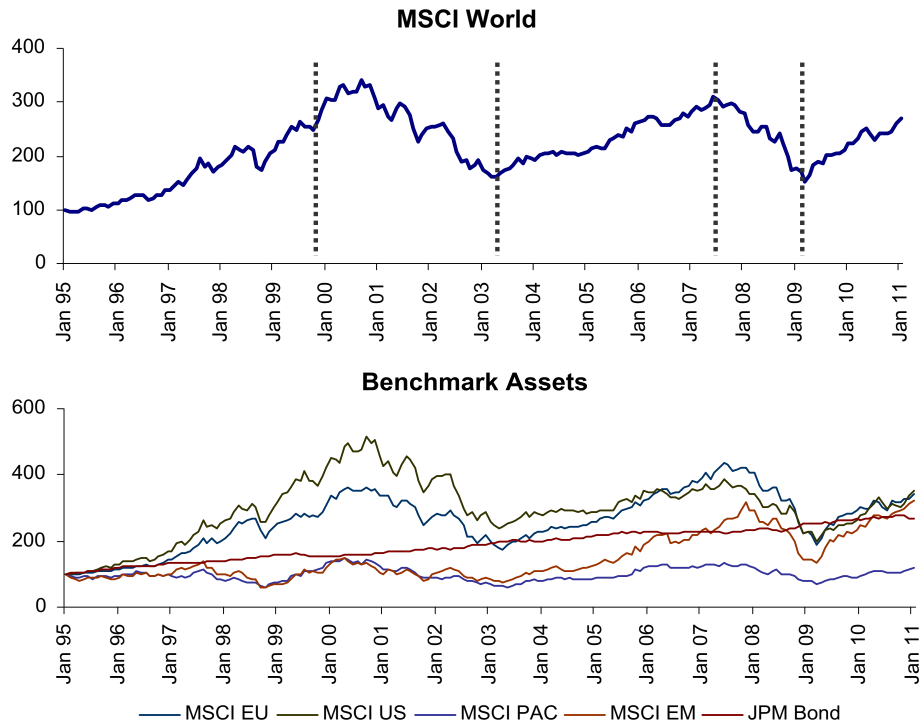


**Fig. 1.** Price development of MSCI World (above) and benchmark assets (below).

The differentiation between bull and bear markets is carried out on the basis of the performance of benchmark assets. As is seen in Fig. 1, the J.P. Morgan bond index steadily increased in value, indicating that there were no price fluctuations in fixed-income markets during the period of analysis. Therefore, the determination of sub-periods of falling and rising markets follows the performance of global equity markets, approximated by the MSCI World index.

Following this approach, the time period from 1995 to 2010 is divided into non-overlapping sub-periods of rising and falling equity markets, of which one time series of bull and bear markets is composed.[11] Therefore, the sample of bull markets contains the following time frames: January 1995 to December 1999, May 2003 to June 2007 and April 2009 to December 2010. Respectively, the sample of bear markets includes the time periods of the dot-com crisis, January 2000 to April 2003, and of the sub-prime crisis, July 2007 to March 2009.[12] Hence, spanning tests are repeated for the periods of bull and bear markets and the results are reported in Appendix B.

In bull markets, crude oil, gas oil and heating oil contribute to the enhancement of returns. However, only heating oil preserves its ability to simultaneously reduce the risk. In bear markets, the investment benefits of energy commodities change: the diversification gains stem from the reduction of portfolio risk. As is the case during the overall period of analysis, spanning tests fail to detect the diversification potential of natural gas.

In both sub-periods, evidence of the diversification contribution is also found for the group of precious metals. In bull markets, all precious metals lead to lower portfolio volatility, while silver also enhances portfolio return. In bear markets, gold and silver reduce portfolio risk, while platinum loses its diversification properties. In the sector of industrial metals, only aluminium has the diversification potential in bull markets. However, the diversification properties of industrial metals are stronger in bear markets. In addition to aluminium, the null-hypothesis of spanning tests is also rejected for copper and zinc.

The inclusion of soft commodity groups yields almost no investment benefits in bear markets. Spanning tests detect the diversification impact of coffee in the softs sector, of soybeans in the grains sector and of feeder cattle in the livestock sector. Other commodities show no contribution to the portfolio improvement. In contrast, soft commodities have a strong diversification potential in bull markets. All commodities in the grains category, cocoa and sugar in the softs sector, and feeder cattle and live steers in the livestock sector contribute to the reduction of portfolio risk. Thus, the diversification properties in the grains, softs and livestock sectors, detected throughout the entire period of analysis, are attributable to the periods of rising markets.

The variations in the diversification gains suggest that the benefits of commodity diversification can be enhanced by implementing a tactical allocation strategy linked to the price movements in equity markets. Adams et al. (2008) establish the connection between the macroeconomic conditions and the developments in equity markets. Booming equity markets mostly correspond to periods of economic growth and of high inflation. This provides an incentive to central banks to follow a restrictive monetary policy with the objective of counteracting inflationary concerns. Respectively, falling equity markets coincide with periods of expansive monetary policy, which involves the reduction of interest rates to stimulate economic growth. Based on this relation, the outcomes of spanning tests indicate that there is a variation in the diversification contribution of commodity sectors in response to economic, monetary and inflationary factors.

[11] The rationale for the accumulation of time periods is that the analysis has the objective to investigate the diversification benefits during bull and bear markets and does not intend to focus on the historical perspective.

[12] The period of bull markets is longer than that of bear markets. Therefore, spanning tests are also repeated for the period of bull markets with the length of time series corresponding to bear markets. Unreported results show that the differing periods do not have an impact on the outcomes of spanning tests in sub-periods.

**Table A1**
Constituents of major commodity indices, 2010. *Source*: Dow Jones Indexes (2011), Standard and Poor's (2011), Thomson Reuters/Jefferies (2010), Beeland Interests (2011), and Arnold (2008).

| Index weights | DJ-UBSCI (%) | S&P GSCI (%) | TRJ/CRB (%) | RICI (%) | DBLCI (%) |
|---|---|---|---|---|---|
| Energy | | | | | |
| Crude oil (Brent) | – | 14.58 | – | 14.00 | – |
| Crude oil (WTI) | 14.59 | 36.45 | 23.00 | 21.00 | 35.00 |
| Gas oil | – | 5.70 | – | 1.20 | – |
| Heating oil | 3.76 | 4.54 | 5.00 | 1.80 | 20.00 |
| Natural gas | 10.87 | 4.24 | 6.00 | 3.00 | – |
| Unleaded gasoline | 3.45 | 4.51 | 5.00 | 3.00 | – |
| *Total energy* | 32.67 | 70.02 | 39.00 | 44.00 | 55.00 |
| Industrial metals | | | | | |
| Aluminium | 5.01 | 2.54 | 6.00 | 4.00 | 12.50 |
| Copper | 7.50 | 3.63 | 6.00 | 4.00 | – |
| Lead | – | 0.50 | – | 2.00 | – |
| Nickel | 2.42 | 0.83 | 1.00 | 1.00 | – |
| Tin | – | – | – | 1.00 | – |
| Zinc | 2.71 | 0.70 | – | 2.00 | – |
| *Total industrial metals* | 17.64 | 8.20 | 13.00 | 14.00 | 12.50 |
| Precious metals | | | | | |
| Gold | 9.82 | 2.93 | 6.00 | 3.00 | 10.00 |
| Palladium | – | – | – | 0.30 | – |
| Platinum | – | – | – | 1.80 | – |
| Silver | 3.07 | 0.36 | 1.00 | 2.00 | – |
| *Total precious metals* | 12.89 | 3.29 | 7.00 | 7.10 | 10.00 |
| Agriculture | | | | | |
| Azuki beans | – | – | – | 0.15 | – |
| Canola | – | – | – | 0.75 | – |
| Chicago wheat | 4.74 | 3.10 | – | 5.75 | – |
| Cocoa | – | 0.38 | 5.00 | 1.00 | – |
| Coffee | 2.39 | 0.77 | 5.00 | 2.00 | – |
| Corn | 7.38 | 3.25 | 6.00 | 4.75 | 11.25 |
| Cotton | 2.30 | 1.18 | 5.00 | 4.20 | |
| Greasy wool | – | – | – | 0.10 | – |
| Kansas wheat | – | 0.62 | 1.00 | 1.25 | 11.25 |
| Lumber | – | – | – | 1.00 | – |
| Oats | – | – | – | 0.50 | – |
| Orange juice | – | – | 1.00 | 0.60 | – |
| Rapeseed | – | – | – | 0.25 | – |
| Rice | – | – | – | 0.50 | – |
| Rubber | – | – | – | 1.00 | – |
| Soybean meal | – | – | – | 0.75 | – |
| soybean oil | 2.86 | – | – | 2.00 | – |
| Soybeans | 7.78 | 2.31 | 6.00 | 3.35 | – |
| Sugar | 3.61 | 2.25 | 5.00 | 2.00 | – |
| *Total agriculture* | 31.06 | 13.86 | 34.00 | 31.90 | 22.50 |
| Livestock | | | | | |
| Feeder cattle | – | 0.45 | – | – | – |
| Lean hogs | 2.27 | 1.55 | 1.00 | 1.00 | – |
| Live cattle | 3.47 | 2.63 | 6.00 | 2.00 | – |
| *Total livestock* | 5.74 | 4.63 | 7.00 | 3.00 | 0.00 |

By combining the results of sub-periods with those of the overall period of investigation, the inclusion of the following individual commodities contributes to the enhancement of the portfolio performance. The strongest evidence of diversification is found for energy and precious metals. In the energy sector, crude oil, gas oil, heating oil and unleaded gasoline show similar diversification properties: they improve portfolio return and simultaneously reduce risk. Concerning natural gas, the diversification potential cannot be detected. All precious metals are powerful diversifiers. However, platinum has a slightly weaker diversification contribution than that of gold and silver; it loses its diversification properties in bear markets.

