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Dynamic Spillovers between Commodity and Currency Markets

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Abstract

In this study, we examine the dynamic link between returns and volatility of commodities and currency markets. Based on weekly data over the period from January 6, 1987 to July 22, 2014, we find the following empirical regularities. First, our results suggest that the information contents of gold, silver, platinum, and the CHF/USD and GBP/USD exchange rates can help improve forecast accuracy of returns and volatilities of palladium, crude oil and the EUR/CHF and GBP/USD exchange rates. Second, gold (CHF/USD) is the dominant commodity (currency) transmitter of return and volatility spillovers to the remaining assets in our model. Third, the analysis of dynamic spillovers shows time– and event–specific patterns. For instance, the dynamic spillover effects originating in gold and silver (platinum) returns and volatility intensified (degraded) in the period marked by the global financial crisis. After the global financial crisis, the net transmitting role of gold and silver (platinum) returns shocks weakened (strengthened), while the net transmitting role of gold, silver and platinum volatility shocks remained relatively high. Overall, our findings reveal that, while the static analysis clearly classifies the aforementioned variables into net transmitters and net receivers, the dynamic analysis denotes episodes wherein the role of transmitters and receivers of return (volatility) spillovers can be interrupted or even reversed. Hence, even if certain commonalities prevail in each identified category of commodities, such commonalities are time– and event–dependent.

Keywords: Precious metals, Oil prices, Exchange rates, Static and dynamic spillovers

JEL codes: C32, O13, Q30, Q43

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1. Introduction

In the wake of the global financial crisis, international bond, derivatives and stock markets have experienced episodes of heightened instability and risk, as investors have become increasingly concerned about the quality of assets traded in these markets. An ensuing collapse in the market value of bonds, derivatives and stocks induced investors to consider alternative vehicles of investment. Financial media often refers to precious metals, such as gold, silver, platinum and palladium, as safe havens in periods of financial crises (FT, 2014). The resilience of precious metals (with a particular emphasis on gold, silver, platinum and palladium) markets to financial crises has been recently accentuated also by academic scholars, including Lucey and Li (2015), Batten et al. (2015), Baur and Lucey (2010), Baur and McDermott (2010), Ciner et al. (2013) and Agyei-Ampomah et al. (2014). Hillier et al. (2006) and Belousova and Dorfleitner (2012) show that the inclusion of precious metals in an equity portfolio can reduce systematic risk of investment and accrue diversification benefits, particularly in periods of elevated equity market volatility.

Whilst precious metals arguably provide a secure means to store wealth, their prices themselves often become subject to increased turbulence and uncertainty (Schwartz, 1997; Arezki et al., 2013).[1]

Demand for the four precious metals stems from a number of different sources. Demand for gold and, to a lesser extent, for silver, platinum and palladium is geared towards non-industrial investment uses. Specifically, due to the investment demand (36% of total demand) and demand for official reserves (12%), gold is predominantly a monetary asset (Lucey and Li, 2015). [2] Demand for silver comprises industrial (40%), jewelry (45%) and financial investment (11%) components (Hillier et al. 2006). Platinum is extracted together with other metals, especially palladium. Demand for platinum arises from the construction of catalytic converters for automobiles, which overshadows private investment in platinum (10% of the total amount demanded) (Hillier et al., 2006). Similarly to platinum, palladium is mainly used for making auto-catalyst converters and hybrid integrated circuits, with more than 50% of global production consumed by the automobile industry (Chng, 2009). Supply of gold is dominated by mine production, sale of official gold reserves, scrap recycling, disinvestment (Radetzki, 1989). Supply of silver mainly emanates from mine production, scrap recycling, disinvestment, government sales and producer hedging (Lucey and Tully, 2006). Concentrated natural resources of platinum and palladium are rare. They are produced from a mixture of six platinoid elements. Indeed, 80% of the world's platinum resources is supplied by the Bushveld complex in South Africa (Yang, 2009). However, Russia (followed by South Africa) is the largest supplier of palladium, due to the higher palladium content of platinoid elements (Kim, 2013).

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[1]For instance, the price of gold bullion in a decade preceding the global financial crisis (dated in September 2008) grew at an average annual rate of 17.22%. In the subsequent three years, from October 2008 to September 2011, it galloped at an average annual rate of 36%, stimulating a research inquiry into the presence of speculative bubbles in the gold price Biłkowski et al. (2014). However, in the next three years, from October 2011 to August 2014, it has decreased at an average annual rate of 7.16%, as the gold market has been driven predominantly driven by bearish trading.

[2]Jewelry consumption is responsible for another 43% of total demand (Lucey and Li, 2015).

In addition to the four precious metals, our study also features crude oil. Crude oil is viewed as an input in production of the four precious metals. An increase in oil prices may provoke power shortages with an adverse effect on production of precious metals (Sari et al. 2010). An increase in crude oil volatility exerts the so-called "cooling" (i.e., negative) effect on precious metals volatility (Hammoudeh and Yuan, 2008).[3] Further, gold can act as a hedge instrument against fluctuations in the foreign exchange value of the United States Dollar (USD) (see, Capie et al., 2005; Hammoudeh et al., 2009; Reboredo, 2013, inter alia). According to the Bank of International Settlements' Triennial Central Bank Survey on Foreign exchange turnover (BIS, 2013), USD is mainly traded against the Euro (EUR), the Japanese Yen (JPY), the Great Britain Pound (GBP) and the Swiss Franc (CHF). Thus, our study also includes the corresponding exchange rates expressed as indirect (European) quotations, i.e., EUR/USD, JPY/USD, GBP/USD and CHF/USD, respectively. The dollar-denominated precious metals and crude oil may be simultaneously driven by the value of the dollar (Sari et al., 2010). The aforementioned exchange rates are also investigated in Reboredo (2013). The EUR/USD, JPY/USD and CHF/USD exchange rates are considered in Pukthuanthong and Roll (2011).

Notwithstanding the commodity-specific demand and supply, the academic literature often considers gold as an integral component of a broader commodity index. In particular, the co-movement among prices and volatilities of different and often unrelated commodity categories – such as precious metals, industrial metals, agricultural commodities, oil and gas – (Pindyck and Rotemberg, 1990; Batten et al., 2010)[4], the macroeconomic and financial determinants of commodity prices (Groen and Pesenti, 2011; Pierdzioch et al., 2014) and the information contents of commodity futures (Sari et al., 2007; Chinn and Coibion, 2014) have been at the heart of commodity research. Unsurprisingly, against the heterogeneous background of distinct commodities, only a week evidence of co-movement among prices and volatilities of the precious metals is reported (wherein Gorton and Rouwenhorst, 2006, may be an exception). In particular, prices and volatilities of different categories of commodities (i) respond to different macroeconomic fundamentals (Erb and Harvey, 2006; Batten et al., 2010; Chen, 2010)[5], (ii) do not share a long-run equilibrium relation (Sari et al., 2010), and (iii) futures trading strategies, such as hedging and speculation, are commodity-specific (Büyükşahin and Harris, 2011).

Thus, we identify the following notable gaps in the literature. First, there is dearth of research that considers dynamic (time–varying) spillovers among different commodities

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[3]Noteworthy, the observed negative relation between volatilities of crude oil and precious metals can be exploited by commodity portfolio managers the pricing of options (Hammoudeh and Yuan, 2008).

[4]Pindyck and Rotemberg (1990) and Labys et al. (1999) propound that co-movement in commodity prices has three main explanations. First, supply- and demand-related shocks in one commodity market may spill over into other markets. Second, macroeconomic shocks, such as anticipated changes in the policy rate, may simultaneously affect all commodity prices. Third, speculators' overreaction to new information may trigger volatility transmission across commodity markets, a phenomenon termed as "excess" co-movement.

[5]Batten et al. (2010) find that: a) gold volatility is influenced only by monetary variables, b) platinum and palladium volatilities are influenced by both monetary and financial variables, and c) silver volatility does not respond to either monetary of financial variables.

and currency markets, and/or that fully accounts for the potential effects of the period surrounding (before, during and after) the global financial crisis. Second, and to the best of our knowledge, there is no research taking into account both return and volatility in the analysis of the transmission process in commodity and currency markets. Such analysis would be of key importance to investors in commodity and futures markets and to portfolio managers alike. We aim to fill the aforementioned gaps in the literature.

Methodologically, our research resembles Sari et al. (2010), who use an autoregressive distributed lag (ARDL) model and a vector autoregression (VAR) model to study return transmission across the four precious metals (gold, silver, platinum and palladium), the oil price and the USD/EUR exchange rate. Conceptually, our research resembles Ciner et al. (2013) and Lucey and Li (2015), who build upon the dynamic conditional correlation (DCC) methodology of Engle (2002), and Aboura and Chevallier (2014), who draw on a more advanced factor dynamic conditional correlation (FDCC) methodology of Zhang and Chan (2009) to study time-varying conditional correlations between various asset classes. A distinctive feature of our research is that, building upon a VAR model, we estimate and study dynamic rather than only static transmission. In terms of the methodology, our research is dissimilar to Ciner et al. (2013) and Aboura and Chevallier (2014). To this end, we use the spillover index, proposed by Diebold and Yilmaz (2009, 2012). The spillover index is constructed by performing a rolling-window forecast error variance decomposition (FEVD) by transmitters and receivers of shocks. Importantly, this methodology allows identifying time-varying patterns of transmission and identifies the changing structure in the information contents of variables to this study. The spillover index is also used by Batten et al. (2015) to study return and volatility spillovers among four metals; gold, silver, platinum and palladium.

This research contributes to the existing literature in four ways. The first contribution consists of testing for dynamic transmission among returns and volatilities of four precious metals (gold, silver, platinum and palladium), returns on crude oil and the change in the EUR/USD, JPY/USD, GBP/USD and CHF/USD exchange rates. Thus, we complement and extend the work of Ciner et al. (2013), Aboura and Chevallier (2014) and Batten et al. (2015). The second contribution is to evaluate return and volatility spillover effects using the econometric framework proposed by Diebold and Yilmaz (2009, 2012). Within this framework, both dynamic and static spillovers can be estimated, thus extending the work of Sari et al. (2010), who identify static spillovers. The third contribution is to shed light on the dynamic interdependence of commodity returns and volatilities, and the change in the EUR/USD, JPY/USD, GBP/USD and CHF/USD exchange rates in the time interval entailing a widespread collapse in the precious metals' prices that commenced in around September 2011. By contrast, most of the existing studies are confined to the time period, in which the precious metals' prices were increasing at an accelerated rate. Last but not least, we assess the information content of the variables in forecasting commodity and currency returns and volatilities.

The empirical findings are as follows. First, the analysis of static spillover effects in the commodity market (currency market) shows that gold, silver and platinum (CHF/USD and GBP/USD exchange rates) are net transmitters of return and volatility spillovers during the

sample period, whereas palladium and crude oil (EUR/USD and JPY/USD exchange rates) are net receivers. Therefore, in general, the information contents of gold, silver, platinum, and the CHF/USD and GBP/USD exchange rates can help improve forecast accuracy of returns and volatility of palladium, crude oil, and the EUR/USD and JPY/USD exchange rates. Moreover, gold (CHF/USD) is the largest gross commodity (currency) transmitter of return and volatility spillovers to the remaining assets in our model. Gold (EUR/USD) is the largest commodity (currency) receiver of return spillovers. Platinum (GBP/USD) is the largest commodity (currency) receiver of volatility spillovers.

The analysis of dynamic return (volatility) spillovers shows that gold, silver and, to a lesser extent, platinum act as net commodity transmitters of spillovers to palladium and crude oil. Interestingly, the observed net transmission shows time– and event–specific patterns. For instance, for gold and silver (platinum) returns and volatility, it intensified (degraded) in the period marked by the US subprime mortgage crisis, the global financial crisis and the ensuing worldwide recession. After the global financial crisis, the role of gold and silver (platinum) returns as net transmitters of shocks weakened (strengthened), while the role of gold, silver and platinum volatility as net transmitters of shocks remained relatively high. Last but not least, our findings are very robust to several robustness checks.

Taken together, our research shows that, while the static FEVD clearly classifies the variables of the study into net transmitters and net receivers, the dynamic FEVD identifies episodes wherein the role of transmitters and receivers of return (volatility) spillovers can be interrupted or even reversed. Hence, even if certain commonalities prevail in each identified category of commodities, such commonalities are time– and event–specific.

The above findings can be helpful for managers of companies that use industrial metals and crude oil as inputs in production processes. For instance, changes in the prices of these inputs can significantly influence the cost of production, the price-setting process of final products and, more generally, pricing and purchasing decisions. Therefore, the results of dynamic interdependence should be considered in the planning of future purchases of commodities that will be used as inputs in the production process.

Our findings can also help by professional forecasters, financial analysts, managers of exchange-traded commodities (ETCs) and exchange-traded funds (ETFs), and portfolio investors. For instance, the finding that the CHF/USD exchange rate, gold, silver and, to a lesser extent, platinum have collectively a greater forecasting ability than palladium, crude oil and the EUR/USD exchange, can be used by professional forecasters to improve the accuracy of their forecasts. Based on our findings, financial analysts can provide a comprehensive analysis of investment opportunity, whereas managers of commodity and exchange-traded funds can design optimal hedging instruments against undesired movements in the precious metals and currency markets. Portfolio investors can also benefit from a diversified portfolio of assets, in which returns on commodity futures are imperfectly correlated with bond and stock returns. Specifically, the (relative) information contents of net return and volatility spillovers can be used to evaluate the potential determinants of future risk-adjusted portfolio returns and thus can help investors to reach superior investment decisions. Additionally, the pricing of options can benefit from our results on net volatility spillovers.

The rest of this paper is organized as follows. Section 2 describes the data used and

outlines the econometric methodology, Section 3 reports the empirical results, while Section 4 concludes the paper and discusses points for further research.

