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Dynamic risk spillovers and portfolio risk management between precious metals and global foreign exchange markets

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ABSTRACT

This study examines portfolio management and risk spillovers between four major precious metals (gold, silver, palladium and platinum) and 20 important U.S. exchange markets. To this end, we employ the multivariate DECO-GARCH model and the spillover index developed by Diebold and Yilmaz (2014, 2016) to examine the spillovers between those metal prices and the exchange rates and design portfolios and hedging strategies using different risk measures. The results show evidence of weak average conditional equicorrelations among the considered markets over time, excluding the turbulent 2008–2010 period. Furthermore, the precious metals (excluding platinum) and the currencies (with the exception of the Australian, Brazilian, Denmark, Euro, Mexican, Norwegian, New Zealand and Swedish currencies) are net receivers of shocks. Finally, the four precious metals provide strong risk and downside risk reductions, underscoring the usefulness of including precious metals in a traditional foreign exchange-dominated portfolio.

1. Introduction

Information transmission across asset markets, particularity precious metals and currencies, is an important research area for investors, portfolio managers and policy makers. It has several significant practical implications in terms of hedging and portfolio management. Designing higher portfolio diversification is a strategic goal for investors and portfolio managers and requires a thorough knowledge of comovements, interdependence, and spillovers among various markets or asset classes. The value of such knowledge has increasingly become more important to conducting successful portfolio design and risk management due to increasing regulatory and fundamental convergence across financial markets, confounding diversification potential for investors and magnifying financial market volatilities (e.g., Aloui, 2011; Forbes & Rigobon, 2002; Markwat, Kole, & Van Dijk, 2009). Today, market convergence due to sweeping deregulations as evident in increasing cross-border financial flows is resulting in pure contagious behavior (Masson, 1999). This convergence driven by financial globalization, standardization of financial transaction mechanisms and

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accompanied by rapid financial innovation has also stimulated powerful common shocks to various economies. It has also resulted in spillovers (Masson, 1999), interdependence (Forbes & Rigobon, 2002), or fundamentals-based contagion (Kaminsky & Reinhart, 2000).

In the pursuit of achieving a higher degree of diversification, investors and portfolio managers have moved to other forms of asset classes including commodities. Accordingly, commodities have stepped in as financial assets eligible for portfolio diversification. For this reason, many investors have considered the safe-haven property of precious metals (particularly gold), underlying the capacity of gold to function as a hedge or a safe haven asset for traditional assets during times of extreme market turmoil (Baur & Lucey, 2010; Baur & McDermott, 2010; Berdin, Conlon, & Potì, 2017; Lucey & Li, 2015). Not surprisingly, precious metals are viewed as safe haven assets because their values are considered more stable than those of stocks, industrial commodities and other assets. They also afford investors hedging opportunities in combination with equity and foreign exchange markets because in theory their price drivers are usually different from those of equities and other financial assets and are related to their own supply and demand structure.[1] Moreover, commodities are useful in protecting against unexpected inflation. Portfolios consisting heavily of equities and traditional bonds are sensitive to losses in value from inflation. In contrast, commodities are real assets (Ankrim and Hensel, 1993) since their values reflect prices in areas such as energy, industry and agriculture, and thus they provide purchasing power protection against rising prices.

The objective of this paper is threefold. First, it studies the evolution of the equicorrelation between the major four precious metals (gold, silver, palladium and platinum) and 20 key U.S. dollar exchange rates which is crucial to examining potential diversification opportunities. Second, we examine the directional spillovers between the considered markets' spillovers in order to detect the market which constitutes a source or a receipt of risk. Finally, it addresses portfolio risk evaluation by using different risk measures and designing different portfolios composed of different precious metals and foreign exchange markets. Those objectives are achieved by employing a family of different GARCH models and measures of spillovers.

The foreign exchange market is the most volatile financial market and its flexibility has significant implications for resource allocation, economic growth and the financial system (Rodrik, 2008). This study which deals with many exchange rates is different from previous works that have dealt with one exchange rate (ER). More specifically, our paper considers different ERs from different geographic zones, different degrees of exchange rate flexibility and has different regimes (fixed and flexible exchange rates). In addition, it is crucial to study the nexus between oil and ERs with different liquidity degrees and trading volumes. Taking the Asian region as an example, smaller economies in this region peg their currencies to a more prominent currency. For example, Hong Kong pegs the Hong Kong dollar to the US dollar, Brunei pegs the Brunei dollar to the Singapore dollar, and both Bhutan and Nepal peg the Bhutan ngultrum and the Nepal rupee, respectively, to the Indian rupee. These countries appear to prefer some form of a single currency peg. In contrast, the South Asian economics of Bangladesh and Sri Lanka and the East and Southeast Asian economies of Indonesia, Korea and the Philippines officially adopt flexible exchange rate regimes. Thus, the selection of currencies from different geographic zones provides a better understanding and a more complete picture of the risk spillovers and hedging strategies between the oil and currency markets.