In the group of industrial metals, aluminium stands out; its diversification impact is found during the overall period of the analysis and in both sub-periods. Also, the diversification potential is detected for copper and zinc. In the grains sector, there are no substantial differences between individual commodities; all grains contribute to the reduction of the portfolio risk. In the softs sector, the performed spanning tests indicate the diversification gains for cocoa and sugar. Regarding livestock, feeder cattle and live steers improve the portfolio performance. Due to the excessive volatility of pork bellies, their inclusion does not show benefits for investors.

## 5. Conclusion

This paper takes the perspective of euro investors and differs from prior literature with respect to both the methodology and to setting the focus on the level of individual commodities. Spanning tests detect that commodities remain valuable investments in the perspective of diversification. As commodity futures preserve the diversification characteristics of physical commodities, investors do not face difficulties concerning the implementability of diversification gains. Accomplished on the basis of 25 individual commodities, the investigation reveals that generalisations cannot be made, when it comes to policy recommendations.

**Table B1**
Results of spanning tests, for bull market periods.

| Commodities | LR | Wald | LM | GMM-Wald | $F_1$ | $F_2$ |
|---|---|---|---|---|---|---|
| Energy | | | | | | |
| Crude oil (Brent) | 4.5020 | 4.5808 | 4.4249 | 5.1940 | 3.5799 | 0.7735 |
| | (0.1053) | (0.1012) | (0.1094) | (0.0745) | (0.0608) | (0.3808) |
| Crude oil (WTI) | 4.7577 | 4.8458 | 4.6717 | 6.0166 | 2.8709 | 1.7255 |
| | (0.0927) | (0.0887) | (0.0967) | (0.0494) | (0.0927) | (0.1914) |
| Gas oil | 4.0570 | 4.1210 | 3.9944 | 4.5475 | 3.2347 | 0.6839 |
| | (0.1315) | (0.1274) | (0.1357) | (0.1029) | (0.0745) | (0.4098) |
| Heating oil | 13.0049 | 13.6777 | 12.3756 | 14.1970 | 7.1419 | 5.6279 |
| | (0.0015) | (0.0011) | (0.0021) | (0.0008) | (0.0085) | (0.0192) |
| Natural gas | 1.8151 | 1.8278 | 1.8025 | 1.2329 | 0.4054 | 1.3445 |
| | (0.4035) | (0.4009) | (0.4061) | (0.5399) | (0.5255) | (0.2485) |
| Unleaded gasoline | 2.4509 | 2.4741 | 2.4279 | 3.5138 | 2.1427 | 0.2152 |
| | (0.2936) | (0.2902) | (0.2970) | (0.1726) | (0.1458) | (0.6435) |
| *Portfolio energy* | 19.1343 | 20.1097 | 18.2282 | 19.7650 | 1.3815 | 1.6625 |
| | (0.0853) | (0.0650) | (0.1089) | (0.0717) | (0.2276) | (0.1360) |
| Industrial metals | | | | | | |
| Aluminium | 6.4169 | 6.5779 | 6.2611 | 7.1050 | 1.1246 | 5.1446 |
| | (0.0404) | (0.0373) | (0.0437) | (0.0287) | (0.2910) | (0.0250) |
| Copper | 2.1318 | 2.1493 | 2.1144 | 1.8107 | 1.0579 | 0.9918 |
| | (0.3444) | (0.3414) | (0.3474) | (0.4044) | (0.3057) | (0.3212) |
| Lead | 0.9897 | 0.9934 | 0.9859 | 1.1518 | 0.6215 | 0.3271 |
| | (0.6097) | (0.6085) | (0.6108) | (0.5622) | (0.4320) | (0.5684) |
| Nickel | 2.2014 | 2.2202 | 2.1829 | 2.3653 | 1.5671 | 0.5481 |
| | (0.3326) | (0.3295) | (0.3357) | (0.3065) | (0.2130) | (0.4605) |
| Zinc | 2.4381 | 2.4611 | 2.4154 | 2.4739 | 1.2070 | 1.1387 |
| | (0.2955) | (0.2921) | (0.2989) | (0.2903) | (0.2741) | (0.2880) |
| *Portfolio industrial metals* | 9.7884 | 10.1210 | 9.4709 | 12.3240 | 0.6308 | 1.2243 |
| | (0.4593) | (0.4299) | (0.4881) | (0.2640) | (0.6766) | (0.3019) |
| Precious metals | | | | | | |
| Gold | 6.2716 | 6.4254 | 6.1228 | 5.4860 | 1.2069 | 4.9138 |
| | (0.0435) | (0.0402) | (0.0468) | (0.0644) | (0.2741) | (0.0285) |
| Platinum | 8.1857 | 8.4489 | 7.9333 | 8.0335 | 0.9011 | 7.1636 |
| | (0.0167) | (0.0146) | (0.0189) | (0.0180) | (0.3443) | (0.0084) |
| Silver | 7.1470 | 7.3471 | 6.9541 | 5.9521 | 3.5672 | 3.3716 |
| | (0.0281) | (0.0254) | (0.0309) | (0.0510) | (0.0613) | (0.0687) |
| *Portfolio precious metals* | 11.9336 | 12.3749 | 11.5150 | 12.7890 | 1.1844 | 2.6699 |
| | (0.0635) | (0.0541) | (0.0737) | (0.0465) | (0.3186) | (0.0505) |
| Softs | | | | | | |
| Cocoa | 13.4528 | 14.1735 | 12.7802 | 12.1630 | 0.0030 | 13.6251 |
| | (0.0012) | (0.0008) | (0.0017) | (0.0023) | (0.9567) | (0.0003) |
| Coffee | 0.9760 | 0.9797 | 0.9724 | 0.9029 | 0.0494 | 0.8919 |
| | (0.6138) | (0.6127) | (0.6150) | (0.6367) | (0.8245) | (0.3468) |
| Cotton | 0.7310 | 0.7331 | 0.7290 | 0.8144 | 0.0045 | 0.7003 |
| | (0.6938) | (0.6931) | (0.6946) | (0.6655) | (0.9468) | (0.4043) |
| Sugar | 16.2377 | 17.2953 | 15.2645 | 18.9330 | 0.2389 | 16.3577 |
| | (0.0003) | (0.0002) | (0.0005) | (0.0001) | (0.6258) | (0.0001) |
| *Portfolio softs* | 30.5027 | 34.3356 | 27.2223 | 34.8160 | 0.0658 | 7.9820 |
| | (0.0002) | (0.0000) | (0.0006) | (0.0000) | (0.9920) | (0.0000) |
| Grains | | | | | | |
| Corn | 5.1840 | 5.2888 | 5.0820 | 6.1003 | 0.1426 | 4.9359 |
| | (0.0749) | (0.0710) | (0.0788) | (0.0474) | (0.7064) | (0.0281) |
| Soybeans | 4.4919 | 4.5704 | 4.4152 | 4.6993 | 0.0264 | 4.3670 |
| | (0.1058) | (0.1018) | (0.1100) | (0.0954) | (0.8711) | (0.0387) |
| Wheat (Chicago) | 4.0251 | 4.0881 | 3.9635 | 5.4482 | 0.0552 | 3.8735 |
| | (0.1336) | (0.1295) | (0.1378) | (0.0656) | (0.8146) | (0.0513) |
| Wheat (Kansas) | 5.7111 | 5.8384 | 5.5875 | 5.9419 | 0.0323 | 5.5799 |
| | (0.0575) | (0.0540) | (0.0612) | (0.0513) | (0.8577) | (0.0197) |
| *Portfolio grains* | 9.2217 | 9.5058 | 8.9497 | 10.7860 | 0.1809 | 2.0475 |
| | (0.3239) | (0.3014) | (0.3466) | (0.2141) | (0.9479) | (0.0919) |
| Livestock | | | | | | |
| Feeder cattle | 19.7046 | 21.2764 | 18.2840 | 24.5420 | 0.2021 | 20.2213 |
| | (0.0001) | (0.0000) | (0.0001) | (0.0000) | (0.6538) | (0.0000) |
| Live steers | 13.7536 | 14.5075 | 13.0511 | 13.1080 | 0.0825 | 13.8572 |
| | (0.0010) | (0.0007) | (0.0015) | (0.0014) | (0.7744) | (0.0003) |
| Pork bellies | 1.1069 | 1.1117 | 1.1022 | 0.9747 | 0.8076 | 0.2532 |
| | (0.5750) | (0.5736) | (0.5763) | (0.6143) | (0.3706) | (0.6157) |
| *Portfolio livestock* | 23.4525 | 25.4320 | 21.6834 | 27.0040 | 0.4616 | 7.5546 |
| | (0.0007) | (0.0003) | (0.0014) | (0.0001) | (0.7096) | (0.0001) |