2. Methodology and data description

2.1. Data

We use weekly time series data for the four precious metals' spot prices (gold, silver, platinum and palladium), crude oil spot price and euro (EUR/USD), Japanese yen (JPY/USD), British pound (GBP/USD) and the Swiss franc (CHF/USD) spot exchange rate, each versus the US dollar. The use of weekly data ameliorates concerns over non-synchronicities and bid-ask effects in daily data (see, e.g. Batten et al., 2015; Sadorsky, 2014). Data are retrieved from Thomson Reuters Datastream. The sample spans the period from January 6, 1987 to July 22, 2014, totaling 1438 observations. The precious metals' spot prices are given in US Dollars per ounce of Troy of bullion. The precious metals are traded at COMEX in New York. They have been considered in other studies, such as Batten et al. (2010), Hammoudeh et al. (2010, 2011), inter alia. The crude oil spot price is for the West Texas Intermediate (WTI). It is also known as Texas light sweet, and is a grade of crude oil used as a benchmark in oil pricing. The spot price is expressed in US Dollars per barrel. The choice of these assets is dictated by their importance for the global economy. Whilst gold is mainly regarded as a reserve asset, traditionally held by central banks as a stabilizer of the monetary system, a non-negligible demand component owes to gold jewelry. Platinum and Palladium are primarily used for manufacturing auto-catalytic converters and hybrid integrated circuits, which are used in the automobile industry. Silver, like gold, is also a reserve asset, although it has been increasingly utilized in production processes. Oil is a major fuel source used throughout the world. These commodities have been examined in Hammoudeh et al. (2013). The spot exchange rates are expressed in terms of euros, pounds, yens or francs per one US dollar. An increase in the exchange rate denotes an appreciation of the US dollar. The choice of these specific exchange rates is because these are the four of the most traded currencies versus the US dollar in international transcations, according to the Bank of International Settlements' Triennial Central Bank Survey on Foreign exchange turnover (BIS, 2013). All these variables are also examined in Reboredo (2013), whereas the EUR/USD, JPY/USD and GBP/USD exchange rates are investigated by Pukthuanthong and Roll (2011).

Panel A (Panel B, Panel C) of Table 1 summarizes descriptive statistics of the prices (returns, absolute returns) of the precious metals, oil and EUR/USD, GBP/USD, JPY/USD and the CHF/USD exchange rates. Panel A shows that, based on the sample mean price, platinum is the most expensive commodity (798.03 USD per ounce of Troy), followed by gold (602.53 USD per ounce of Troy), whereas silver is the least expensive (10.03 USD per ounce of Troy). The sample mean of the exchange rates are not comparable due to a different unit of measurement involved. As in the case for the sample mean, the standard deviation is the highest (lowest) for platinum (silver) with the value of 479.84 USD (8.55 USD). The spot price for all the variables, except for the GBP/USD and the CHF/USD exchange rates, is positively skewed. The prices of gold, silver, palladium, and the EUR/USD exchange rate

are leptokurtic, whereas the remaining commodities and exchange rates have platykurtic prices. The distribution of the spot prices significantly deviates from normality, as witness by the Jarque-Bera test statistic and the associated p-value.

[Insert Table 1 around here]

Panel B shows that, relative to the other commodities, palladium provides the most profitable investment opportunity, reflected in the sample weekly mean return of 0.1378%. By contrast, the mean return on investment in gold (silver, platinum, oil, EUR/USD, GBP/USD, JPY/USD and CHF/USD) is 0.0822% (0.0939%, 0.0778%, 0.1216%, -0.0109%, -0.0099%, -0.0306% and -0.0403%). However, the average profitability of the aforementioned investments must be adjusted by their idiosyncratic risk, measured by the sample standard deviation or volatility or by the range of variation (calculated as the difference between the minimum and maximum returns). In this regard, crude oil is the most volatile, and hence most risky, with the weekly standard deviation estimated at 5.1355%, and with maximum and minimum weekly returns of 36.4427% and 37.0059%, respectively. Returns on the GBP/USD exchange rate feature the lowest standard deviation of 1.3584%, and range between 5.5801% and 10.8286%. Gold is also a relatively safe instrument of investment with the standard deviation of 2.1698%, and with weekly returns that vary between 13.2571% and 15.0945%. All variables, except for gold, and the EUR/USD and GBP/USD exchange rates, are negatively skewed. Negative (positive) skewness displays higher (lower) probability of large negative versus large positive price developments. In particular, the higher likelihood of large positive changes in the spot price of gold relative to other commodities makes it more appealing as safe haven in the periods of financial turmoil. All variables are also leptokurtic relative to a normal distribution, with EUR/USD currency returns being least leptokurtic and oil return being most leptokurtic. Naturally, skewness (either positive or negative) and excess positive kurtosis collectively result in a non-normal distribution, consistently with the Jarque-Bera test.

Insofar as absolute returns are volatility estimates, the sample mean absolute return is consonant with the standard deviation of returns (Panel B). Thus, oil (the EUR/USD exchange rate) has the highest (lowest) mean absolute return (3.7376%, 1.0836%). The particulary high volatility of oil returns can hinder the interpretaton of market signals and may restrain new investment (Choi and Hammoudeh, 2010). The mean absolute return for gold is relatively low (1.5652%). An analogous pattern is displayed by the sample standard deviation of absolute returns. In particular, it is the highest (lowest) for oil (the EUR/USD exchange rate) with the value of 3.5226% (0.8963%). The absolute return of gold deviates fom its mean on average by 1.5044%. Along similar lines, the widest (narrowest) range of variation, calculated as the difference between the minimum and maximum absolute returns, is for oil (the EUR/USD exchange rate). For all variables, absolute returns are positively skewed and leptokurtic. The former implies that more volatile episodes in commodity and currency returns are more likely to occur then less volatile episodes. The latter implies that (i) the distribution is more clustered around the mean and (ii) episodes of extreme volatility movements are more likely to occur within the heavy tails relative to a normal distribution.

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As a consequence of positive skewness and excess kurtosis, the null of normality is rejected by the Jarque-Bera test statistic.

Figures 1, 2 and 3 depict the spot prices, returns and volatilities, respectively, of the series employed in this study. Returns are calculated as a rate of growth in the weekly spot price. In line with previous studies (see, e.g. Khalifa et al., 2011), we use the absolute value of returns to define volatility, as it is one of the most common academic definitions of volatility and provides the most stable results given varying sample sizes (see, e.g. Zhang and Wang, 2014).[6] The spot prices of gold and silver were relatively stable (and even decreasing) before 2003/2004, but they experienced accelerated growth thereafter. The spot prices of platinum and palladium share some similarities. For instance, after a period of relative stability before 2000/2001, the spot prices of platinum and palladium increased, only to recuperate thereafter to somewhat lower levels. However, as in the case of gold and silver, since 2003 the spot prices of platinum and palladium gathered a momentum. The observed steep rise in the commodity prices has spurred a heated debate in the literature, with major drivers being (i) the 2003−2008 business cycle expansion in the global economy (Radetzki, 2006), with industrial metals being used as inputs in industrial production processes (Issler et al., 2014); (ii) growing demand for commodities from emerging market economies, such as Brazil, China, India and Russia (Humphreys, 2010), coupled with slow supply responses (Helbling et al., 2008); (iii) strongly synchronized price increases across metals (Roberts, 2008); (iv) biofuel policy changes (Helbling et al., 2008); (v) low interest rates and effective dollar depreciation (Helbling et al., 2008) and (vi) growing financial activity by institutional investors, hedge funds and exchange-trade funds (EFTs)(Silvennoinen and Thorp, 2013).

[Insert Figure 1 around here]

[Insert Figure 2 around here]

[Insert Figure 3 around here]

Table 2 summarizes results of the unit root tests. Panel A (Panel B, Panel C) reports the unit root tests for spot prices (returns, absolute returns). We use four different unit root tests - the Augmented Dickey-Fuller (ADF) test, the Phillips-Perron (PP), the Zivot-Andrews (ZA) test and Lee-Strazicich (LS) test - to test for a unit root in the data. The choice of the tests is based on the following criteria. First, the ADF and PP tests are classical and most frequently used in empirical analyses parametric and semi-parametric unit root tests, respectively. Second, the ADF, PP, ZA and LS tests hypothesize a unit root as a null hypothesis. Third, unlike the other two tests, the ZA and LS tests allow for the possibility of an endogenous break in the series that may curtail the power of classical unit root tests.[7]

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[6]Moreover, Forsberg and Ghysels (2007) find that absolute returns predict volatility quite well and show that regressors involving volatility measures based on absolute returns are better at predicting future volatility for the following reasons: (i) desirable population predictability features, (ii) better sampling error behavior, and (iii) immunity to jumps.

[7]Indeed, if there is a break in the series, a classical unit root test will diagnose the series as difference-stationary, although before and after the break the series are actually trend-stationary. Thus, if the presence of a break in the series is neglected, misleading inference may ensue.

The LS test has two distinctive features. First, by allowing for a structural break under both the null and alternative hypotheses, it addresses the problem of size distortion, inherent in other unit root tests (such as the ZA test) (Ghoshray, 2011). Second, it allows for more than one break in the series.[8] More generally, in a longer time series, the likelihood of breaks is naturally higher and thus the choice of a more general unit root test is warranted. We also distinguish between two cases in terms of the presence of deterministic components in the test equation, a test equation with a constant, and a test equation with a constant and a linear trend. Table 2 shows that the commodity and currency spot prices generally have a unit root. The presence of a unit root is supported by Schwartz (1997) who is not able to identify mean reversion in precious metals' prices. Thus, the unit root tests endorse the use of variables in first differences in our empirical models. Further, consistent with the findings of Sari et al. (2010), we discard the possibility of cointegration among commodity and currency spot prices. The unit root tests in Panels B and C affirm that returns and absolute returns, respectively, are stationary.

[Insert Table 2 around here]

In Table 3, the coefficients of pairwise correlation for returns (Panel A) and absolute returns (Panel B) are reported. One key result is that both commodity and currency returns show positive pairwise correlations. However, the correlations between commodity and currency returns are mainly negative. This finding suggests that the U.S. Dollar can be used as a hedging instrument against unanticipated movements in commodity markets. On the other hand, for absolute returns, all pairwise correlations are positive. With regard to the return correlation, the largest coefficient is shown between gold and silver (0.672263), whereas the smallest coefficient between gold and the EUR/USD exchange rate (-0.334422). The pairwise absolute return correlation is again the largest between gold and silver (0.505494), and the lowest between palladium and the CHF/USD exchange rate (0.003648).

[Insert Table 3 around here]

2.2. Empirical methodology

This study employs the spillover index by Diebold and Yilmaz (2012), which generalises the original index, first developed by Diebold and Yilmaz (2012). Spillovers allow for the identification of the inter-linkages between the variables of interest. Diebold and Yilmaz (2009) framework allows the estimation of the total spillover index, whereas Diebold and Yilmaz (2012) extend the work of Diebold and Yilmaz (2009) in two respects.

First, they provide refined measures of directional spillovers and net spillovers, providing an 'input-output' decomposition of total spillovers into those coming from (or to) a particular source/variable and allowing the identification of the main recipients and transmitters of shocks. Second, in line with Koop et al. (1996) and Pesaran and Shin (1998), a generalized

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[8]In our test equations, we assume two structural breaks.

vector autoregressive framework in used by Diebold and Yilmaz (2012), where forecast-error variance decompositions are invariant to the ordering of the variables (in contrast to Cholesky-factor identification used in Diebold and Yilmaz, 2012). In the context of the present study, this is particularly important since it is hard, if not impossible, to justify one particular ordering of the variables under consideration.

Following Diebold and Yilmaz (2012), we estimate a VAR model, which takes the following general form (for a detailed description of the VAR model, see Lutkepohl, 2006):

$$\mathbf{y}_t = \sum_{i=1}^{q} \mathbf{B}_i y_{t-1} + \varepsilon_t, \tag{1}$$

where y_t is $N \times 1$ vector of endogenous variables, $\mathbf{B}_i$ are $N \times N$ are autoregressive coefficient matrices and ε_t is a vector of error terms that are assumed to be serially uncorrelated. The VAR model contains nine variables ($N = 9$), namely the returns (volatility) of gold, silver, platinum, palladium and oil prices, and the EUR/USD, GBP/USD, JPY/USD and CHF/USD exchange rates. Key to the dynamics of the system is the moving average representation of Equation (1) which is written as $\mathbf{y}_t = \sum_{j=1}^{\infty} \mathbf{A}_j \varepsilon_t$, where the $N \times N$ coefficient matrices $\mathbf{A}_j$ obey the recursion of form $\mathbf{A}_j = B_1 \mathbf{A}_{j-1} + B_2 \mathbf{A}_{j-2} + ... + B_p \mathbf{A}_{j-p}$, with $\mathbf{A}_0$ being the $N \times N$ identity matrix and $\mathbf{A}_j = 0$ for $j < 0$. The total, directional and net growth rate spillovers are produced by the generalized forecast-error variance decompositions of the moving average representation of the VAR model in Equation (1). The advantage of the generalized variance decomposition is that it eliminates any possible dependence of the results on the ordering of the variables. Pesaran and Shin (1998) define the H-step-ahead generalized forecast-error variance decomposition as:

$$\theta_{ij}(H) = \frac{\sigma_{jj}^{-1} \sum_{h=0}^{H-1} (e_i' A_h \Sigma e_j)^2}{\sum_{h=0}^{H-1} (e_i' A_h \Sigma A_h' e_i)}, \tag{2}$$

where Σ denotes the variance matrix of the error vector ε, σ_{jj} denotes the error term's standard deviation for the j-th equation and e_i a selection vector with one as the i-th element and zeros otherwise. This yields a $N \times N$ matrix $\theta(H) = [\theta_{ij}(H)]_{i,j=1,2}$, where each entry gives the contribution of variable j to the forecast error variance of variable i. The own-variable and cross-variable contributions are contained in the main diagonal and the off-diagonal elements of $\theta(H)$ matrix, respectively.

Since the own and cross-variable variance contribution shares do not sum to one under the generalized decomposition, i.e., $\sum_{j=1}^{N} \theta_{ij}(H) \neq 1$, each entry of the variance decomposition matrix is normalized by its row sum, as follows:

$$\tilde{\theta}_{ij}(H) = \frac{\theta_{ij}(H)}{\sum_{j=1}^{N} \theta_{ij}(H)} \tag{3}$$

with $\sum_{j=1}^{N} \tilde{\theta}_{ij}(H) = 1$ and $\sum_{i,j=1}^{N} \tilde{\theta}_{ij}(H) = N$ by construction.