The choice of the precious metal markets is motivated by their strong role as refuge assets during turbulent periods (Baur & Lucey, 2010; Baur & McDermott, 2010; Lucey & Li, 2015). Those metal markets are characterized by their liquidity and varying hedging capabilities. As for the currencies, we use the maximum number of foreign exchange markets that are located in different geographic zones to have a complete and insightful picture of the precious metal-currency markets nexus related to different regions of the world and are pertinent to portfolio designs and risk management. The choice of these different currency markets is also motivated by their liquidity, different regime arrangements (fixed or flexible exchange rates) and trading volumes. Big (small) foreign market is characterized by high (low) liquidity and substantial (low) trading volume. Note that foreign exchange markets are more liquid and have lower transaction costs than precious metals (Jobst & Ugolini, 2014).

Empirically, we initially use different GARCH family models including the dynamic equicorrelation (DECO)-fractionally integrated GARCH (FIGARCH) model in order to examine the time-varying conditional correlation between the considered markets. The DECO-FIGARCH model is more flexible than the standard GARCH model since it accounts for a long memory process in the conditional volatility of the return series, and assumes a dynamic correlation among assets. DECO supposes that each pair of returns in a given system displays the same correlation that changes over time. Second, we investigate the directional spillovers and net spillovers across the currency and precious metal markets using the Diebold and Yilmaz (2014, 2016) spillover index. Third, we study the risk reduction and three downside risk measures including the Value at Risk (VaR), semi variance and regret risk.

Our results show weak average conditional equicorrelations among the considered markets over the sample period, with the exception of the turbulent 2008–2010 period. Furthermore, all precious metals (except platinum) and the U.S. dollar exchange rates (with the exception of the Australian, Brazilian, Danish, Euro, Mexican, Norwegian, New Zealand and Swedish rates) are net receivers of shocks. Finally, the precious metals provide a strong risk reduction and downside risk reductions. This result captures the usefulness of including precious metals in a traditional foreign exchange portfolio.

The remainder of this study is organized as follows. Section 2 introduces the methodology used in this study. Section 3 describes the data and provides some preliminary analysis. Section 4 reports and discusses the empirical results. Section 5 draws implications

[1] For example, both the precious and base metals have important and diversified uses in jewelry, electronic, chemical, automotive and manufacturing industries. Therefore, a structurally different supply and demand model is expected for them. Similarly, energy commodities are the major inputs used globally in the physical production in almost any sector. Therefore, having different supply–demand structures for these commodities is not surprising.

for risk management. Section 6 provides concluding remarks.

2. Econometric modelling framework

This section discusses the methodology followed in this study. We begin with a multivariate DECO-GARCH model, which measures the equicorrelation among the four precious metals futures markets and the 20 dollar exchange rates. We also use the spillover index of Diebold and Yilmaz (2014, 2016) to identify the dynamic directional spillover effects[2] across the considered markets.

2.1. DECO-GARCH model

Since the introduction of the dynamic conditional correlation (DCC)-GARCH model, many recent empirical studies have applied different multivariate GARCH (MGARCH) model to measure the volatility spillovers across different financial markets, asset classes and countries (Sadorsky, 2014; Mimouni, Charfeddine, & Al-Azzam, 2016; Jain & Biswal, 2016; Karanasos, Yfanti, & Karoglou, 2016; Kang, Mclver, & Yoon, 2017; Mensi et al., 2015, 2016; Mensi, Al-Yahyee, & Kang, 2017; Tsukuda, Shimada, & Miyakosh, 2017 and others). However, the DCC-GARCH model of Engle (2002) is unable to compute DCC estimations as an increase in number of variables, and remains complicated to interpret (Aboura & Chevallier, 2014). To compute large scales correlation matrices, Engle and Kelly (2012) propose the DECO-GARCH model to capture the average of the conditional correlations which is set equal to the average of all pair correlations.

Let r_t be n × 1 vector of asset returns. An AR(1) process for r_t conditional on the information set I_{t-1} can be expressed as:

$$r_t = \mu + \varphi r_{t-1} + \varepsilon_t \tag{1}$$

with

$$\varepsilon_t = H_t^{1/2} v_t \tag{2}$$

where H_t is the conditional covariance matrix of r_t and v_t is an n × 1 independent vector of standardized Student-t random variables. In the first stage, we estimates univariate GARCH parameters. The expressions for h are univariate GARCH models (H_t is a diagonal matrix). For the GARCH (1,1) processes as specified in Eq. (3).

$$h_{i,t} = \omega_i + \alpha_i \varepsilon_{i,t-1}^2 + \beta_i h_{i.t-1}, \tag{3}$$

where $\omega > 0$, $\alpha \geq 0$, and $\beta \geq 0$, and $\alpha + \beta < 1$.