The table presents test statistics and the respective *p*-values, which are given in parentheses, for the null hypothesis that physical commodities span a portfolio of stocks and bonds during the cumulative period of bull markets. The portfolio of each sub-class includes all commodities belonging to the sub-class. The analysis is based on monthly excess returns over the risk-free rate. The first three columns report the results for the Likelihood Ratio (LR), Wald (W) and Lagrange Multiplier (LM) tests. The fourth column presents the results for the Wald test based on the GMM-estimation to control for the heteroscedasticity. The last two columns show the results of the step-down procedure, which allow for the differentiation of the diversification gains: $F_1$tests the ability of commodities to improve return, while $F_2$ tests the ability to reduce the level of risk.

**Table B2**
Results of spanning tests, for bear market periods.

| Commodities | LR | Wald | LM | GMM-Wald | $F_1$ | $F_2$ |
|---|---|---|---|---|---|---|
| Energy | | | | | | |
| Crude oil (Brent) | 7.5722 | 8.0623 | 7.1211 | 10.6190 | 0.4128 | 6.9291 |
| | (0.0227) | (0.0178) | (0.0284) | (0.0049) | (0.5232) | (0.0109) |
| Crude oil (WTI) | 7.7237 | 8.2340 | 7.2548 | 8.2021 | 0.7051 | 6.7546 |
| | (0.0210) | (0.0163) | (0.0266) | (0.0166) | (0.4047) | (0.0119) |
| Gas oil | 6.9423 | 7.3528 | 6.5618 | 9.6493 | 1.2778 | 5.3254 |
| | (0.0311) | (0.0253) | (0.0376) | (0.0080) | (0.2632) | (0.0247) |
| Heating oil | 4.9684 | 5.1763 | 4.7714 | 5.4907 | 1.3743 | 3.2710 |
| | (0.0834) | (0.0752) | (0.0920) | (0.0642) | (0.2461) | (0.0759) |
| Natural gas | 3.1005 | 3.1807 | 3.0231 | 2.6465 | 1.9769 | 0.8757 |
| | (0.2122) | (0.2039) | (0.2206) | (0.2663) | (0.1653) | (0.3534) |
| Unleaded gasoline | 7.9410 | 8.4810 | 7.4458 | 8.9827 | 0.5180 | 7.1907 |
| | (0.0189) | (0.0144) | (0.0242) | (0.0112) | (0.4747) | (0.0096) |
| *Portfolio energy* | 15.6377 | 17.1420 | 14.3227 | 21.3620 | 0.4147 | 1.9631 |
| | (0.2084) | (0.1443) | (0.2806) | (0.0453) | (0.8658) | (0.0884) |
| Industrial metals | | | | | | |
| Aluminium | 8.7996 | 9.4659 | 8.1943 | 11.4860 | 2.5653 | 5.8072 |
| | (0.0123) | (0.0088) | (0.0166) | (0.0032) | (0.1150) | (0.0193) |
| Copper | 7.8367 | 8.3623 | 7.3542 | 11.3700 | 1.1767 | 6.3431 |
| | (0.0199) | (0.0153) | (0.0253) | (0.0034) | (0.2828) | (0.0147) |
| Lead | 1.9792 | 2.0116 | 1.9474 | 2.4417 | 1.6455 | 0.1663 |
| | (0.3717) | (0.3657) | (0.3777) | (0.2950) | (0.2049) | (0.6850) |
| Nickel | 0.4020 | 0.4033 | 0.4007 | 0.4162 | 0.3294 | 0.0346 |
| | (0.8179) | (0.8174) | (0.8185) | (0.8121) | (0.5683) | (0.8530) |
| Zinc | 7.3800 | 7.8450 | 6.9511 | 9.0975 | 6.9475 | 0.1138 |
| | (0.0250) | (0.0198) | (0.0309) | (0.0106) | (0.0109) | (0.7371) |
| *Portfolio industrial metals* | 33.2724 | 38.9785 | 28.6999 | 34.5490 | 2.1344 | 4.4389 |
| | (0.0002) | (0.0000) | (0.0014) | (0.0001) | (0.0762) | (0.0019) |
| Precious metals | | | | | | |
| Gold | 7.4870 | 7.9659 | 7.0458 | 7.3861 | 0.2315 | 7.0475 |
| | (0.0237) | (0.0186) | (0.0295) | (0.0249) | (0.6323) | (0.0103) |
| Platinum | 2.3712 | 2.4179 | 2.3257 | 3.2233 | 0.3968 | 1.8027 |
| | (0.3056) | (0.2985) | (0.3126) | (0.1996) | (0.5313) | (0.1848) |
| Silver | 8.9009 | 9.5831 | 8.2820 | 10.6000 | 0.6656 | 8.0228 |
| | (0.0117) | (0.0083) | (0.0159) | (0.0050) | (0.4181) | (0.0064) |
| *Portfolio precious metals* | 14.6775 | 15.6995 | 13.7483 | 18.3240 | 1.6481 | 2.9428 |
| | (0.0229) | (0.0155) | (0.0326) | (0.0055) | (0.1893) | (0.0411) |
| Softs | | | | | | |
| Cocoa | 1.0793 | 1.0889 | 1.0698 | 1.4335 | 0.0257 | 0.9730 |
| | (0.5830) | (0.5802) | (0.5857) | (0.4883) | (0.8731) | (0.3282) |
| Coffee | 5.1541 | 5.3781 | 4.9423 | 5.6579 | 0.9710 | 3.8802 |
| | (0.0760) | (0.0679) | (0.0845) | (0.0591) | (0.3288) | (0.0538) |
| Cotton | 1.4807 | 1.4988 | 1.4629 | 1.6300 | 0.0236 | 1.3514 |
| | (0.4769) | (0.4726) | (0.4812) | (0.4426) | (0.8785) | (0.2500) |
| Sugar | 0.1323 | 0.1325 | 0.1322 | 0.1553 | 0.0956 | 0.0242 |
| | (0.9360) | (0.9359) | (0.9361) | (0.9253) | (0.7584) | (0.8768) |
| *Portfolio softs* | 6.5021 | 6.8037 | 6.2194 | 7.5449 | 0.3545 | 1.0990 |
| | (0.5912) | (0.5580) | (0.6227) | (0.4791) | (0.8397) | (0.3667) |
| Grains | | | | | | |
| Corn | 2.6870 | 2.7470 | 2.6287 | 2.4551 | 0.1921 | 2.3182 |
| | (0.2609) | (0.2532) | (0.2687) | (0.293) | (0.6629) | (0.1335) |
| Soybeans | 4.6593 | 4.8418 | 4.4858 | 3.0150 | 1.0164 | 3.3482 |
| | (0.0973) | (0.0888) | (0.1062) | (0.2215) | (0.3178) | (0.0726) |
| Wheat (Chicago) | 0.5621 | 0.5647 | 0.5595 | 0.5614 | 0.0107 | 0.5075 |
| | (0.7550) | (0.7540) | (0.7560) | (0.7553) | (0.9181) | (0.4792) |
| Wheat (Kansas) | 0.2243 | 0.2247 | 0.2239 | 0.2867 | 0.2025 | 0.0001 |
| | (0.8939) | (0.8937) | (0.8941) | (0.8664) | (0.6545) | (0.9909) |
| *Portfolio grains* | 10.2462 | 11.0846 | 9.4932 | 10.4010 | 0.4120 | 1.9420 |
| | (0.2482) | (0.1970) | (0.3024) | (0.238) | (0.7992) | (0.1170) |
| Livestock | | | | | | |
| Feeder cattle | 3.4574 | 3.5573 | 3.3613 | 5.1809 | 0.1350 | 3.1206 |
| | (0.1775) | (0.1689) | (0.1863) | (0.0750) | (0.7148) | (0.0828) |
| Live steers | 1.0905 | 1.1003 | 1.0808 | 1.6528 | 0.3145 | 0.6860 |
| | (0.5797) | (0.5797) | (0.5825) | (0.4376) | (0.5772) | (0.4110) |
| Pork bellies | 0.2248 | 0.2252 | 0.2244 | 0.2904 | 0.0969 | 0.1079 |
| | (0.8937) | (0.8935) | (0.8939) | (0.8649) | (0.7567) | (0.7567) |
| *Portfolio livestock* | 3.9252 | 4.0295 | 3.8248 | 5.3010 | 0.1686 | 1.0149 |
| | (0.6868) | (0.6727) | (0.7004) | (0.5058) | (0.9171) | (0.3933) |