This ultimately allows to define a total growth spillover index, as:

$$TS(H) = \frac{\sum_{i,j=1, i\neq j}^{N} \tilde{\theta}_{ij}(H)}{\sum_{i,j=1}^{N} \tilde{\theta}_{ij}(H)} \times 100 = \frac{\sum_{i,j=1, i\neq j}^{N} \tilde{\theta}_{ij}(H)}{N} \times 100 \tag{4}$$

which gives the average contribution of spillovers from shocks to all (other) variables/markets to the total forecast error variance.

Moreover, this approach is quite flexible and allows to obtain a more differentiated picture by considering directional spillovers: Specifically, the directional spillovers received by market i from all other market j are defined as

$$DS_{i \leftarrow j}(H) = \frac{\sum_{j=1, j \neq i}^{N} \tilde{\theta}_{ij}(H)}{\sum_{i,j=1}^{N} \tilde{\theta}_{ij}(H)} \times 100 = \frac{\sum_{j=1, j \neq i}^{N} \tilde{\theta}_{ij}(H)}{N} \times 100 \tag{5}$$

and the directional spillovers transmitted by market i to all other market j as

$$DS_{i \rightarrow j}(H) = \frac{\sum_{j=1, j \neq i}^{N} \tilde{\theta}_{ji}(H)}{\sum_{i,j=1}^{N} \tilde{\theta}_{ji}(H)} \times 100 = \frac{\sum_{j=1, j \neq i}^{N} \tilde{\theta}_{ji}(H)}{N} \times 100. \tag{6}$$

Notice that the set of directional spillovers provides a decomposition of total spillovers into those coming from (or to) a particular market. For instance, in the present application this means that our spillover matrix $\theta(H)$ consists of the main diagonal elements reflecting own-market spillovers, and the off-diagonal elements reflecting cross-market spillovers.

Finally, subtracting Equation (6) from Equation (5), we can obtain the net spillovers from each market to all other markets as:

$$NS_i(H) = DS_{i \rightarrow j}(H) - DS_{i \leftarrow j}(H). \tag{7}$$

The net spillovers indicate which of the markets in our system is a transmitter/receiver of spillovers in net terms.

The spillover index approach provides measures of the intensity of interdependencies across the four precious metals (gold, silver, platinum and palladium), crude oil and the EUR/USD, GBP/USD, JPY/USD and CHF/USD exchange markets, and allows a decomposition of spillover effects by market source and recipient.

3. Empirical findings

The generalized VAR framework of Diebold and Yilmaz (2012) is used to construct total, directional and net (pairwise) spillovers. The Akaike Information Criterion (AIC) is used to select the optimal lag length for the VAR models. Returns are calculated as a week-to-week rate of change in the spot price. Absolute value of returns is used to measure volatility. Section 3.1 presents the estimation results of the nine-variate VARs featuring returns on commodity (gold, silver, platinum, palladium and oil) and on currencies (EUR/USD, GBP/USD, JPY/USD and CHF/USD). The estimation results are summarized in the form of static and dynamic total, direction and net spillovers among commodity and currency returns. Section 3.2 reports the estimation results of the nine-variate VARs that feature commodity and currency volatilities, and are summarized in a similar fashion to those of return spillovers.

3.1. Return Spillovers

Table 4 summarizes the total static spillover index among commodity and currency returns and decomposes it by transmitters and receivers of return spillovers. It also measures the extent to which the variables are net return transmitters or net receivers.

[Insert Table 4 about here]

The following results from Table 4 stand out. The total spillover index indicates average contribution (42.41%) of unanticipated changes to returns in the dependent variables (gold, silver, platinum, palladium, oil, and EUR/USD, JPY/USD, GBP/USD and CHF/USD exchange rates) in the 10-step-ahead forecast error variance decomposition (FEVD) of all other variables in the VAR. With regard to the commodities, we identify that Gold is the largest contributor to the FEVD of the other variables in the VAR. It contributes to the FEVD of the other variables on average by 56.02%, while it receives from the other variables 52.09%. Hence, in net terms, it contributes 3.93 percentage points more to the forecasting of the other variables than it receives from the other variables. The second largest contributor to the FEVD of all other is platinum, with the net contribution estimated at 2.78%. Silver is also a net transmitter, with the contribution standing at 1.88%. The remaining commodities contribute to the FEVD of all other variables less than they receive from all other variables. With regard to the currencies, CHF/USD exchange rate is the largest net transmitter of spillovers (13.92%), followed by GBP/USD exchange rate (1.63%). While this measure is the lowest for the EUR/USD exchange rate (-6.35%), this does not reflect the differences between gross contributions. For instance, the directional spillover 'from' and 'to' oil is considerably smaller than for, e.g., EUR/USD exchange rate. Overall, the findings suggest that the return spillover index divides the variables into two groups according to whether they are net transmitters of net receivers of spillovers. The former comprise gold, platinum, silver, and CHF/USD and GBP/USD exchange rates, while the latter comprise palladium, oil, and EUR/USD and JPY/USD exchange rates. The observed pattern in return spillovers indicates evidence of co-movement between prices of different categories of commodities, wherein the precious metals are identified as the net transmitters of return spillovers, with a particular emphasis on gold (Morales and Andreosso-OCallaghan, 2011). Gold is also considered as a safe haven in periods of heightened turbulence (Ciner et al., 2013). In agreement with this finding, Baffes (2007) documents lower pass-through from crude oil to prices of precious metals' prices than to prices of other commodities. Further, large swings in precious metals' prices are a source of changes in terms of trade (Aizenman et al., 2012; Pierdzioch et al., 2013), which by turn can trigger changes in the exchange rate (De Gregorio and Wolf, 1994). Also, commodity-price fluctuations can be an important source of changes in the exchange rate of commodity-dependent countries (Cashin et al., 2004). Within the currencies, the Swiss Franc is considered a safe haven (Khalifa et al., 2012).

Central to static return spillovers is the assumption that the observed intensity of interdependence among the nine commodity and currency markets are constant across time. Nevertheless, the various economic, financial and geopolitical events that have taken place during the sample period could have triggered appreciable period– and event–specific variations

in the patterns of return transmissions. Thus, relaxing the assumption of time-invariance can gain additional insights into short– and long–memory components in return spillovers. For instance, the time–varying spillover index, depicted in Figure 4 suggests that the intensity of return spillovers can significantly deviate from the average (static) total spillover index (42.41%), reported in Table 4. Indeed, the time–varying spillover index has varied from 29% in 2001 to 58% in 2008. Specifically, it has undergone periods of gradual decline (1991−−1996), steep decline (1997−−2000), accelerated growth (2002−−2008). In the last five years, it remains very high and seems to have stabilized between 48% and 53%. The theory of portfolio choice predicts that an increase in the price of one asset (such as gold) will cause a rebalancing of portfolios away from that asset to alternative assets (such as silver, platinum, palladium etc.), whose prices may increase due to the shift in demand (Tilton et al., 2011). However, whether prices of other assets will eventually increase depends on the strength of the substitution relative to the income effect (Akram, 2009). The latter stems from an increase in real investment expenditure due to the initial price increase, thus making commodity investors to reduce the demand for all assets. In this regard, our results suggest that in the period of accelerated growth in commodity prices, the substitution effect outweighed the income effect, as in that period the commodity prices were increasing in unison, and the US Dollar was depreciating against the other currencies. Alternatively, the increasing importance in the cross–market information content in commodity prices in the wake of the global financial crisis can be symptomatic of the 'flight–to–quality' phenomenon, whereas investments in one asset class (such as bonds or stocks) can be turn into investments in totally different asset classes (such as commodities). Following Garrett and Taylor (2001), greater comovement in the returns on commodities 'tends to coincide with periods where the holding of commodities as part of the optimal portfolio leads to significant increases in utility', and where a boom in commodity prices becomes a commonplace in the world economy.

[Insert Figure 4 around here]

In an attempt to further disentangle the link between commodity returns and currency market returns, we estimate model (1) using 200-week rolling windows and compute the time-varying net spillovers, as defined in equation (7). By concentrating on net spillovers we can deduce whether one of the variables is either a net transmitter or a net receiver of spillover effects.[9] We thus proceed by examining the net spillover effects between commodity returns and currency market returns. We concentrate on the nature (i.e. net transmitter or net recipient) of each one of the variables of interest in contrast to all other variables. Unlike Figures A.2 and A.3 in Appendix A.1, Figure 5 highlights episodes, in which the variables act as net transmitters and net receivers of return spillovers. The variable of interest is considered to be a net transmitter of spillover effects when the line lies within the positive upper part of each panel.

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[9]Net spillovers are estimated based on the directional spillovers. Thus, for sake of brevity and without loss of generality, we only report the net spillovers' analysis. Nevertheless, the directional spillovers analysis can be found in Appendix A.1.

The plots of the net return spillovers are shown in Figure 5. Though findings summarized in Table 4 are broadly supported by the time-varying net return spillovers, periods in which the role of net transmitter/net receiver is reversed can be identified in Figure 5. In particular, gold receives return spillovers from the other variables in the VAR after the 2008/2009 US recession. The silver–transmitted net spillover becomes negative two years before the 2001 US recession. For platinum, the positive net spillover is reversed before the 2008/2009 US recession, but it becomes positive again soon after the US economy starts recovering. The CHF/USD is a net transmitter of spillovers throughout the whole sample period, although the strength of transmission diminishes after the 2008/2009 US recession. The GBP/USD is a net transmitter except for the period of 1997–2000, and occasionally thereafter. By contrast, the other variables, while generally acting as net receivers of spillovers, in certain periods they also act as transmitters. This result is particularly apparent for palladium that acts as net transmitter in the period of 2011–2013.

[Insert Figure 5 around here]

3.2. Volatility Spillovers

Table 5 summarizes the total static spillover index among commodity and currency volatilities and decomposes it by transmitters and receivers of return spillovers. It also measures the extent to which the variables are net volatility transmitters or net receivers.

[Insert Table 5 about here]

The results reported in Table 5 indicate that the average contribution of surprises to commodity and currency volatility (gold, silver, platinum, palladium, oil, and EUR/USD, JPY/USD, GBP/USD and CHF/USD exchange rates) in the 10-step-ahead FEVD of all other variables in the VAR is 25.70%. Within the commodities, gold is identified as the largest average contributor of volatility spillovers to the other variables in the VAR (34.45%), closely followed by platinum (33.57%) and silver (32.29%). Platinum and silver are the largest recipients of volatility spillovers, with the average contribution of all other variables estimated at 31.79% and 31.38%, respectively. By contrast, oil and palladium are the lowest transmitters (6.24% and 22.70%, respectively) and receivers (14.14% and 24.55%, respectively) of volatility spillovers. With regard to the commodities, the CHF/USD and GBP/USD exchange rates are the largest transmitters (33.19% and 30.02%, respectively), whereas the GBP/USD and EUR/USD exchange rates are the largest receivers (28.58% and 28.25%, respectively). In terms of net volatility spillovers, a similar pattern as for the return spillovers is observed. Within the five commodities, gold, platinum and silver are identified as the net transmitters, while palladium and oil are the net receivers of volatility spillovers. Gold is again the largest net transmitter of volatility spillovers, with its net contribution of 3.89%. The leading role of gold is accentuated in other empirical studies. For instance, Adrangi et al. (2000) report evidence of significant bi-directional spillover effects between gold and silver, especially originating from the gold contract. Moreover, an unanticipated increase in the price of gold increases uncertainty in the gold market more

than an unanticipated decrease; additionally, an unanticipated increase in the price of gold can be interpreted as a signal of future adverse conditions and uncertainty in other asset markets (Baur, 2012). The information complexity of gold market volatility that involves price–sensitive information about other assets is underlined by Batten and Lucey (2009). Further, oil is the largest net receiver of volatility spillovers, with its net contribution standing at -7.90%. These findings receive support from Sari et al. (2007), who find that gold and silver are significant determinants of the volatility of forecast errors in oil prices. On the currencies' side, the CHF/USD exchange rate is unambiguously the net transmitter of volatility spillovers (6.19%), whereas the EUR/USD exchange rate is clearly a net receiver (-3.39%). These results are broadly in agreement with Antonakakis (2012), who find that the Swiss Franc is generally a net transmitter of volatility spillovers, whereas the Japanese Yen as a net receiver in the context of the four currency markets. Our results are also in line with Khalifa et al. (2012), who report evidence that the CHF and GBP leads volatility spillovers to other commodities and currencies.

One key shortcoming of the static volatility spillovers is that the intensity of interdependence among commodities and currency marketz are constant over time. However, the various economic, financial and geopolitical events that have taken place during the sample period could have been determinants of material period– and event–specific variations in the cross–market volatility transmission. More generally, static volatility spillovers ignore price and volatility jumps that are typically witnessed by such events. In this context, Brooks and Prokopczuk (2013) demonstrate that models with return and volatility jumps exhibit superior performance than models that do not allow for such jumps. Thus, we next relax the assumption of time–invariant volatility spillovers. The ensuing dynamic total spillover index is presented in Figure 6.

[Insert Figure 6 around here]

Figure 6 provides evidence of dynamic volatility transmission. Several salient features of the total volatility spillover index are in order. First, in the period preceding the Dot-com bubble collapse, the total volatility spillover index decreased from 47% to 27%. Second, the total spillover index started to increase again in 2003, and it experienced a notable jump during the global financial crisis to 54%. Third, after the 2008/2009 U.S. recession, the spillover index stabilized and even decreased to, albeit still high, around 42%. Thus, the dynamic volatility spillover resonates well with the dynamic return spillover. Indeed, the time variation in the total volatility spillover has endured four phases, i) relative stability and gradual decrease (1991−1996), ii) steep decline (1997−2001), accelerated growth (2003−2008) and relative tranquillity with some tendency to decline (2009−2014).