In the second stage, we obtain the dynamic correlations using the conditional variance-covariance matrix, H_t, can be written as:

$$H_t = D_t R_t D_t, \tag{4}$$

where $D_t = diag(\sqrt{h_{i,t}}, \cdots, \sqrt{h_{n,t}})$is a diagonal matrix of time-varying variances $h_{i,t}$ from the univariate GARCH process and R_t is the $n \times n$ time-varying conditional correlation matrix of standardized residuals. The conditional correlation matrix R_t is defined as:

$$R_t = diag(Q_t)^{-1/2} Q_t\, diag(Q_t)^{-1/2} \tag{5}$$

$$Q_t = (1 - a - b)S + a\,diag(Q_{t-1})^{1/2} \hat{\varepsilon}_{i,t-1} \hat{\varepsilon}_{i,t-1}^{'} diag(Q_{t-1})^{1/2} + bQ_{t-1}, \tag{6}$$

where S is the $n \times n$ unconditional covariance matrix of standardized residuals v_t, and a, b are non-negative scalars satisfying $a + b < 1$. Finally, the DECO model of Engle and Kelly (2012) uses a definition of the correlation matrix, R_t , which is more appropriate for large systems.

$$R_t = (1 - \rho_t) I_n + \rho_t J_n \tag{7}$$

where ρ_t is the scalar equicorrelation measure, J_n is the $n \times n$ matrix of ones and I_n is the n-dimensional identity matrix. All pairs of returns are restricted to have equal correlation on a given day. The DECO model averages the pairwise DCC correlations to give:

$$\rho_t = \frac{1}{n(n-1)}(J_n^{'} R_t^{DCC} j_n - n) = \frac{2}{n(n-1)} \sum_{i=1}^{n-1} \sum_{j=i+1}^{n-1} \frac{q_{ij,t}}{\sqrt{q_{ii,t} q_{jj,t}}}, \tag{8}$$

where $q_{ij,t}$, is the $(i, j)^{\text{th}}$ element of the time-varying correlation matrix Q_t from the DCC model. Under the multivariate Student's t-distribution, the estimation of the DECO model is conducted by the maximum likelihood function expressed as:

$$L(\Theta) = log\left\{\left(\Gamma\left(\frac{v+2}{2}\right)v\right) \Big/ (v\pi)\Gamma\left(\frac{v}{2}\right)(v-1)\right\} - (1/2)log(|H_t|) - (1/2) \times (v+2)log[1 + (\varepsilon_t^{'} H_t^{-1} \varepsilon_t)/(v-2)], \tag{9}$$

where $\Gamma(\bullet)$ is the Gama function and v is the degree of freedom for the Student's t-distribution. In the new structure, the DECO modeling is less burdensome and is computationally quicker to estimate because we avoid the inversion of matrix R_t. Besides, it makes it possible to represent the co-movement of a group of markets with a single dynamic correlation coefficient.

[2] One of the reviewers recommended the application of Bai and Perron (2003) methodology in estimating the VAR model as an extension for future work.

2.2. Spillover index framework

To analyze the volatility spillover between precious metals and foreign exchange markets, we use the spillover index of Diebold and Yilmaz (2014, 2016), which allow us to measure total spillover as well as directional and net spillover. Let market volatilities, y_t, be assumed by a covariance N-variable VAR (p)as:

$$y_t = \sum_{i=1}^{P} \Phi_i y_{t-i} + \varepsilon_t, \tag{10}$$

where $y_t$is an N × 1 vector of volatility variables, Φ_i are $N \times N$autoregressive coefficient matrices, and ε_t (0, Σ) is a vector of error terms assumed to be an i.i.d. process with zero mean Σcovariance matrix.

The moving average representation of VAR (p) can be written as $y_i = \sum_{j=0}^{\infty} \Psi_j \varepsilon_{t-j}$, where Ψ_j represents the $N \times N$ coefficient matrices and it keeps a recursion of the form $\Psi_j = \Phi_1 \Psi_{j-1} + \Phi_2 \Psi_{j-2} + \cdots + \Phi_p \Psi_{j-p}$, with Ψ_0 representing identity matrix and $\Psi_j = 0$ for j < 0.