The table presents test statistics and the respective *p*-values, which are given in parentheses, for the null hypothesis that physical commodities span a portfolio of stocks and bonds during the cumulative period of bear markets. The portfolio of each sub-class includes all commodities belonging to the sub-class. The analysis is based on monthly excess returns over the risk-free rate. The first three columns report the results for the Likelihood Ratio (LR), Wald (W) and Lagrange Multiplier (LM) tests. The fourth column presents the results for the Wald test based on the GMM-estimation to control for the heteroscedasticity. The last two columns show the results of the step-down procedure, which allow for the differentiation of the diversification gains: $F_1$tests the ability of commodities to improve return, while $F_2$ tests the ability to reduce the level of risk.

**Table C1**
Overview of the sample of physical commodities.

| Commodity | Mnemonic | Unit | Currency | Source |
|---|---|---|---|---|
| Energy | | | | |
| Crude oil (Brent) | OILBRNP | Barrel | US-dollar | ICIS Pricing |
| Crude oil (WTI) | CRUDOIL | Barrel | US-dollar | ICIS Pricing |
| Gas oil | OILGASO | Metric Tonne | US-dollar | ICIS Pricing |
| Heating oil | HOLDEEE | Gallon | Euro | European Commision |
| Natural gas | NATLGAS | MMBtu | US-dollar | Wall Street Journal |
| *Unleaded gasoline* | GASUSPB | Gallon | US-dollar | ICIS Pricing |
| Industrial metals | | | | |
| Aluminium | LAHCASH | Metric Tonne | US-dollar | London Metal Exchange |
| Copper | LCPCASH | Metric Tonne | US-dollar | London Metal Exchange |
| Lead | LEDCASH | Metric Tonne | US-dollar | London Metal Exchange |
| Nickel | LNICASH | Metric Tonne | US-dollar | London Metal Exchange |
| Zinc | LZZCASH | Metric Tonne | US-dollar | London Metal Exchange |
| Precious metals | | | | |
| Gold | GOLDBLN | Troy Ounce | US-dollar | London Bullion Market |
| Platinum | PLTFREE | Troy Ounce | US-dollar | Wall Street Journal |
| Silver | SLVCASH | Troy Ounce | US-cent | London Bullion Market |
| Softs | | | | |
| Cocoa | COCINUS | Metric Tonne | US-dollar | International Cocoa Organisation |
| Coffee | COFCOMA | Pound | US-cent | International Coffee Organisation |
| Cotton | COTTONM | Pound | US-cent | US Department of Agriculture |
| Sugar | WSUGDLY | Pound | US-cent | Public Ledger |
| Grains | | | | |
| Corn | CORNUS2 | Buschel | US-cent | US Department of Agriculture |
| Soybeans | SOYBEAN | Buschel | US-cent | US Department of Agriculture |
| Wheat (Chicago) | WHEATSF | Buschel | US-cent | US Department of Agriculture |
| Wheat (Kansas) | WHEATHD | Buschel | US-cent | US Department of Agriculture |
| Livestock | | | | |
| Feeder cattle | CFCINDX | Pound | US-dollar | Chicago Mercantile Exchange |
| Live steers | USTEERS | Pound | US-dollar | US Department of Agriculture |
| Pork bellies | PORKBEL | Pound | US-cent | US Department of Agriculture |

**Table C2**
Descriptive statistics of physical commodities.

| Commodities/benchmark assets | Annual. mean (%) | Annual. volatility (%) | Sharpe ratio | Skewness | Excess kurtosis | Range | Min return (%) | Max return (%) | No of pos. returns | No of neg. returns |
|---|---|---|---|---|---|---|---|---|---|---|
| *Benchmark assets* | | | | | | | | | | |
| MSCI Europe | 9.42 | 18.93 | 0.33 | −0.67 | 0.80 | 27.11 | −14.32 | 12.80 | 121 | 70 |
| MSCI USA | 9.80 | 20.13 | 0.33 | −0.34 | 0.36 | 30.77 | −15.57 | 15.20 | 114 | 77 |
| MSCI Pacific | 2.65 | 19.50 | −0.02 | 0.05 | 0.11 | 31.55 | −14.16 | 17.39 | 99 | 92 |
| MSCI EM | 10.85 | 27.74 | 0.28 | −0.62 | 1.41 | 46.87 | −30.29 | 16.58 | 114 | 77 |
| JPM EMU bond index | 6.47 | 4.01 | 0.84 | −0.22 | 0.01 | 6.57 | −2.69 | 3.88 | 136 | 55 |
| *Energy* | | | | | | | | | | |
| Crude oil (Brent) | 19.32 | 47.10 | 0.34 | 0.12 | 1.21 | 75.85 | −34.34 | 41.50 | 106 | 85 |
| Crude oil (WTI) | 16.20 | 38.33 | 0.34 | −0.03 | 0.90 | 66.33 | −28.82 | 37.51 | 107 | 84 |
| Gas oil | 16.37 | 38.86 | 0.34 | 0.01 | 0.99 | 58.87 | −25.67 | 33.19 | 114 | 77 |
| Heating oil | 11.71 | 28.35 | 0.30 | 0.12 | 1.17 | 48.06 | −21.83 | 26.23 | 107 | 84 |
| Natural gas | 41.08 | 133.27 | 0.29 | 2.09 | 12.67 | 230.40 | −57.73 | 172.67 | 101 | 90 |
| Unleaded gasoline | 23.29 | 64.49 | 0.31 | 0.71 | 2.71 | 106.38 | −37.28 | 69.09 | 101 | 90 |
| *Industrial metals* | | | | | | | | | | |
| Aluminium | 3.66 | 24.27 | 0.02 | 0.08 | 0.81 | 43.49 | −23.35 | 20.14 | 88 | 103 |
| Copper | 10.49 | 30.50 | 0.24 | 0.00 | 1.15 | 49.35 | −27.35 | 21.99 | 99 | 92 |
| Lead | 12.84 | 35.05 | 0.28 | 0.09 | 0.73 | 55.67 | −25.73 | 29.94 | 102 | 89 |
| Nickel | 13.33 | 42.52 | 0.24 | 0.02 | −0.17 | 55.93 | −29.11 | 26.82 | 99 | 92 |
| Zinc | 7.70 | 29.99 | 0.15 | 0.13 | 0.70 | 50.75 | −24.12 | 26.63 | 95 | 96 |
| *Precious metals* | | | | | | | | | | |
| Gold | 9.37 | 17.10 | 0.37 | 0.64 | 1.79 | 32.32 | −12.64 | 19.68 | 106 | 85 |
| Platinum | 11.52 | 24.89 | 0.34 | −0.36 | 2.67 | 49.63 | −28.85 | 20.79 | 105 | 86 |
| Silver | 15.40 | 30.92 | 0.40 | 0.16 | 0.64 | 47.54 | −22.49 | 25.05 | 105 | 86 |
| *Softs* | | | | | | | | | | |
| Cocoa | 8.39 | 31.62 | 0.17 | 0.72 | 2.36 | 59.28 | −24.22 | 35.06 | 98 | 93 |
| Coffee | 7.22 | 36.56 | 0.11 | 0.91 | 2.90 | 65.76 | −23.18 | 42.58 | 97 | 94 |
| Cotton | 6.86 | 34.02 | 0.11 | 0.39 | 0.77 | 55.82 | −22.56 | 33.27 | 98 | 93 |
| Sugar | 9.10 | 37.68 | 0.16 | 0.30 | 0.43 | 57.96 | −29.27 | 28.69 | 97 | 94 |
| *Grains* | | | | | | | | | | |
| Corn | 10.94 | 35.23 | 0.22 | −0.32 | 0.81 | 55.30 | −24.39 | 30.91 | 109 | 82 |
| Soybeans | 10.03 | 33.12 | 0.21 | −0.61 | 1.87 | 58.46 | −36.07 | 22.39 | 108 | 83 |
| Wheat (Chicago) | 10.19 | 39.57 | 0.18 | −0.23 | 1.33 | 69.94 | −39.61 | 30.33 | 109 | 82 |
| Wheat (Kansas) | 7.52 | 31.20 | 0.14 | 0.04 | 0.97 | 50.64 | −25.00 | 25.64 | 99 | 92 |
| *Livestock* | | | | | | | | | | |
| Feeder cattle | 4.20 | 19.48 | 0.06 | 0.20 | 0.41 | 35.34 | −15.28 | 20.06 | 100 | 91 |
| Live steers | 3.90 | 20.42 | 0.04 | −0.38 | 2.38 | 42.31 | −26.72 | 15.60 | 97 | 94 |
| Pork bellies | 28.19 | 86.45 | 0.29 | 0.63 | 1.63 | 112.75 | −42.54 | 70.21 | 98 | 93 |

The table reports the summary statistics for physical commodities and commodity futures, respectively: annualised mean, volatility, Sharpe ratio, skewness, excess kurtosis, range, minimum and maximum return, the number of positive and negative returns based on monthly returns from January 1995 to December 2010.