Although in Table 5 sheds light on the level of net volatility spillovers, there are periods in which the actual net volatility spillovers are below or above the average level. In this regard, Figure 7 reports time-varying net volatility spillovers which also extend and complement evidence provided in Table 5. Although gold, platinum and silver are generally net transmitters of volatility spillovers, in certain periods they also act as net recipients. For instance, gold becomes a net receiver of volatility spillovers during 2003–2005. Platinum

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receives spillovers during 1996–1997 and shortly before the 2008/2009 U.S. recession. Silver receives spillovers during a period of 1991–1994, and then again in 2001–2004. By contrast, palladium – that generally acts as a net recipient of volatility spillovers – it becomes a net transmitter before the 2008/2009 U.S. recession. Oil receives spillovers during the entire sample period, except for the years of 1992–1993. By contrast, exchange rates follow a different pattern. The CHF/USD (GBP/USD) exchange rate becomes a net recipient during the period of the U.S. recession (since 2005). The EUR/USD (JPY/USD) exchange rate becomes a net transmitter in 1993–1994, 2000–2002, 2005–2006 and from 2013 (1996–1997 and during 2004–2005).

[Insert Figure 7 around here]

3.3. Robustness Checks

In an attempt to check the robustness of our results, we undertake several robustness checks. First, we explore whether the use of alternative H-step-ahead forecast error variance decompositions and alternative rolling windows affects the results of the return and volatility spillovers. In particular, we allow the forecast horizon H to range from 5 to 30 weeks while holding constant the rolling window (200 weeks). The results remain qualitatively similar. Second, we utilize alternative rolling windows from 100 to 300 weeks while holding the forecast horizon H constant at 10 weeks. The main results obtained used the rolling window of 200 weeks are again validated. A third robustness check addresses the importance of controlling for the interdependence between commodity and stock markets. To this end, we additionally include return and volatility on the S&P 500 stock market index. Once again, the results for the return and volatility spillovers remain qualitatively similar. Finally, to check the robustness of the results obtained based on the generalized version of the spillover index by Diebold and Yilmaz (2012), we also employ the spillover index approach of Diebold and Yilmaz (2009), which is based on the Cholesky decomposition and in which the forecast error variance decomposition is sensitive to the ordering of the variables in the VAR. In particular, we analyse 100 random permutations (different orderings of the variables in the VAR) and construct the corresponding spillover indices for each ordering. Figure A.1 in the Appendix presents the minimum and maximum values that the total return and volatility spillover index, respectively, receive based on Cholesky factorization. According to this figure, the results are in line with those of our main approach reported in Figures 4 and 6.

4. Summary and Concluding Remarks

In this study, we examine the dynamic link between returns and volatilities of commodities and currency markets. In particular, based on weekly data on five commodities (gold, silver, platinum, palladium, oil) and four exchange rates (EUR/USD, JPY/USD, GBP/USD and CHF/USD) over the period January 6, 1987 to July 22, 2014 we find the following empirical regularities. First, the analysis of static spillover effects in the commodity (currency) market shows that gold, silver and platinum (CHF/USD and GBP/USD) are net transmitters of returns and volatility spillovers during the sample period, whereas palladium and

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crude oil (EUR/USD and JPY/USD) are net receivers. These results suggest that, the information contents of gold, silver and platinum can help improve forecast accuracy of returns and volatilities on palladium and crude oil returns and volatilities. Second, gold (CHF/USD) is the largest gross commodity (currency) transmitter of return and volatility spillovers to the remaining assets in our model. Third, pairwise commodity return (volatility) spillovers reveal relatively stronger bidirectional interdependencies between gold and silver, and platinum and palladium. Fourth, the analysis of dynamic spillovers shows time– and event–specific patterns. For instance, for gold and silver (platinum) returns and volatility, the transmission procees intensified (degraded) in the period marked by the US subprime mortgage crisis, the global financial crisis and the ensuing worldwide recession. After the global financial crisis, the role of gold and silver (platinum) returns as net transmitters of shocks weakened (strengthened), while the role of gold, silver and platinum volatility as net transmitters of shocks remained relatively high. Last but not least, our findings are very robust to several robustness checks. Overall, our findings reveal that, while the static analysis clearly classifies the aforementioned variables into net transmitters and net receivers, the dynamic analysis denotes episodes wherein the role of transmitters and receivers of return (volatility) spillovers can be interrupted or even reversed. Hence, even if certain commonalities prevail in each identified category of commodities, such commonalities are time– and event–dependent. These results are of great importance as they can be used to evaluate the potential determinants of future risk-adjusted portfolio returns and thus can help investors to reach superior investment decisions. Additionally, the pricing of options can benefit from our results on net volatility spillovers.

This study can open new avenues for future research. As a first extension, alternative volatility measures can be employed to study dynamic volatility spillovers. These include realized and conditional volatility. Considering the latter, future research could use multi-variate GARCH methodologies, e.g. the DCC-MGARCH model proposed by Engle (2002), so as to extract conditional volatility. As a second extension, future research could study the determinants of dynamic return and volatility spillovers. On this subject, Brooks and Prokopczuk (2013) show that stochastic volatility models with simultaneous jumps in both prices and volatility of commodities show better performance than models that do not allow for such jumps. They argue that in periods of stress, a simultaneous jump in commodity prices is associated with increased levels of uncertainty that further result in a volatility jump. This should lead to an increase in the total volatility spillover index. To this end, the VIX volatility index could be use to capture periods of stress and, hence, should simultaneously impact on return and volatility spillovers. In addition, interest rate is vindicated as a crucial driver of comovement between commodity prices (Akram, 2009; Byrne et al., 2013)

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Figure 1: Spot prices in the commodity and currency markets
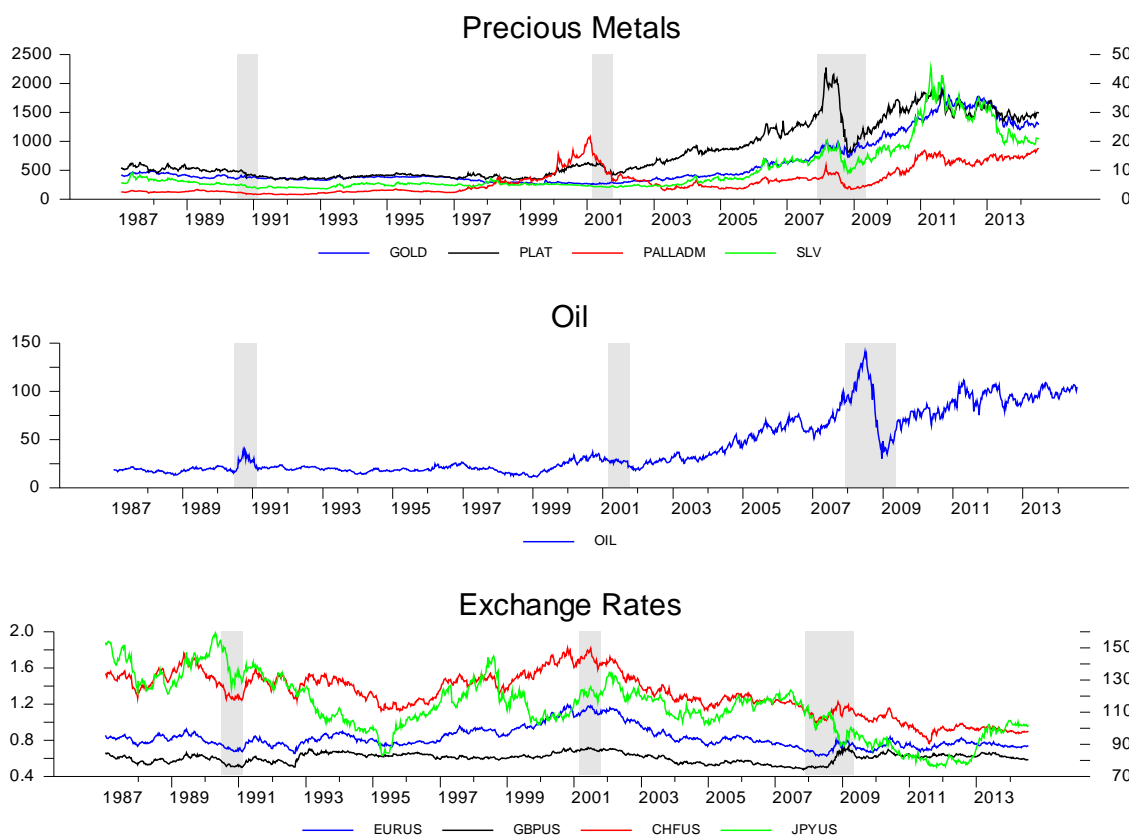
Note: In this figure, the prices of gold, silver, platinum and paladium (top panel), oil (middle panel) and the EUR/USD, GBP/USD, JPY/USD and CHF/USD exchange rates (bottom panel) are depicted. The prices of gold, platinum and palladium are shown on the left scale, whereas price of silver is shown on the right scale. The prices of precious metals are expressed in US Dollars per ounce of Try. The price of crude oil is benchmarked to WTI and is expressed in US Dollars per barrel. The EUR/USD, GBP/USD and CHF/USD exchange rates are shown on the left scale, whereas the JPY/USD is shown on the right scale. These exchange rates are expressed in units of foreign currency (i.e., EUR, GBP, JPY or CHF) required to buy one unit of domestic currency (i.e., USD). Thus, an increase in the exchange rate denotes an appreciation of the USD. Shaded areas represent the NBER-dated recessions in the United States. The sample period is $06/01/1987-07/22/2014$.
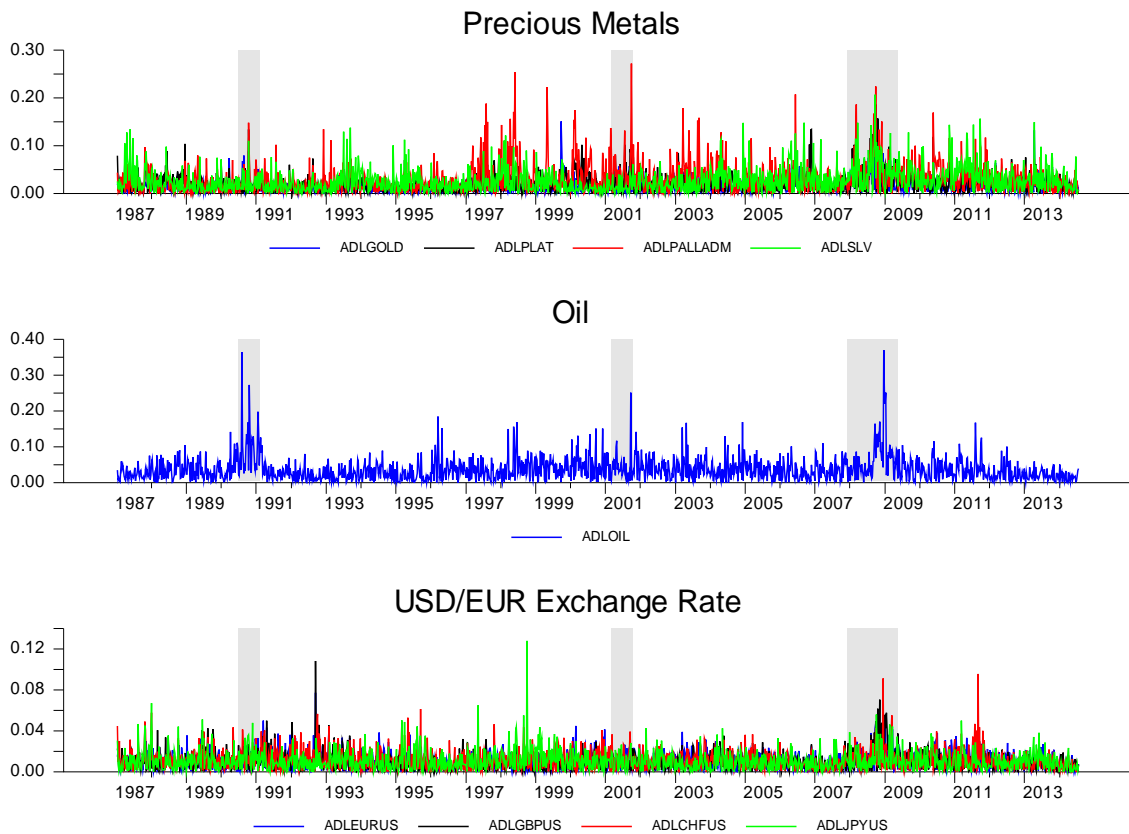
Figure 2: Returns in the commodity and currency markets
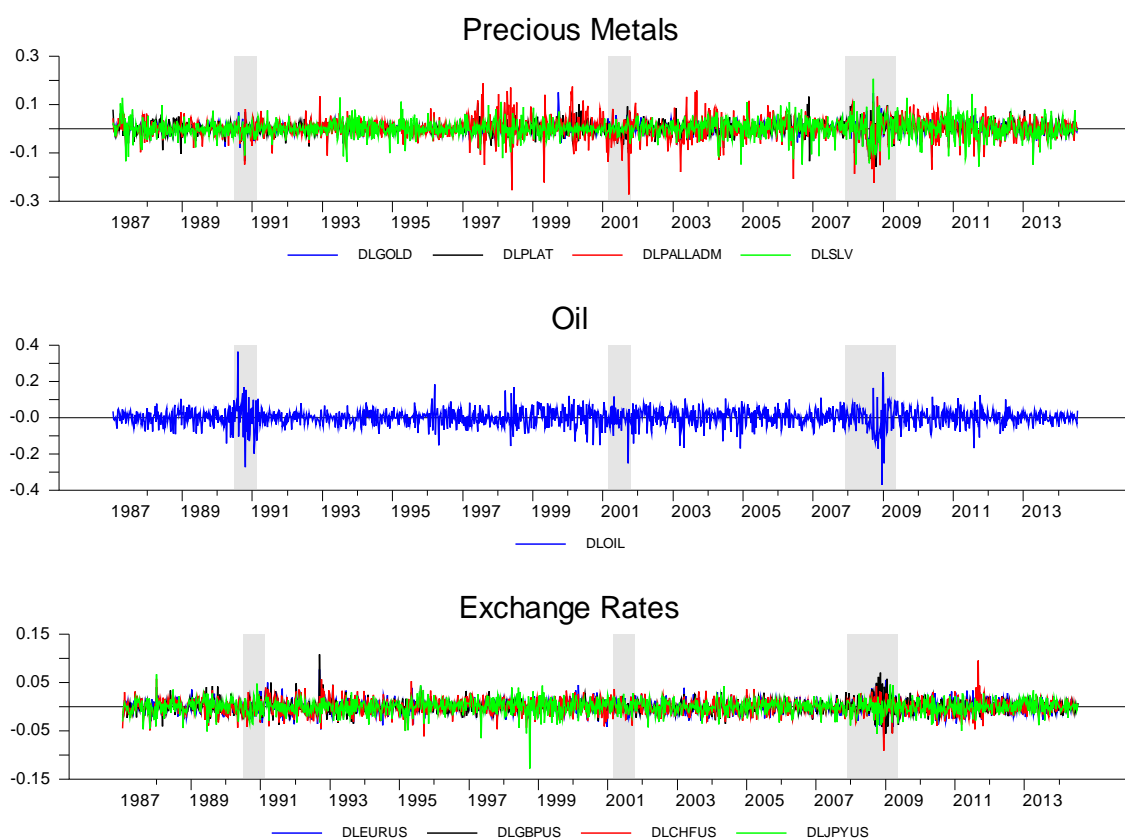
Note: In this figure, returns of gold, silver, platinum and paladium (top panel), oil (middle panel) and the EUR/USD, GBP/USD, JPY/USD and CHF/USD exchange rates(bottom panel) are depicted. Returns are calculated as a week-to-week rate of growth in the value of investment. Shaded areas represent the NBER-dated recessions in the United States. The sample period is 06/01/1987−07/22/2014.

Figure 3: Absolute returns in the commodity and currency markets

Note: In this figure, absolute returns of gold, silver, platinum and paladium (top panel), oil (middle panel) and the EUR/USD, GBP/USD, JPY/USD and CHF/USD exchange rates (bottom panel) are depicted. Absolute returns are calculated as the absolute value of the week-to-week rate of growth in the value of investment. Shaded areas represent the NBER-dated recessions in the United States. The sample period is 06/01/1987 – 07/22/2014.

Figure 4: Total return spillover index of commodity and currency markets
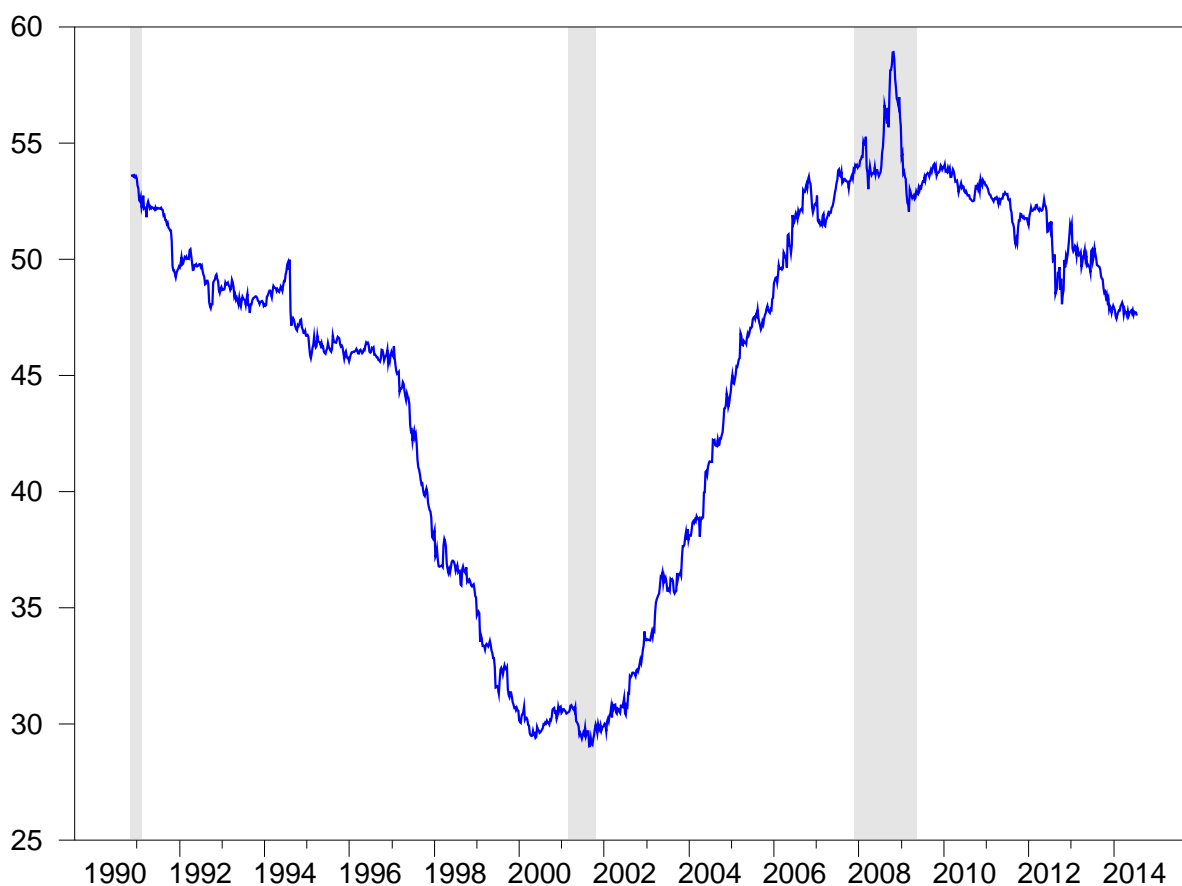
Note: Dynamic total return spillover is represented in this figure. It is calculated from the forecast error variance decompositions (FEVDs) on 10-step-ahead forecasts. The underlying FEVD is based upon a nine-variate VAR of order 1, which is dictated by the Akaike Information Criterion. Total spillover, estimated using 200-day rolling windows, is given by Equation 4. Shading denotes US recessions as defined by the NBER. The sample period is 06/01/1987 – 07/22/2014.

Figure 5: Net return spillovers of commodity and currency markets
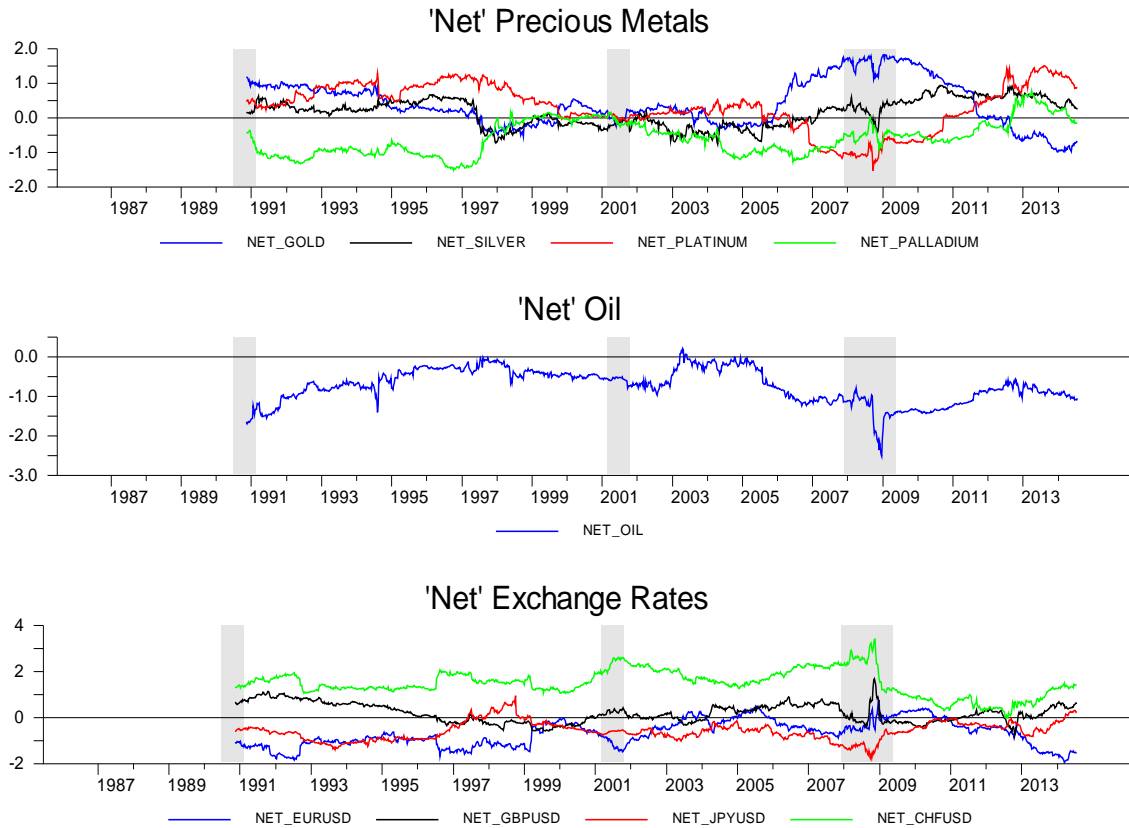
Note: Dynamic net return spillovers are depicted in this figure. In the top (middle, bottom) panel, net spillovers 'from' gold, silver, platinum and palladium (oil, EUR/USD, GBP/USD, JPY/USD and CHF/USD exchange rates) are depicted. Net spillovers are calculated by subtracting directional 'to' spillovers from directional 'from' spillovers. Positive (negative) values of the net spillover indicate that the variable is a net transmitter (receiver) of spillovers. Net spillovers are calculated from the FEVDs on 10-step-ahead forecasts. The underlying FEVD is based upon a nine-variate VAR of order 1, which is dictated by the Akaike Information Criterion. Net spillovers, estimated using 200-day rolling windows, are given by Equation 7. Shading denotes US recessions as defined by the NBER. The sample period is 06/01/1987 – 07/22/2014.

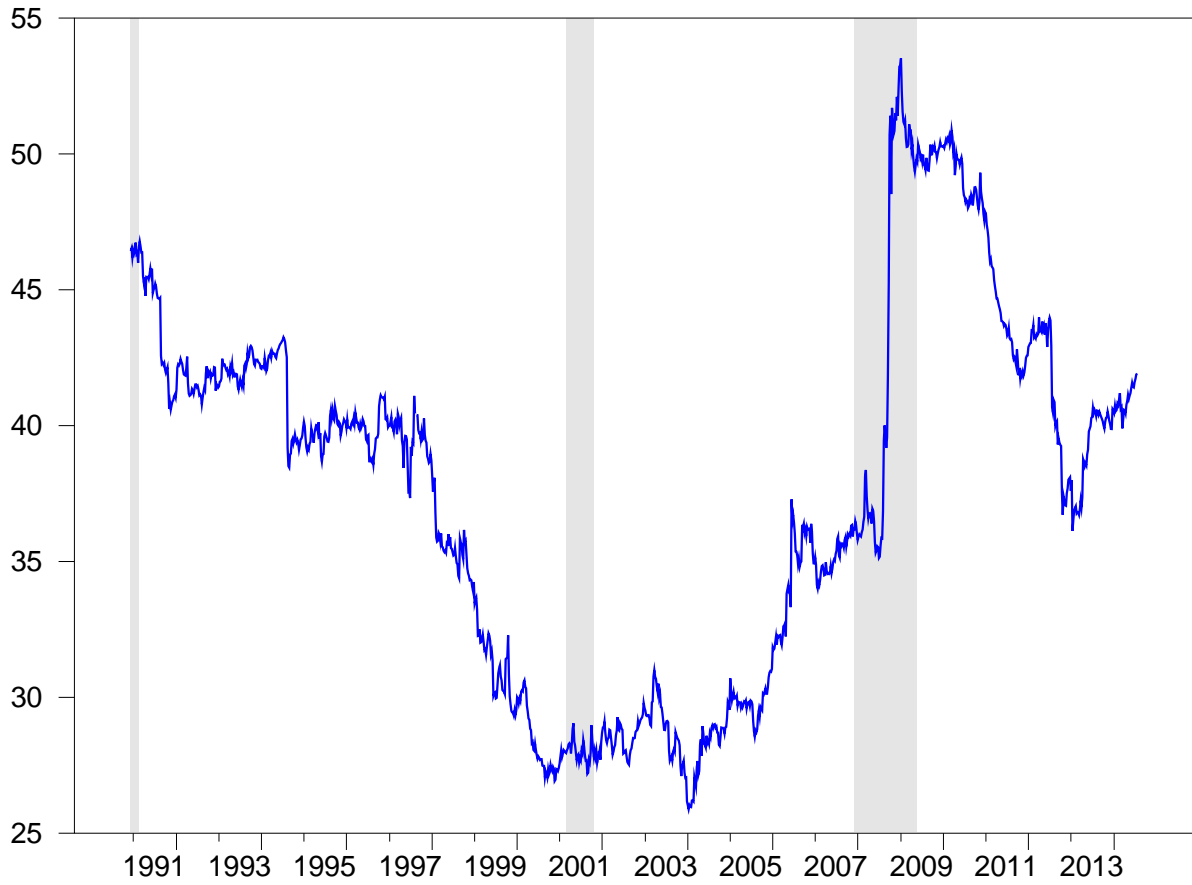Figure 6: Total volatility spillover index of commodity and currency markets

Note: Dynamic total volatility spillover is represented in this figure. It is calculated from the forecast error variance decompositions (FEVDs) on 10-step-ahead forecasts. The underlying FEVD is based upon a nine-variate VAR of order 5, which is dictated by the Akaike Information Criterion. Total spillover, estimated using 200-day rolling windows, is given by Equation 4. Volatility is measured with absolute returns. Shading denotes US recessions as defined by the NBER. The sample period is 06/01/1987 – 07/22/2014.