**Table C3**
Correlation analysis of physical commodities.

| | MSCI Europe | MSCI USA | MSCI Pacific | MSCI EM | JPM EMU | Euribor 1m | Crude oil (Brent) | Crude oil (WTI) | Gas oil | Heating oil | Natural gas | Unleaded gasoline |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MSCI Europe | 1.00 | | | | | | | | | | | |
| MSCI USA | 0.83 | 1.00 | | | | | | | | | | |
| MSCI Pacific | 0.65 | 0.67 | 1.00 | | | | | | | | | |
| MSCI EM | 0.77 | 0.73 | 0.73 | 1.00 | | | | | | | | |
| JPM EMU | −0.18 | −0.12 | −0.13 | −0.18 | 1.00 | | | | | | | |
| Euribor 1m | −0.22 | −0.16 | −0.26 | −0.27 | 0.19 | 1.00 | | | | | | |
| Crude oil (Brent) | 0.15 | 0.18 | 0.29 | 0.33 | −0.17 | −0.14 | 1.00 | | | | | |
| Crude oil (WTI) | 0.21 | 0.20 | 0.32 | 0.34 | −0.19 | −0.15 | 0.92 | 1.00 | | | | |
| gas oil | 0.15 | 0.18 | 0.30 | 0.27 | −0.14 | −0.13 | 0.81 | 0.83 | 1.00 | | | |
| Heating oil | 0.04 | 0.07 | 0.19 | 0.11 | −0.15 | −0.12 | 0.58 | 0.61 | 0.76 | 1.00 | | |
| Natural gas | 0.04 | 0.04 | 0.04 | 0.04 | 0.13 | 0.01 | 0.10 | 0.16 | 0.20 | 0.15 | 1.00 | |
| Unleaded gasoline | 0.12 | 0.12 | 0.23 | 0.19 | −0.15 | −0.11 | 0.69 | 0.70 | 0.58 | 0.42 | 0.14 | 1.00 |

| | MSCI Europe | MSCI USA | MSCI Pacific | MSCI EM | JPM EMU | Euribor 1m | Aluminium | Copper | Lead | Nickel | Zinc |
|---|---|---|---|---|---|---|---|---|---|---|---|
| MSCI Europe | 1.00 | | | | | | | | | | |
| MSCI USA | 0.83 | 1.00 | | | | | | | | | |
| MSCI Pacific | 0.65 | 0.67 | 1.00 | | | | | | | | |
| MSCI EM | 0.77 | 0.73 | 0.73 | 1.00 | | | | | | | |
| JPM EMU | −0.18 | −0.12 | −0.13 | −0.18 | 1.00 | | | | | | |
| Euribor 1m | −0.22 | −0.16 | −0.26 | −0.27 | 0.19 | 1.00 | | | | | |
| Aluminium | 0.10 | 0.18 | 0.15 | 0.15 | −0.13 | −0.19 | 1.00 | | | | |
| Copper | 0.32 | 0.31 | 0.30 | 0.41 | −0.18 | −0.31 | 0.14 | 1.00 | | | |
| Lead | 0.35 | 0.27 | 0.20 | 0.38 | −0.05 | −0.17 | 0.09 | 0.41 | 1.00 | | |
| Nickel | 0.40 | 0.38 | 0.33 | 0.44 | −0.14 | −0.24 | 0.12 | 0.46 | 0.38 | 1.00 | |
| Zinc | 0.38 | 0.32 | 0.29 | 0.39 | −0.09 | −0.30 | 0.15 | 0.61 | 0.54 | 0.47 | 1.00 |

| | MSCI Europe | MSCI USA | MSCI Pacific | MSCI EM | JPM EMU | Euribor 1m | Gold | Platinum | Silver |
|---|---|---|---|---|---|---|---|---|---|
| MSCI Europe | 1.00 | | | | | | | | |
| MSCI USA | 0.83 | 1.00 | | | | | | | |
| MSCI Pacific | 0.65 | 0.67 | 1.00 | | | | | | |
| MSCI EM | 0.77 | 0.73 | 0.73 | 1.00 | | | | | |
| JPM EMU | −0.18 | −0.12 | −0.13 | −0.18 | 1.00 | | | | |
| Euribor 1m | −0.22 | −0.16 | −0.26 | −0.27 | 0.19 | 1.00 | | | |
| Gold | −0.02 | 0.07 | 0.25 | 0.20 | −0.04 | −0.13 | 1.00 | | |
| Platinum | 0.19 | 0.24 | 0.29 | 0.32 | −0.14 | −0.18 | 0.48 | 1.00 | |
| Silver | 0.12 | 0.18 | 0.25 | 0.30 | −0.16 | −0.19 | 0.64 | 0.52 | 1.00 |

| | MSCI Europe | MSCI USA | MSCI Pacific | MSCI EM | JPM EMU | Euribor 1m | Cocoa | Coffee | Cotton | Sugar |
|---|---|---|---|---|---|---|---|---|---|---|
| MSCI Europe | 1.00 | | | | | | | | | |
| MSCI USA | 0.83 | 1.00 | | | | | | | | |
| MSCI Pacific | 0.65 | 0.67 | 1.00 | | | | | | | |
| MSCI EM | 0.77 | 0.73 | 0.73 | 1.00 | | | | | | |
| JPM EMU | −0.18 | −0.12 | −0.13 | −0.18 | 1.00 | | | | | |
| Euribor 1m | −0.22 | −0.16 | −0.26 | −0.27 | 0.19 | 1.00 | | | | |
| Cocoa | −0.07 | 0.04 | 0.06 | 0.12 | −0.09 | 0.03 | 1.00 | | | |
| Coffee | 0.21 | 0.24 | 0.19 | 0.32 | −0.10 | −0.14 | 0.14 | 1.00 | | |
| Cotton | 0.12 | 0.18 | 0.14 | 0.20 | −0.04 | −0.18 | 0.24 | 0.25 | 1.00 | |
| Sugar | −0.02 | 0.06 | 0.01 | 0.05 | −0.16 | −0.13 | 0.10 | 0.23 | 0.11 | 1.00 |

| | MSCI Europe | MSCI USA | MSCI Pacific | MSCI EM | JPM EMU | Euribor 1m | Corn | Soybeans | Wheat (Chicago) | Wheat (Kansas) |
|---|---|---|---|---|---|---|---|---|---|---|
| MSCI Europe | 1.00 | | | | | | | | | |
| MSCI USA | 0.83 | 1.00 | | | | | | | | |
| MSCI Pacific | 0.65 | 0.67 | 1.00 | | | | | | | |
| MSCI EM | 0.77 | 0.73 | 0.73 | 1.00 | | | | | | |
| JPM EMU | −0.18 | −0.12 | −0.13 | −0.18 | 1.00 | | | | | |
| Euribor 1m | −0.22 | −0.16 | −0.26 | −0.27 | 0.19 | 1.00 | | | | |
| Corn | 0.17 | 0.26 | 0.16 | 0.20 | −0.14 | −0.02 | 1.00 | | | |
| Soybeans | 0.20 | 0.26 | 0.27 | 0.25 | −0.16 | −0.02 | 0.65 | 1.00 | | |
| Wheat (Chicago) | 0.09 | 0.16 | 0.14 | 0.18 | −0.03 | −0.07 | 0.50 | 0.46 | 1.00 | |
| Wheat (Kansas) | 0.11 | 0.21 | 0.17 | 0.18 | −0.06 | −0.03 | 0.46 | 0.38 | 0.76 | 1.00 |

| | MSCI Europe | MSCI USA | MSCI Pacific | MSCI EM | JPM EMU | Euribor 1m | Feeder cattle | Live steers | Pork bellies |
|---|---|---|---|---|---|---|---|---|---|
| MSCI Europe | 1.00 | | | | | | | | |
| MSCI USA | 0.83 | 1.00 | | | | | | | |
| MSCI Pacific | 0.65 | 0.67 | 1.00 | | | | | | |

**Table C3** (*continued*)

| | MSCI Europe | MSCI USA | MSCI Pacific | MSCI EM | JPM EMU | Euribor 1m | Feeder cattle | Live steers | Pork bellies |
|---|---|---|---|---|---|---|---|---|---|
| MSCI EM | 0.77 | 0.73 | 0.73 | 1.00 | | | | | |
| JPM EMU | −0.18 | −0.12 | −0.13 | −0.18 | 1.00 | | | | |
| Euribor 1m | −0.22 | −0.16 | −0.26 | −0.27 | 0.19 | 1.00 | | | |
| Feeder cattle | 0.16 | 0.38 | 0.24 | 0.18 | −0.17 | −0.13 | 1.00 | | |
| Live steers | 0.15 | 0.30 | 0.22 | 0.19 | −0.11 | −0.08 | 0.61 | 1.00 | |
| Pork bellies | 0.02 | 0.13 | 0.09 | 0.06 | 0.05 | 0.00 | 0.16 | 0.13 | 1.00 |

The table presents the correlation coefficients of traditional assets with physical commodities and commodity futures, respectively based on monthly returns from January 1995 to December 2010.