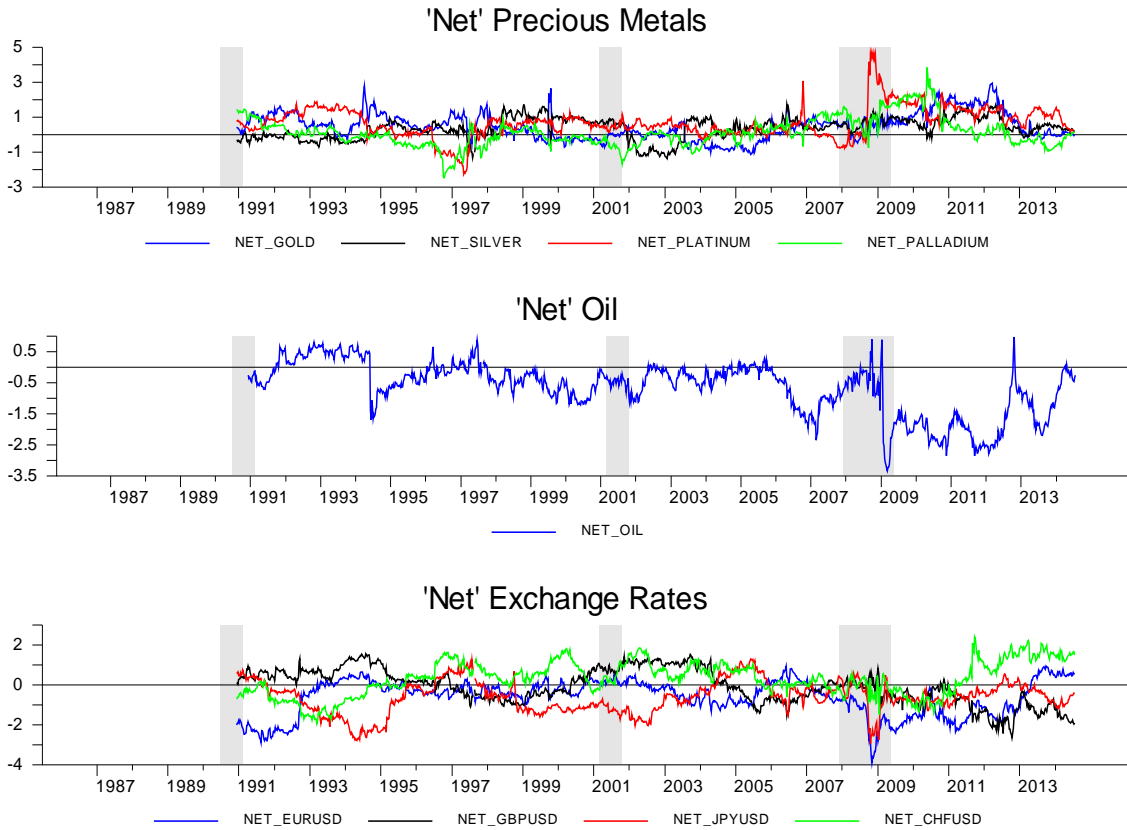Figure 7: Net volatility spillovers of commodity and currency markets

Note: Dynamic net volatility spillovers are depicted in this figure. In the top (middle, bottom) panel, net spillovers 'from' gold, silver, platinum and palladium (oil, EUR/USD, GBP/USD, JPY/USD and CHF/USD exchange rates) are depicted. Net spillovers are calculated by subtracting directional 'to' spillovers from directional 'from' spillovers. Positive (negative) values of the net spillover indicate that the variable is a net transmitter (receiver) of spillovers. Net spillovers are calculated from the FEVDs on 10-step-ahead forecasts. The underlying FEVD is based upon a nine-variate VAR of order 5, which is dictated by the Akaike Information Criterion. Net spillovers, estimated using 200-day rolling windows, are given by Equation 7. Shading denotes US recessions as defined by the NBER. The sample period is 06/01/1987 – 07/22/2014.

Table 1: Descriptive Statistics

Panel A: Spot Prices

Variables	Obs	Mean	Median	Max	Min	Std	Skew	Kurt	JB	Prob
GOLD	1438	602.5390	391.3500	1887.55	252.85	420.03646	1.478821	3.847445	567.15975	0.000000
SILVER	1438	10.03258	5.55750	45.4800	3.5600	8.558504	1.799839	5.432319	1130.8590	0.000000
PLATINUM	1438	798.0347	552.875	2273.00	332.00	479.83668	0.917358	2.464484	218.87337	0.000000
PALLADIUM	1438	314.5813	226.000	1075.00	79.250	224.24996	1.061982	3.002663	270.29806	0.000000
CRUDE OIL	1438	43.02586	26.9850	141.060	10.990	30.993969	0.974631	2.564741	239.01175	0.000000
EUR/USD	1438	0.825551	0.793512	1.194458	0.625841	0.115082	1.244935	4.222138	460.9434	0.000000
JPY/USD	1438	113.1564	112.9775	159.22	75.960	18.0382	0.026625	2.601469	9.686303	0.007882
GBP/USD	1438	0.607551	0.615764	0.727379	0.474361	0.052968	-0.346211	2.467246	45.73298	0.000000
CHF/USD	1438	1.311175	1.31655	1.8201	0.7626	0.235167	-0.198392	2.210059	46.82152	0.000000

Panel B: Returns

Variables	Obs	Mean	Median	Max	Min	Std	Skew	Kurt	JB	Prob
GOLD	1437	0.000822	0.001053	0.150945	-0.132571	0.021698	0.099729	8.200640	1621.8007	0.000000
SILVER	1437	0.000939	0.001400	0.206835	-0.156621	0.037731	-0.237906	5.617511	423.7811	0.000000
PLATINUM	1437	0.000778	0.002016	0.133215	-0.186628	0.029905	-0.625152	7.079217	1089.9207	0.000000
PALLADIUM	1437	0.001378	0.000000	0.188197	-0.271934	0.044088	-0.524562	7.659684	1365.9475	0.000000
CRUDE OIL	1437	0.001216	0.004457	0.364427	-0.370059	0.051355	-0.361662	8.624153	1925.2381	0.000000
EUR/USD	1437	-0.000109	-0.000536	0.077283	-0.064963	0.014065	0.246860	4.320193	118.9518	0.000000
JPY/USD	1437	-0.000306	0.000590	0.067118	-0.127917	0.014744	-0.759507	7.796075	1515.421	0.000000
GBP/USD	1437	-0.000099	-0.000895	0.108286	-0.055801	0.013584	0.739347	7.521764	1355.144	0.000000
CHF/USD	1437	-0.000403	-0.000571	0.095653	-0.091263	0.015347	-0.035629	5.328284	324.8809	0.000000

Panel B: Absolute Returns (Volatility)

Variables	Obs	Mean	Median	Max	Min	Std	Skew	Kurt	JB	Prob
GOLD	1437	0.015652	0.011554	0.150945	0.000000	0.015044	2.683776	16.74629	13039.04	0.000000
SILVER	1437	0.027090	0.019478	0.206835	0.000000	0.026271	1.959239	8.217487	2549.277	0.000000
PLATINUM	1437	0.021402	0.016056	0.186628	0.000000	0.020894	2.402206	12.20334	6453.553	0.000000
PALLADIUM	1437	0.030288	0.020493	0.271934	0.000000	0.032058	2.423237	11.87003	6117.175	0.000000
CRUDE OIL	1437	0.037376	0.028524	0.370059	0.000000	0.035226	2.826408	18.79021	16841.95	0.000000
EUR/USD	1437	0.010836	0.008847	0.077283	0.000000	0.008963	1.584876	7.572853	1853.629	0.000000
JPY/USD	1437	0.011003	0.008627	0.127917	0.000000	0.009815	2.536735	19.52537	17892.33	0.000000
GBP/USD	1437	0.009969	0.007691	0.108286	0.000000	0.009223	2.486771	16.14984	11834.56	0.000000
CHF/USD	1437	0.011717	0.009238	0.095653	0.000000	0.009915	1.966787	10.99128	4750.097	0.000000

Note: This table summarizes descriptive statistics (sample mean, median, maximum, minimum, standard deviation, skewness, kurtosis, the Jarque-Bera test statistic, and the p-value associated to the Jarque-Bera test statistic) of precious metals (gold, silver, platinum and palladium), crude oil and the EUR/USD, GBP/USD, JPY/USD and CHF/USD exchange rates. Panel A summarizes spot prices, Panel B summarizes returns, and Panel C summarizes absolute returns (volatility). Returns are calculated as a week-to-week rate of growth in the value of investment. The sample period is 06/01/1987 – 07/22/2014.

Table 2: Unit Root Tests

VARIABLES	OBS	ADF TEST		PP TEST		ZA TEST		LS TEST	
		CONST	TREND	CONST	TREND	CONST	TREND	CONST	TREND
Panel A: Spot Prices									
GOLD	1437	-0.00709	-1.42491	-0.04881	-1.45179	-3.42811	-2.67615	-1.40260	-4.64760
SILVER	1437	-1.19536	-2.23055	-1.22105	-2.25548	-3.78450	-4.38086	-2.34100	-5.34690
PLATINUM	1437	-1.06451	-2.74100	-1.03954	-2.64916	-4.04825	-3.90328	-2.72580	-4.77500
PALLADIUM	1437	-0.85715	-2.13839	-0.79520	-2.06807	-3.74027	-3.83097	-2.63270	-3.81660
OIL	1437	-0.95421	-2.95454	-0.87628	-2.85912	-4.36363	-4.81024	-3.61080	-5.40030
EUR/USD	1437	-1.98386	-2.06666	-1.95255	-2.00645	-3.52695	-3.84584	-2.27080	-4.03870
JPY/USD	1437	-2.50606	-2.82591	-2.63491	-2.89510	-3.35584	-3.76677	-2.75560	-3.75280
GBP/USD	1437	-3.19286*	-3.19524	-3.18385*	-3.18792	-4.48972	-4.57938	-3.04080	-4.5535
CHF/USD	1437	-1.53085	-2.52479	-1.51096	-2.38819	-4.47974	-4.55290	-2.87450	-5.18780
Panel B: Returns									
GOLD	1436	-17.9941**	-18.0848**	-36.9958**	-37.0028**	-18.3238**	-18.4248**	-17.2213**	-19.3691**
SILVER	1436	-17.5708***	-17.5874***	-36.7450***	-36.7604***	-17.6657***	-17.8596***	-16.3294***	-18.2693***
PLATINUM	1436	-17.4675***	-17.4848***	-39.0810***	-39.0989***	-17.7813***	-17.7981***	-9.3337***	-18.0136***
PALLADIUM	1436	-16.8233***	-16.8283***	-36.5748***	-36.5833***	-17.3165***	-17.3162***	-14.9856***	-18.1885***
OIL	1436	-16.0224**	-16.0247**	-42.7991**	-42.8079**	-16.1498**	-16.1829**	-16.2387**	-18.2378**
EUR/USD	1436	-16.3560***	-16.3532***	-37.4468***	-37.4474***	-16.5776***	-16.5721***	-12.8149**	-17.4342**
JPY/USD	1436	-15.5792***	-15.5894***	-38.7796***	-38.7925***	-15.7426**	-15.7800**	-9.8315**	-16.4200**
GBP/USD	1436	-17.0522***	-17.0476***	-37.7074***	-37.7086***	-17.2322**	-16.5721**	-11.2313***	-17.8787***
CHF/USD	1436	-16.5830***	-16.5853***	-37.7682***	-37.7748***	-16.7265**	-16.5721**	-8.2977***	-16.8296***
Panel C: Absolute Returns (Volatility)									
GOLD	1436	-10.9663**	-11.9455**	-32.5156**	-33.7185**	-12.5828**	-12.9968**	-11.3616**	-16.3925**
SILVER	1436	-10.3903***	-10.9375***	-32.1782***	-32.9394***	-11.7580**	-11.9823**	-10.8928***	-14.1686***
PLATINUM	1436	-11.4452***	-11.6476***	-30.6690***	-30.9270***	-11.9793***	-12.6561***	-7.1110***	-12.9071***
PALLADIUM	1436	-11.9681**	-12.3673**	-30.4942**	-31.0136**	-13.5391**	-13.5379**	-11.7245***	-14.6156***
OIL	1436	-11.1665**	-11.1616**	-30.0564**	-30.0591**	-11.5590**	-12.3910**	-11.8652**	-13.8804**
EUR/USD	1436	-12.7681**	-12.7650**	-36.0758**	-36.0771**	-13.2187**	-14.5024**	-13.3554**	-15.0161**
JPY/USD	1436	-13.7604***	-13.8099***	-33.1899***	-33.2266***	-14.0437***	-14.1871***	-10.0126**	-15.1849**
GBP/USD	1436	-11.0892***	-11.1618***	-33.5013***	-33.5903***	-11.9242***	-13.0325***	-10.5301***	-14.0863***
CHF/USD	1436	-14.1391**	-14.2991**	-38.2665**	-38.4269**	-14.5798**	-14.9447**	-6.9907**	-15.5482**

Note: This table summarizes results of the Augmented Dickey-Fuller (ADF), Phillips-Perron (PP), Zivot-Andrews (ZA) and Lee-Strazicich (LS) tests for a unit root for spot prices (Panel A), returns (Panel B) and absolute returns (Panel C). the null hypothesis is that the series features a unit root. Four lags of the lagged dependent variable in first differences are used in the test equation. The 1% (5%) critical value for the ADF test are -3.4377 and -3.9697 (-2.8640 and -3.4154) for a test equation featuring a constant (CONST) and both a constant and a trend (TREND), respectively. The same critical values are utilized for the PP test. The 1% (5%) critical values for the ZA test are -5.3400 and -5.5700 (-4.8000 and -5.0800) under the presence of an endogenous break in the constant (CONST) and in both the constant and the trend (TREND), respectively. The ZA test comprises a constant and a trend, while allowing for a single endogenous break in the constant (CONST) and in both the constant and the trend (TREND). The 1% (5%) critical values for the ZA test are -5.3400 and -5.5700 (-4.8000 and -5.0800) under the assumption of endogenous break in the constant (CONST) and in both the constant and the trend (TREND), respectively. The LS test comprises a constant and a trend, while allowing for two endogenous breaks in the constant (CONST) and in both the constant and the trend (TREND). The 1% and 5% critical values for the LS test with endogenous breaks in the constant are -4.5450 and -3.8420, respetively. The 1% and 5% critical values for the LS test with endogenous breaks in both the constant and the trend depend on breakpoint nuisance parameters describing the location under the null hypothesis. The 1% (5%) critical value varies between -6.1600 and -6.4500 (-5.5900 and -5.7400). ** and * indicate 1% and 5% level of significance.

Table 3: Coefficients of Correlations

Panel A: Returns

Variables	GOLD	SILVER	PLATINUM	PALLADIUM	OIL	EUR/USD	JPY/USD	GBP/USD	CHF/USD
GOLD	1.000000								
SILVER	0.672263	1.000000							
PLATINUM	0.512914	0.527458	1.000000						
PALLADIUM	0.349137	0.397503	0.596191	1.000000					
OIL	0.212183	0.222226	0.183412	0.119986	1.000000				
EUR/USD	-0.334422	-0.258216	-0.199064	-0.178063	-0.110616	1.000000			
JPY/USD	-0.088194	-0.006687	-0.021546	0.000500	0.011491	0.202312	1.000000		
GBP/USD	-0.214884	-0.133742	-0.110636	-0.062341	-0.113149	0.507734	0.269281	1.000000	
CHF/USD	-0.213033	-0.133616	-0.096989	-0.031245	-0.052746	0.506405	0.439526	0.600594	1.000000

Panel B: Absolute Returns (Volatility)

VVariables	GOLD	SILVER	PLATINUM	PALLADIUM	OIL	EUR/USD	JPY/USD	GBP/USD	CHF/USD
GOLD	1.000000								
SILVER	0.505494	1.000000							
PLATINUM	0.338293	0.342230	1.000000						
PALLADIUM	0.197277	0.249946	0.443800	1.000000					
OIL	0.125747	0.065369	0.127266	0.128786	1.000000				
EUR/USD	0.152720	0.108091	0.119576	0.074142	0.097226	1.000000			
JPY/USD	0.037133	0.077001	0.058924	0.045908	0.066407	0.131061	1.000000		
GBP/USD	0.120900	0.058140	0.097126	0.044069	0.111165	0.390129	0.190820	1.000000	
CHF/USD	0.066492	0.029207	0.019755	0.003648	0.033848	0.324258	0.292509	0.388436	1.000000

Note: This table summarizes the Pearson coefficients of correlation among commodity and currency returns (Panel A) and absolute returns (Panel B). All variables are in returns. Returns are calculated as a week-to-week rate of growth in the value of investment. The sample period is 06/01/1987 – 07/22/2014.

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Table 4: Return spillover index of commodities and currency markets

	GOLD	SILVER	PLATINUM	PALLADIUM	OIL	EUR/USD	GBP/USD	JPY/USD	CHF/USD	From Others
GOLD	47.91	21.21	12.39	5.70	2.17	4.47	2.51	0.73	2.92	52.09
SILVER	22.05	49.10	13.33	7.56	2.52	2.50	1.38	0.12	1.43	50.90
PLATINUM	13.12	13.69	50.39	17.84	1.73	1.82	0.80	0.05	0.57	49.61
PALLADIUM	7.07	9.11	21.02	59.51	0.98	1.78	0.34	0.01	0.17	40.49
OIL	3.80	4.32	2.86	1.33	85.02	1.14	1.26	0.01	0.26	14.98
EUR/USD	4.32	2.34	1.68	1.79	0.63	45.68	16.63	4.20	22.74	54.32
GBP/USD	2.46	1.04	0.64	0.23	0.78	15.93	54.59	4.13	20.20	45.41
JPY/USD	0.73	0.16	0.03	0.04	0.09	3.99	5.58	74.91	14.46	25.09
CHF/USD	2.47	0.91	0.44	0.05	0.19	16.34	18.55	9.89	51.17	48.83
Contr. to others	56.02	52.78	52.39	34.53	9.08	47.97	47.04	19.14	62.75	Total Spillover
Contr. incl. own	103.92	101.89	102.79	94.03	94.11	93.65	101.64	94.05	113.92	Index = 42.41%
Net spillovers	3.93	1.88	2.78	-5.96	-5.90	-6.35	1.63	-5.95	13.92	

Note: Spillover indices, given by Equations (2)-(7), calculated from variance decompositions based on 10-step-ahead forecasts. The underlying FEVD is based upon a nine-variate VAR of order 1, which is dictated by the Akaike Information Criterion.

Table 5: Volatility spillover index of commodities and currency markets

	GOLD	SILVER	PLATINUM	PALLADIUM	OIL	EUR/USD	GBP/USD	JPY/USD	CHF/USD	From Others
GOLD	69.44	17.12	6.73	2.44	1.16	1.19	0.96	0.48	0.49	30.56
SILVER	16.78	68.62	7.08	4.15	0.15	0.40	1.13	1.01	0.66	31.38
PLATINUM	8.69	7.76	68.21	12.11	0.66	0.66	0.54	0.61	0.76	31.79
PALLADIUM	2.58	4.33	14.52	75.45	0.87	0.33	0.30	0.57	1.06	24.55
OIL	2.44	1.01	2.21	1.86	85.86	2.34	0.74	1.88	1.66	14.14
EUR/USD	1.56	0.63	1.59	1.02	0.83	71.75	11.63	0.94	10.05	28.25
GBP/USD	1.59	0.46	0.90	0.31	1.44	10.95	71.42	2.33	10.60	28.58
JPY/USD	0.10	0.73	0.40	0.64	0.65	1.00	3.63	84.92	7.92	15.08
CHF/USD	0.70	0.26	0.13	0.18	0.48	7.98	11.08	6.18	73.00	27.00
Contr. to others	34.45	32.29	33.57	22.70	6.24	24.86	30.02	13.99	33.19	Total Spillover
Contr. incl. own	103.89	100.91	101.79	98.15	92.11	96.61	101.44	98.91	106.20	Index = 25.70%
Net spillovers	3.89	0.91	1.78	-1.85	-7.90	-3.39	1.44	-1.09	6.19	

Note: Spillover indices, given by Equations (2)-(7), calculated from variance decompositions based on 10-step-ahead forecasts. The underlying FEVD is based upon a nine-variate VAR of order 5, which is dictated by the Akaike Information Criterion.

Appendix

Figure A.1: Minimum and Maximum total return and volatility spillover indices of commodity and currency markets based on Cholesky factorization with random permutations

Panel A: Minimum and Maximum total return spillover index

Panel B: Minimum and Maximum total volatility spillover index
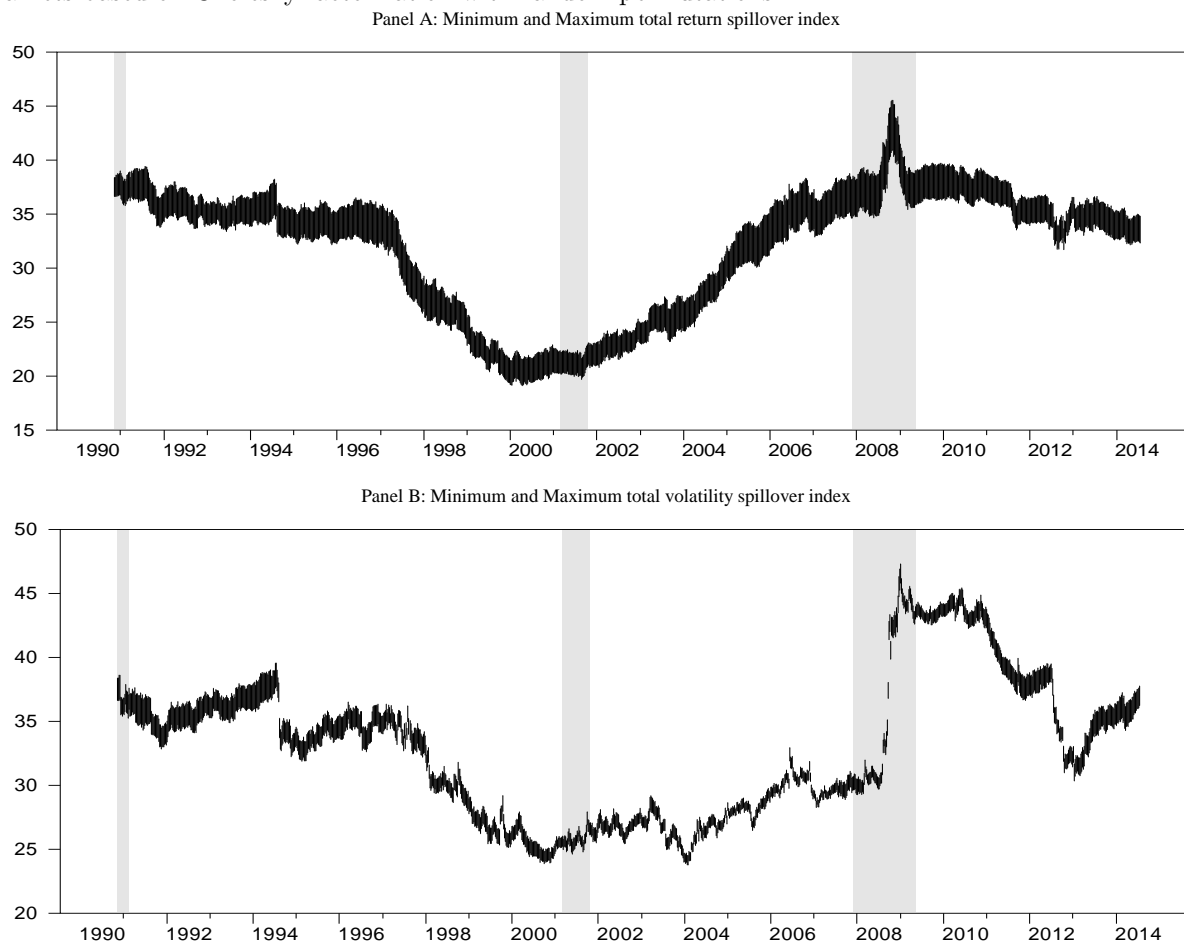
Note: Plot of maximum and minimum moving total spillover indices estimated based on Cholesky factorization with 100 randomly chosen orderings using 200-week rolling windows. Shading denotes US recessions as defined by the NBER. The sample period is 06/01/1987 – 07/22/2014.

A.1. Directional spillovers between commodity returns and currency market returns

In Figure A.2 (A.3), the total spillovers index is decomposed into the sources (uses) of return spillovers, coined as directional 'from' ('to') return spillovers. The results suggest that, similarly to the total volatility index, depicted in Figure 4, the directional 'from' and 'to' spillovers of gold, silver and platinum have experienced periods of relative stability or gradual decay, steep decline, accelerated growth, before stabilizing at high levels in the last 5 years. By contrast, palladium, oil and exchange rates have exhibited different dynamics. For

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palladium, the directional spillover were gradually decreasing before the US recession of 2001. However, they have shown a tendency to increase thereafter. The directional spillovers of oil and currencies have shown an increasing trend throughout the sample period (except maybe for the directional 'to' spillover for oil, which showed mean reversion until around 2005, and has been increasing thereafter). The directional spillovers 'from' and 'to' oil returns find support in Ji and Fan (2012), who identify significant bi–directional effects between oil and metal returns.

Figure A.2: Directional return spillover *FROM* commodity and currency markets
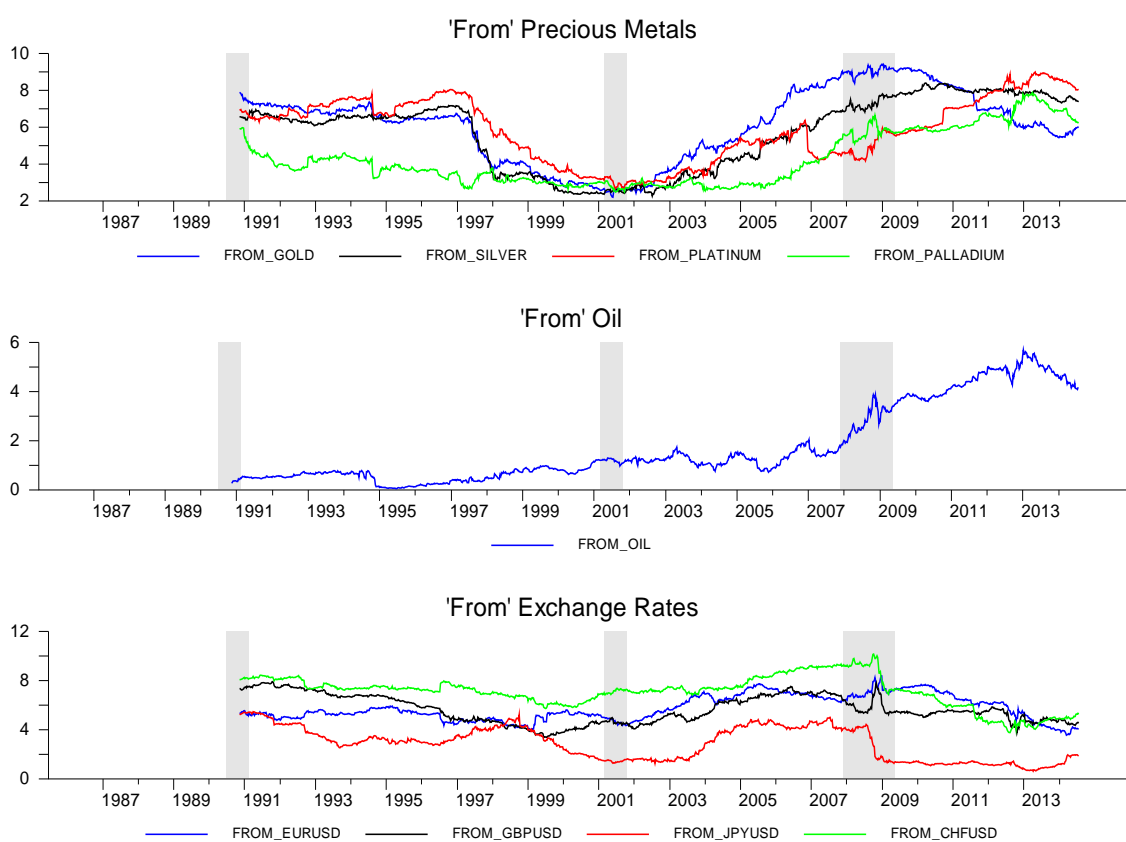
Note: Dynamic directional return spillovers 'from' commodities and currencies are represented in this figure. In the top (middle, bottom) panel, directional spillovers 'from' gold, silver, platinum and palladium (oil, exchange rate) are depicted. Directional spillovers are calculated from the FEVDs on 10-step-ahead forecasts. The underlying FEVD is based upon a nine-variate VAR of order 1, which is dictated by the Akaike Information Criterion. Directional spillovers, estimated using 200-day rolling windows, are given by Equation 5. Shading denotes US recessions as defined by the NBER. The sample period is 06/01/1987 – 07/22/2014.