**Table C4**
Descriptive statistics of commodity futures.

| Commodity futures/ benchmark assets | Annual. mean (%) | Annual. volatility (%) | Sharpe ratio | Skewness | Excess kurtosis | Range | Min return (%) | Max return (%) | No of pos. returns | No of neg. returns |
|---|---|---|---|---|---|---|---|---|---|---|
| *Benchmark assets* | | | | | | | | | | |
| MSCI Europe | 9.42 | 18.93 | 0.33 | −0.67 | 0.80 | 27.11 | −14.32 | 12.80 | 121 | 70 |
| MSCI USA | 9.80 | 20.13 | 0.33 | −0.34 | 0.36 | 30.77 | −15.57 | 15.20 | 114 | 77 |
| MSCI Pacific | 2.65 | 19.50 | −0.02 | 0.05 | 0.11 | 31.55 | −14.16 | 17.39 | 99 | 92 |
| MSCI EM | 10.85 | 27.74 | 0.28 | −0.62 | 1.41 | 46.87 | −30.29 | 16.58 | 114 | 77 |
| JPM EMU bond index | 6.47 | 4.01 | 0.84 | −0.22 | 0.01 | 6.57 | −2.69 | 3.88 | 136 | 55 |
| *Energy* | | | | | | | | | | |
| Crude oil (Brent) | 22.38 | 40.68 | 0.47 | −0.21 | 1.06 | 64.49 | −30.40 | 34.09 | 85 | 57 |
| Crude oil (WTI) | 12.82 | 38.80 | 0.25 | 0.01 | 0.62 | 65.71 | −28.66 | 37.05 | 108 | 83 |
| Gas oil | 21.60 | 41.51 | 0.45 | 0.03 | 1.00 | 60.42 | −26.96 | 33.46 | 81 | 61 |
| Heating oil | 11.74 | 39.42 | 0.22 | 0.17 | 0.66 | 66.33 | −31.23 | 35.10 | 100 | 91 |
| Natural gas | −12.19 | 49.11 | −0.31 | 0.32 | 0.08 | 79.68 | −34.77 | 44.91 | 91 | 100 |
| Unleaded gasoline | 19.53 | 46.10 | 0.36 | 0.15 | 1.38 | 77.82 | −37.09 | 40.73 | 106 | 85 |
| *Industrial metals* | | | | | | | | | | |
| Aluminium | −2.28 | 20.20 | −0.27 | 0.20 | 0.82 | 36.04 | −20.19 | 15.85 | 83 | 108 |
| Copper | 12.46 | 30.59 | 0.31 | −0.05 | 0.96 | 49.35 | −27.14 | 22.21 | 100 | 91 |
| Lead | 11.75 | 35.66 | 0.24 | 0.28 | 0.76 | 53.67 | −21.39 | 32.28 | 107 | 84 |
| Nickel | 13.46 | 42.36 | 0.24 | 0.02 | −0.25 | 52.25 | −26.20 | 26.05 | 100 | 91 |
| Zinc | 1.89 | 27.75 | −0.04 | 0.25 | 0.76 | 50.74 | −24.41 | 26.33 | 84 | 107 |
| *Precious metals* | | | | | | | | | | |
| Gold | 5.74 | 16.64 | 0.16 | 0.52 | 1.13 | 30.78 | −12.51 | 18.27 | 96 | 95 |
| Platinum | 13.36 | 25.45 | 0.40 | −0.38 | 2.32 | 50.90 | −27.43 | 23.47 | 107 | 84 |
| Silver | 11.57 | 31.15 | 0.27 | −0.04 | 0.31 | 46.34 | −23.65 | 22.69 | 98 | 93 |
| *Softs* | | | | | | | | | | |
| Cocoa | 1.46 | 31.16 | −0.05 | 0.76 | 2.57 | 64.59 | −26.14 | 38.45 | 87 | 104 |
| Coffee | 0.80 | 41.45 | −0.06 | 0.71 | 0.96 | 63.21 | −24.90 | 38.31 | 90 | 101 |
| Cotton | −4.79 | 28.70 | −0.27 | 0.73 | 1.13 | 49.61 | −19.08 | 30.53 | 85 | 106 |
| Sugar | 7.62 | 36.59 | 0.12 | 0.19 | 0.29 | 52.95 | −25.30 | 27.64 | 99 | 92 |
| *Grains* | | | | | | | | | | |
| Corn | −4.55 | 27.15 | −0.28 | 0.02 | 0.86 | 46.17 | −21.88 | 24.28 | 89 | 102 |
| Soybeans | 9.16 | 29.41 | 0.21 | 0.01 | 0.51 | 44.91 | −24.31 | 20.61 | 101 | 90 |
| Wheat (Chicago) | −7.62 | 26.81 | −0.40 | 0.26 | 1.13 | 55.04 | −24.01 | 31.03 | 93 | 98 |
| Wheat (Kansas) | −0.82 | 27.97 | −0.14 | 0.29 | 1.25 | 51.86 | −22.12 | 29.74 | 64 | 78 |
| *Livestock* | | | | | | | | | | |
| Feeder cattle | −1.47 | 20.30 | −0.22 | 0.01 | 1.14 | 39.15 | −21.63 | 17.52 | 49 | 57 |
| Live cattle | −2.01 | 17.25 | −0.30 | −0.43 | 2.94 | 38.84 | −25.52 | 13.32 | 87 | 104 |
| Lean hogs | −9.42 | 25.69 | −0.49 | 0.15 | 0.47 | 50.99 | −22.54 | 28.44 | 84 | 107 |

The table reports the summary statistics for physical commodities and commodity futures, respectively: annualised mean, volatility, Sharpe ratio, skewness, excess kurtosis, range, minimum and maximum return, the number of positive and negative returns based on monthly returns from January 1995 to December 2010.

The diversification benefits in the agricultural, livestock and industrial metals commodities are attributable to the reduction of the portfolio risk level. Thus, these sectors can be assigned to the conservative part of the efficient frontier. This investment property makes them more appropriate for investors, who follow risk-minimising strategy and hold portfolios close to the GMVP. The diversification benefits of these commodities can be enhanced, if the risk management strategy is modified depending on the price movements in equity markets. Industrial metals bear almost no benefits to investors in bull markets, while softs, grains and livestock have only weak diversification properties in bear markets. The inclusion of energy and precious metals yields the highest added value to investors. On the one hand, they have a certain degree of stability as they contribute to the portfolio improvement in both bull and bear markets. On the other hand, the disentanglement of the diversification gains reveals that they enhance the portfolio performance on the level of both return and risk. Therefore, these commodities are attractive investments for both conservative and aggressive investors. Hence, energy and precious metals can be recommended, when investors face the choice concerning the commodity sector exposure.

Our analysis indicates that there is a strong variation in the diversification contribution across individual commodities and commodity sectors, the understanding of which is essential for financial market participants. As a policy implication our research can also be a contribution to the ongoing debate whether it is

**Table C5**
Correlation analysis of commodity futures.

| | MSCI Europe | MSCI USA | MSCI Pacific | MSCI EM | JPM EMU | Euribor 1m | Crude oil (Brent) | Crude oil (WTI) | Gas oil | Heating oil | Natural gas | Unleaded gasoline |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MSCI Europe | 1.00 | | | | | | | | | | | |
| MSCI USA | 0.83 | 1.00 | | | | | | | | | | |
| MSCI Pacific | 0.65 | 0.67 | 1.00 | | | | | | | | | |
| MSCI EM | 0.77 | 0.73 | 0.73 | 1.00 | | | | | | | | |
| JPM EMU | −0.18 | −0.12 | −0.13 | −0.18 | 1.00 | | | | | | | |
| Euribor 1m | −0.22 | −0.16 | −0.26 | −0.27 | 0.19 | 1.00 | | | | | | |
| Crude oil (Brent) | 0.23 | 0.21 | 0.34 | 0.36 | −0.24 | −0.13 | 1.00 | | | | | |
| Crude oil (WTI) | 0.21 | 0.20 | 0.32 | 0.33 | −0.16 | −0.08 | 0.87 | 1.00 | | | | |
| Gas Oil | 0.19 | 0.18 | 0.32 | 0.28 | −0.21 | −0.11 | 0.90 | 0.80 | 1.00 | | | |
| Heating oil | 0.15 | 0.05 | 0.23 | 0.22 | −0.14 | −0.11 | 0.79 | 0.87 | 0.82 | 1.00 | | |
| Natural gas | 0.04 | 0.02 | 0.08 | 0.02 | 0.03 | 0.03 | 0.28 | 0.37 | 0.36 | 0.46 | 1.00 | |
| Unleaded gasoline | 0.18 | 0.17 | 0.28 | 0.25 | −0.18 | −0.11 | 0.80 | 0.83 | 0.76 | 0.81 | 0.41 | 1.00 |

| | MSCI Europe | MSCI USA | MSCI Pacific | MSCI EM | JPM EMU | Euribor 1m | Aluminium | Copper | Lead | Nickel | Zinc |
|---|---|---|---|---|---|---|---|---|---|---|---|
| MSCI Europe | 1.00 | | | | | | | | | | |
| MSCI USA | 0.83 | 1.00 | | | | | | | | | |
| MSCI Pacific | 0.65 | 0.67 | 1.00 | | | | | | | | |
| MSCI EM | 0.77 | 0.73 | 0.73 | 1.00 | | | | | | | |
| JPM EMU | −0.18 | −0.12 | −0.13 | −0.18 | 1.00 | | | | | | |
| Euribor 1m | −0.22 | −0.16 | −0.26 | −0.27 | 0.19 | 1.00 | | | | | |
| Aluminium | 0.36 | 0.38 | 0.36 | 0.43 | −0.17 | −0.24 | 1.00 | | | | |
| Copper | 0.35 | 0.33 | 0.33 | 0.44 | −0.18 | −0.32 | 0.67 | 1.00 | | | |
| Lead | 0.08 | 0.15 | 0.15 | 0.12 | −0.02 | −0.18 | 0.09 | 0.08 | 1.00 | | |
| Nickel | 0.40 | 0.38 | 0.32 | 0.44 | −0.14 | −0.23 | 0.52 | 0.48 | 0.01 | 1.00 | |
| Zinc | 0.40 | 0.33 | 0.29 | 0.40 | −0.10 | −0.30 | 0.56 | 0.64 | 0.02 | 0.50 | 1.00 |

| | MSCI Europe | MSCI USA | MSCI Pacific | MSCI EM | JPM EMU | Euribor 1m | Gold | Platinum | Silver |
|---|---|---|---|---|---|---|---|---|---|
| MSCI Europe | 1.00 | | | | | | | | |
| MSCI USA | 0.83 | 1.00 | | | | | | | |
| MSCI Pacific | 0.65 | 0.67 | 1.00 | | | | | | |
| MSCI EM | 0.77 | 0.73 | 0.73 | 1.00 | | | | | |
| JPM EMU | −0.18 | −0.12 | −0.13 | −0.18 | 1.00 | | | | |
| Euribor 1m | −0.22 | −0.16 | −0.26 | −0.27 | 0.19 | 1.00 | | | |
| Gold | −0.01 | 0.08 | 0.25 | 0.20 | −0.02 | −0.15 | 1.00 | | |
| Platinum | 0.24 | 0.27 | 0.31 | 0.34 | −0.14 | −0.16 | 0.46 | 1.00 | |
| Silver | 0.17 | 0.20 | 0.26 | 0.32 | −0.15 | −0.20 | 0.64 | 0.49 | 1.00 |

| | MSCI Europe | MSCI USA | MSCI Pacific | MSCI EM | JPM EMU | Euribor 1m | Cocoa | Coffee | Cotton | Sugar |
|---|---|---|---|---|---|---|---|---|---|---|
| MSCI Europe | 1.00 | | | | | | | | | |
| MSCI USA | 0.83 | 1.00 | | | | | | | | |
| MSCI Pacific | 0.65 | 0.67 | 1.00 | | | | | | | |
| MSCI EM | 0.77 | 0.73 | 0.73 | 1.00 | | | | | | |
| JPM EMU | −0.18 | −0.12 | −0.13 | −0.18 | 1.00 | | | | | |
| Euribor 1m | −0.22 | −0.16 | −0.26 | −0.27 | 0.19 | 1.00 | | | | |
| Cocoa | −0.02 | 0.04 | 0.05 | 0.13 | −0.10 | 0.03 | 1.00 | | | |
| Coffee | 0.25 | 0.31 | 0.19 | 0.29 | −0.11 | −0.15 | 0.13 | 1.00 | | |
| Cotton | 0.16 | 0.24 | 0.17 | 0.22 | −0.04 | −0.17 | 0.16 | 0.27 | 1.00 | |
| Sugar | 0.06 | 0.13 | 0.08 | 0.13 | −0.17 | −0.12 | 0.13 | 0.21 | 0.18 | 1.00 |

| | MSCI Europe | MSCI USA | MSCI Pacific | MSCI EM | JPM EMU | Euribor 1m | Corn | Soybeans | Wheat (Chicago) | Wheat (Kansas) |
|---|---|---|---|---|---|---|---|---|---|---|
| MSCI Europe | 1.00 | | | | | | | | | |
| MSCI USA | 0.83 | 1.00 | | | | | | | | |
| MSCI Pacific | 0.65 | 0.67 | 1.00 | | | | | | | |
| MSCI EM | 0.77 | 0.73 | 0.73 | 1.00 | | | | | | |
| JPM EMU | −0.18 | −0.12 | −0.13 | −0.18 | 1.00 | | | | | |
| Euribor 1m | −0.22 | −0.16 | −0.26 | −0.27 | 0.19 | 1.00 | | | | |
| Corn | 0.18 | 0.28 | 0.17 | 0.21 | −0.13 | −0.04 | 1.00 | | | |
| Soybeans | 0.21 | 0.29 | 0.27 | 0.27 | −0.14 | −0.08 | 0.69 | 1.00 | | |
| Wheat (Chicago) | 0.18 | 0.23 | 0.19 | 0.23 | −0.07 | −0.04 | 0.59 | 0.51 | 1.00 | |
| Wheat (Kansas) | 0.10 | 0.16 | 0.11 | 0.14 | −0.09 | -0.07 | 0.42 | 0.41 | 0.82 | 1.00 |

| | MSCI Europe | MSCI USA | MSCI Pacific | MSCI EM | JPM EMU | Euribor 1m | Feeder cattle | Live cattle | Lean hogs |
|---|---|---|---|---|---|---|---|---|---|
| MSCI Europe | 1.00 | | | | | | | | |
| MSCI USA | 0.83 | 1.00 | | | | | | | |
| MSCI Pacific | 0.65 | 0.67 | 1.00 | | | | | | |

**Table C5** (*continued*)

| | MSCI Europe | MSCI USA | MSCI Pacific | MSCI EM | JPM EMU | Euribor 1m | Feeder cattle | Live cattle | Lean hogs |
|---|---|---|---|---|---|---|---|---|---|
| MSCI EM | 0.77 | 0.73 | 0.73 | 1.00 | | | | | |
| JPM EMU | −0.18 | −0.12 | −0.13 | −0.18 | 1.00 | | | | |
| Euribor 1m | −0.22 | −0.16 | −0.26 | −0.27 | 0.19 | 1.00 | | | |
| Feeder cattle | 0.08 | 0.25 | 0.13 | 0.06 | −0.16 | −0.13 | 1.00 | | |
| Live cattle | 0.16 | 0.34 | 0.20 | 0.20 | −0.22 | −0.11 | 0.74 | 1.00 | |
| Lean hogs | 0.05 | 0.20 | 0.15 | 0.09 | 0.06 | −0.04 | 0.35 | 0.48 | 1.00 |

The table presents the correlation coefficients of traditional assets with physical commodities and commodity futures, respectively based on monthly returns from January 1995 to December 2010.

ethical at all to invest into agricultural commodities.[13] Our analysis allows to assess and to objectify the potential losses due to the possible prohibition of investments into agricultural commodities.

The need for further research is high since the outcomes deepen the knowledge of the diversification properties of commodities and facilitate investors' asset allocation decisions corresponding to individual preferences.

## Appendix A. Commodity indices

See Table A1.