Figure A.3: Directional return spillover *TO* commodity and currency markets
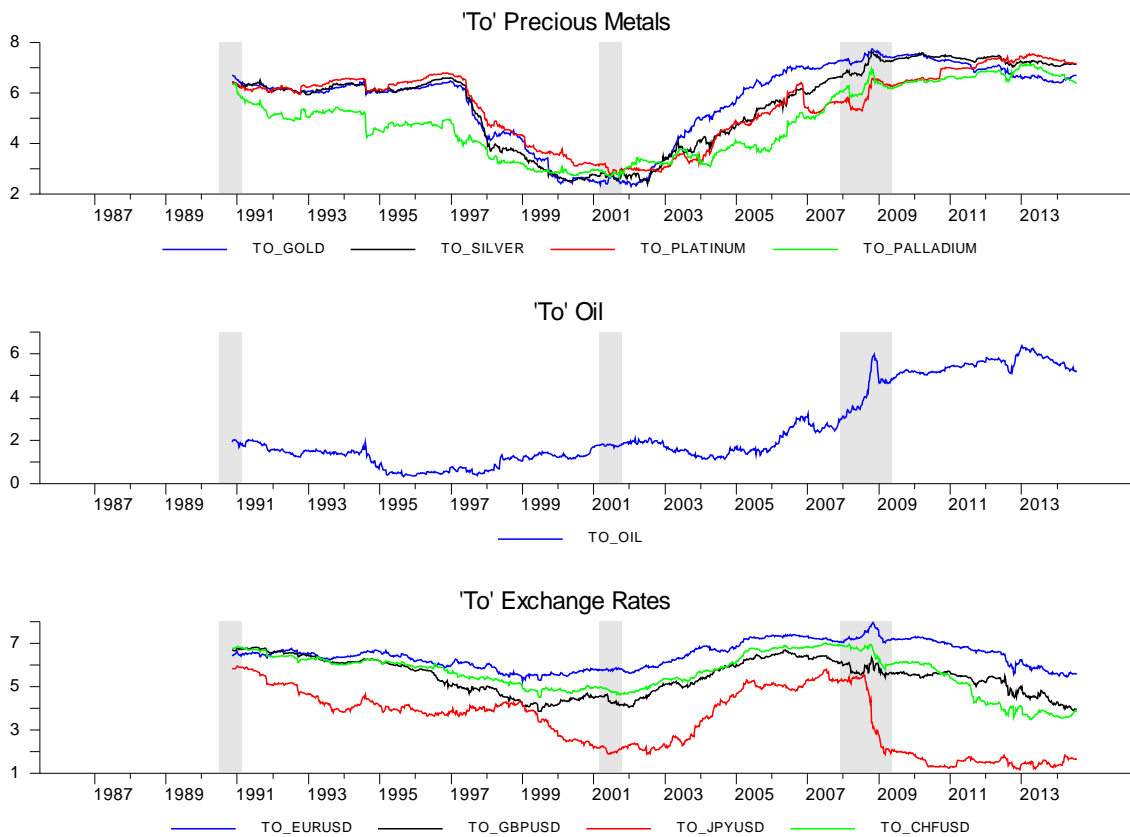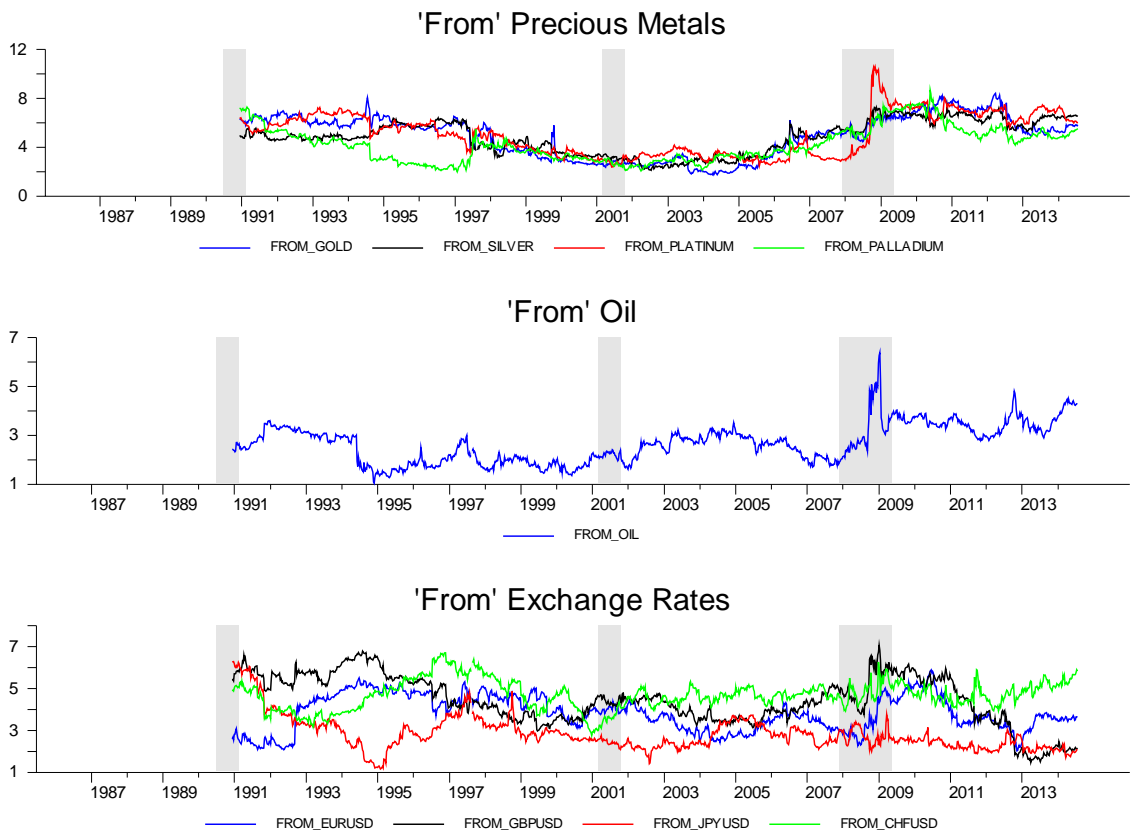

Note: Dynamic directional return spillovers 'to' commodities and currencies are represented in this figure. In the top (middle, bottom) panel, directional spillovers 'to' gold, silver, platinum and palladium (oil, exchange rates) are depicted. Directional spillovers are calculated from the FEVDs on 10-step-ahead forecasts. The underlying FEVD is based upon a nine-variate VAR of order 1, which is dictated by the Akaike Information Criterion. Directional spillovers, estimated using 200-day rolling windows, are given by Equation 6. Shading denotes US recessions as defined by the NBER. The sample period is 06/01/1987 – 07/22/2014.

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A.2. Directional spillovers between commodity volatilities and currency market volatilities
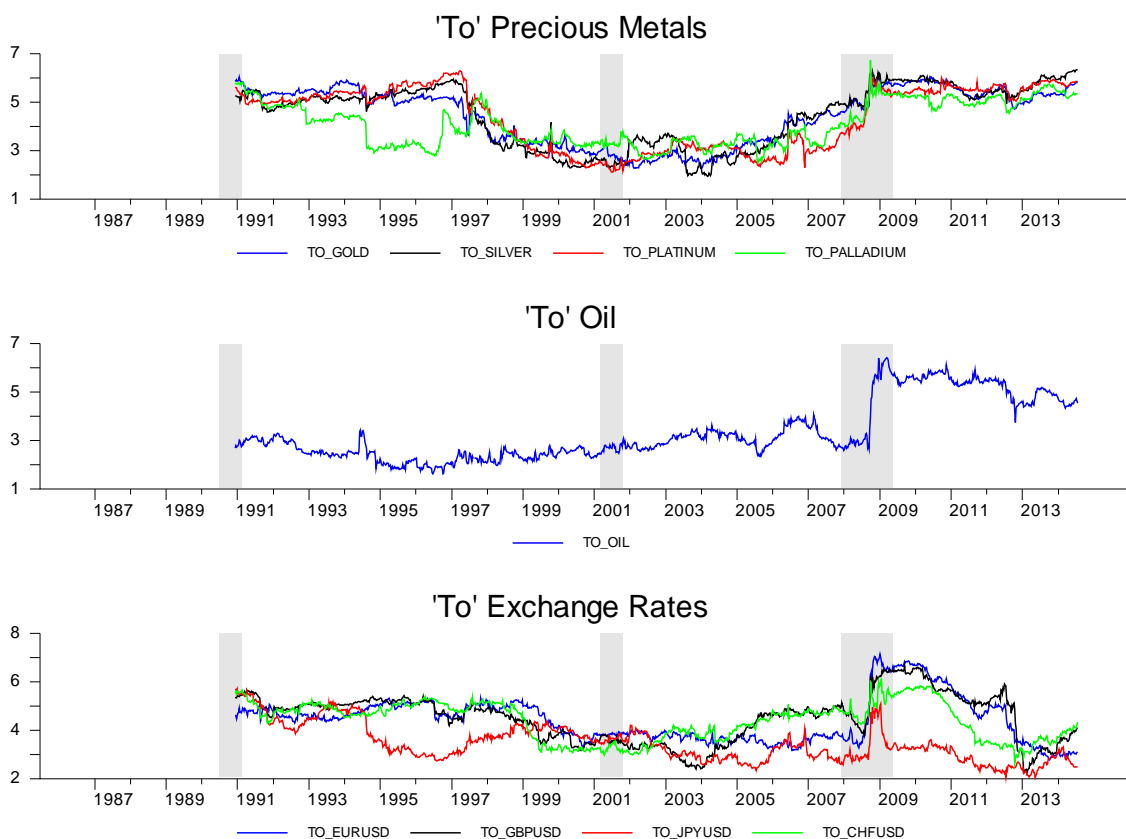
Figure A.4 (Figure A.5), decomposes the total spillover index is into the sources (uses) of return spillovers, termed as directional 'from' ('to') volatility spillovers. The striking similarity between the total volatility spillover index and the directional spillovers of gold, silver and platinum underscores the central role of the information content of the three precious metals in forecasting volatility in commodity and currency markets. For the above commodities, the directional spillovers have experienced periods of relative stability or gradual decay (until 1997), steep decline (1998−2004), accelerated growth culminated in a jump (2005−2008) and relative tranquillity (since 2009). By contrast, palladium, oil and the exchange rates have followed different dynamics. For instance, the directional spillover 'from' palladium was gradually decreasing until 1997. The contribution of oil to the FEVD of the other variables was relative stable before appreciably decreasing in 1994. It then stabilized and started to increase. In 2008, the directional spillover experienced an upward jump, before bouncing back and stabilizing in 2009. Notably, the contribution of the other variables to the FEVD of oil has followed a similar pattern. The directional spillovers 'from' and 'to' oil volatility accord with the significant bi-directional effects between the metals' and oil volatilities identified in Ji and Fan (2012). Further, the directional spillovers 'to' and 'from' the exchange rates have shown a tendency to decrease until 2004/2005. The negative trend was generally reversed in 2005, and the directional spillovers culminated in a noticeable jump in 2008, after which they stabilized and even decreased. With regard to the JPY/USD exchange rate, the directional spillovers experienced a gradual decline since 1997. The observed variation over time in the total and directional volatility spillovers echoes Brooks and Prokopczuk (2013), who propound that in periods of turbulence, a simultaneous jump in commodity prices is associated with increased levels of uncertainty that further result in a volatility jump. Our results are also consonant with Ewing and Malik (2013), who ascribe the increased incidence in volatility transmission between gold and oil futures to cross-market hedging. Moreover, volatility of commodity returns itself can play an important role in designing optimal hedging strategies (Creti et al., 2013). Further, volatility of asset returns depends on the rate of information flow; as a result, information from one market can be incorporated into the volatility generating process of another market Ross (1989).

Figure A.4: Directional volatility spillover *FROM* commodity and currency markets

'From' Precious Metals

'From' Oil

'From' Exchange Rates

Note: Dynamic directional volatility spillovers 'from' commodities and currencies are depicted in this figure. In the top (middle, bottom) panel, directional spillovers 'from' gold, silver, platinum and palladium (oil, exchange rates) are depicted. Directional spillovers are calculated from the FEVDs on 10-step-ahead forecasts. The underlying FEVD is based upon a nine-variate VAR of order 5, which is dictated by the Akaike Information Criterion. Directional spillovers, estimated using 200-day rolling windows, are given by Equation 6. Volatility is measured with absolute returns. Shading denotes US recessions as defined by the NBER. The sample period is 06/01/1987 – 07/22/2014.

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Figure A.5: Directional volatility spillover *TO* commodity and currency markets

Note: Dynamic directional volatility spillovers 'to' commodities and currencies are depicted in this figure. In the top (middle, bottom) panel, directional spillovers 'to' gold, silver, platinum and palladium (oil, exchange rates) are depicted. Directional spillovers are calculated from the FEVDs on 10-step-ahead forecasts. The underlying FEVD is based upon a nine-variate VAR of order 5, which is dictated by the Akaike Information Criterion. Directional spillovers, estimated using 200-day rolling windows, are given by Equation 6. Volatility is measured with absolute returns. Shading denotes US recessions as defined by the NBER. The sample period is 06/01/1987 – 07/22/2014.