## Appendix B. Results of spanning tests in sub-periods

See Tables B1 and B2.

## Appendix C. Descriptive statistics and correlation analysis

See Tables C1–C5.

## References


Adams, Z., Füss, R., Kaiser, D.G., 2008. Macroeconomic determinants of commodity futures returns. In: Fabozzi, F.J., Füss, R., Kaiser, D.G. (Eds.), The Handbook of Commodity Investing. John Wiley & Sons, Hoboken, pp. 87–113.

Ankrim, E.M., Hensel, C.R., 1993. Commodities in asset allocation: a real-asset alternative to real estate. Financial Analysts Journal 49 (3), 20–29.

Anson, M., 1999. Maximising utility with commodity futures diversification. The Journal of Portfolio Management 25 (4), 86–94.

Anson, M.J.P., Fabozzi, F.J., Jones, F.J., 2011. The Handbook of Traditional and Alternative Investment Vehicles. John Wiley & Sons, Hoboken.

Arnold, D.J., 2008. DBIQ Index Guide: DBLCI Commodity Indices. Deutsche Bank Global Markets Research, London.

Bank of America/Merrill Lynch, 2010. Commodity Alpha, Beta and the Investment Super-Cycle. Global Commodity Paper 11, February 22, 2010.

Beeland Interests, 2011. The RICI Handbook: The Guide to the Rogers International Commodity Index. Beeland Interests, Inc., January 21, 2011.

Bekaert, G., Urias, M.S., 1996. Diversification, integration and emerging market closed-end funds. The Journal of Finance 51, 835–869.

Berndt, E.R., Savin, N.E., 1977. Conflict among criteria for testing hypotheses in the multivariate linear regression model. Econometrica 45, 1263–1278.

Breusch, T.S., 1979. Conflict among criteria for testing hypotheses: extensions and comments. Econometrica 47, 203–207.

Cao, B., Jayasuriya, S., Shambora, W., 2010. Holding a commodity index fund in a globally diversified portfolio: a placebo effect? Economics Bulletin 30, 1842–1851.

Carpenter, C., 2011. Commodity Assets at Record $412 Billion in March, Barclays Says. Bloomberg News, <http://www.bloomberg.com/news/2011-04-20/commodity-assets-at-record-412-billion-in-march-barclays-capital-says.html> (retrieved 10.5.11).

Conover, C.M., Jensen, G.R., Johnson, R.R., Mercer, J.M., 2010. Is now the time to add commodities to your portfolio? The Journal of Investing 19 (3), 10–19.

Daskalaki, C., Skiadopoulos, G., 2011. Should investors include commodities in their portfolios after all? New evidence. Journal of Banking and Finance 35, 2606–2626.

DeRoon, F.A., Nijman T.E., Werker, B.J.M., 1996. Testing for Spanning with Futures Contracts and Nontraded Assets: A General Approach. Working Paper 83. Tilburg University.

DeSantis, G., 1993. Volatility Bounds for Stochastic Discount Factors: Tests and Implications from International Financial Markets. Ph.D. Thesis. University of Chicago.

Domanski, D., Heath, A., 2007. Financial investors and commodity markets. BIS Quarterly Review, 53–67.

Dorfleitner, G., 2002. Why the return notion matters. International Journal of Theoretical and Applied Finance 6, 73–86.

Dow Jones Indexes, 2011. Dow Jones-UBS Commodity Index Fact Sheet. CME Group Index Services.

Erb, C.B., Harvey, C.R., 2006. The strategic and tactical value of commodity futures. Financial Analysts Journal 62 (2), 69–97.

ETF Securities, 2011. Global Commodity ETP Quarterly Report, Q1/2011. ETF Securities.

Ferson, W., 1995. Theory and empirical testing of asset pricing models. In: Jarrow, R.A., Ziemba, W.T., Maksimovich, V. (Eds.), Handbooks in Operational Research and Management Science, vol. 9. North Holland Publishers, Amsterdam, pp. 145–200.

Ferson, W., Foerster, S.R., Keim, D.B., 1993. General tests of latent variable models and mean–variance spanning. The Journal of Finance 48, 131–156.

Galvani, V., Plourde, A., 2010. Portfolio diversification in energy markets. Energy Economics 32, 257–268.

Georgiev, G., 2001. Benefits of commodity investment. The Journal of Alternative Investments 4, 40–48.

Gibson, R.C., 2004. The rewards of multiple-asset-class investing. Journal of Financial Planning 17, 58–71.

Hammoudeh, S., Malik, F., McAleer, M., 2011. Risk management of precious metals. Quarterly Review of Economics and Finance 51, 435–441.

Hansen, L.P., 1982. Large sample properties of the generalized method of moments estimators. Econometrica 50, 1029–1054.

Helman, C., 2010. Platinum: Like Gold, Only Better – Why Buy Gold when Platinum is Rarer, Dearer and Far More Useful. Forbes March 24, 2010. <http://www.forbes.com/2010/03/24/platinum-precious-metals-business-etf-gold-investing.html> (retrieved 24.5.11).

Huang, J., Zhong, Z., 2006. Time-Variation in Diversification Benefits of Commodity, REITs and TIPS. Working Paper. The Pennsylvania State University, The Smeal College of Business.

Huberman, G., Kandel, S., 1987. Mean–variance spanning. The Journal of Finance 42, 873–888.

Idzorek, T.M., 2007. Commodities and strategic asset allocation. In: Till, H., Eagleeye, J. (Eds.), Intelligent Commodity Investing: New Strategies and Practical Insights for Informed Decision Making. Risk Books, London, pp. 113–177.

Jensen, G.R., Johnson, R.R., Mercer, J.M., 2000. Efficient use of commodity futures in diversified portfolios. The Journal of Futures Markets 20, 489–506.

Jensen, G.R., Johnson, R.R., Mercer, J.M., 2002. Tactical asset allocation and commodity futures. The Journal of Portfolio Management 28 (4), 100–111.

Jones, T., 2010. The Great Hunger Lottery: How Banking Speculation Causes Food Crises. World Development Movement Report, July 2010.

Kan, R., Zhou, G., 2008. Tests of Mean–Variance Spanning. Working Paper. Washington University.

Kat, H.M., Oomen, R.C.A., 2007. What every investor should know about commodities – Part 1: Univariate return analysis. Journal of Investment Management 5, 4–28.

Markowitz, H., 1952. Portfolio selection. The Journal of Finance 7, 77–91.

Maslakovic, M., 2011. Commodities Trading March 2011. Financial Market Series. TheCityUK, London.

Merton, R.C., 1972. An analytic derivation of the efficient portfolio frontier. Journal of Financial and Quantitative Analysis 7, 1851–1872.

Nijman, T.E., Swinkels, L.A.P., 2008. Strategic and tactical allocation to commodities for retirement savings schemes. In: Fabozzi, F.J., Füss, R., Kaiser, D.G. (Eds.), The Handbook of Commodity Investing. John Wiley & Sons, Hoboken, pp. 522–547.

Satyanarayan, S., Varangis, P., 1996. Diversification benefits of commodity assets in global portfolios. The Journal of Investing 5 (1), 69–78.

Scherer, B., He, L., 2008. The diversification benefits of commodity futures indexes: a mean–variance spanning test. In: Fabozzi, F.J., Füss, R., Kaiser, D.G. (Eds.), The Handbook of Commodity Investing. John Wiley & Sons, Hoboken, pp. 241–265.

Seeking Alpha, 2009. Gold vs. Platinum: Is There a Favorite? <http://seekingalpha.com/article/114123-gold-vs-platinum-is-there-a-favorite> (retrieved 24.05.11).

Silvennoinen, A., Thorp, S., 2010. Financialization, Crisis and Commodity Correlations Dynamics. Working Paper. Queensland University of Technology.


[13] See Jones (2010) as an example.

Standard & Poor's, 2011. S&P GSCI Index Methodology. McGraw-Hill, New York, March 2011.
Stoll, H.R., Whaley, R.E., 2011. Commodity index investing: speculation or diversification. The Journal of Alternative Investments 4 (1), 50–60.
Tang, K., Xiong, W., 2010. Index Investment and Financialization of Commodities. Working Paper. Princeton University, Renmin University of China.
Thomson Reuters/Jefferies, 2010. The Thomson Reuters/Jefferies CRB Index Calculation Supplement. Jefferies Financial Products, LLC.
Woodard, J.D., 2008. Commodity futures investments: a review of strategic motivations and tactical opportunities. In: Fabozzi, F.J., Füss, R., Kaiser, D.G. (Eds.), The Handbook of Commodity Investing. John Wiley & Sons, Hoboken, pp. 56–87.
You, L., Daigler, R.T., 2010. A Markowitz Optimization of Commodity Futures Portfolios. Working Paper. Texas State University-San Marcos, University of Alaska Anchorage, Florida International University.