For covariance stationarity, the moving average representation of the VaR is presented as

$$x_t = \circledast(\mathrm{L})\varepsilon_\mathrm{t} \tag{11}$$

In the above expression, $\circledast(\mathrm{L}) = (\mathrm{I} - \varnothing \mathrm{L})^{-1}$. For moving average representation, we write the following equation.

$$x_t = A(L)\ u_t \tag{12}$$

where $A(L) = \circledast(\mathrm{L})\mathrm{Q}_\mathrm{t}^{-1}$, $u_t = Q_t \varepsilon_t$, $E(u_t u_t^{'}) = I$, where Q_t^{-1} represents unique lower-triangular Cholesky factor.

Using the GVAR framework, we denote the entries of the connectedness table as $c_{ij}^{g}(H)$, which estimates the contribution of variable j to the H-step-ahead generalized forecast error variance of variable i as;

$$c_{ij}^{g}(H) = \frac{\sigma_{jj}^{-1} \sum_{h=0}^{H-1} (e_i^{'} \Psi_h \Sigma e_j)^2}{\sum_{h=0}^{H-1} (e_i^{'} \Psi_h \Sigma \Psi_h^{'} e_j)}, \tag{13}$$

where Σdenotes the variance matrix for the error vector ε, σ_{jj} denotes the standard deviation of the error term of the j^{th} equation and e_i is an $N \times 1$ vector, which has one as the i^{th} element and zero otherwise. Finally, $\Psi_h$is the coefficient matrix which multiplies h-lagged error in the infinite moving-average representation of non-orthogonalized VAR.

In the connectedness table, $c_{ij}^{g}(H)$ measures pairwise directional connectedness from j to i as;

$$C_{i \leftarrow j}^{H} = c_{ij}^{g}(H), \tag{14}$$

The off-diagonal sums of rows represent the total directional connectedness from others to i as;

$$C_{i \leftarrow *}^{H} = \sum_{\substack{j=1 \\ j \neq i}}^{N} c_{ij}^{g}(H), \tag{15}$$

Similarly, off-diagonal sums of columns represent the total directional connectedness to others from j as;

$$C_{* \leftarrow j}^{H} = \sum_{\substack{i,j=1 \\ j \neq i}}^{N} c_{ij}^{g}(H), \tag{16}$$

We can also define net directional connectedness as:

$$C_i^H = C_{* \leftarrow i}^{H} - C_{i \leftarrow *}^{H}. \tag{17}$$

Finally, the total connectedness (system-wide connectedness) is the ratio of the sum of the to-others (from-others) elements of the variance decompositions matrix to the sum of all elements;

$$C^H = \frac{1}{N} \sum_{\substack{i,j=1 \\ j \neq 1}}^{N} c_{ij}^{g}(H), \tag{18}$$

To develop the visual network of market connectedness, we interpret our connectedness table as the adjacency matrix of a weighted directed network (Diebold and Yilmaz, 2014, 2016). The elements of the adjacency matrix are our pairwise directional connectedness, $C_{i \leftarrow j}^{H}$; the row sums of the adjacency matrix (node in-degrees) are our total directional connectedness "from," $C_{i \leftarrow *}^{H}$; and the column sums of the adjacency matrix (node out-degrees) are our total directional connectedness "to," $C_{* \leftarrow i}^{H}$.

3. Data and preliminary analysis

The study considers the daily closing prices of the four major precious metals futures (gold, silver, palladium and platinum), and 20 spot U.S. exchange rates, namely Australian Dollar (AUD), Canadian Dollar (CAD), Eurozone (EURO), Swedish Krona (SEK), UK Pound Sterling (GBP), Japanese Yen (JPY), Swiss Franc (CHF), Brazilian Real (BRL), Denmark Krone (DKK), Indian Rupee (INR), Indonesian Rupiah (IDR), Korean Won (KRW), Mexican Peso (MXN), Norwegian Krone (NOK), New Zealand Dollar (NZD), Russia

Table 1
Statistical properties of the precious metal and the US foreign currency market returns.

	Mean (%)	Max.	Min.	Std. dev.	Skewness	Excess Kurtosis	Jarque-Bera	Q(30)	$Q^2(30)$	ADF	PP	KPSS	ARCH-LM(10)
Gold	0.0383	8.625	−9.8105	1.1879	−0.3833	4.8519	3771.***	51.577***	819.79***	−61.444***	−61.462***	0.3796	18.283***
Silver	0.0349	12.196	−19.489	2.1076	−0.9009	6.8734	7891.***	43.990**	756.29***	−61.938***	−61.942***	0.2067	21.838***
Palladium	0.0149	10.018	−13.366	2.0624	−0.4452	6.2529	1777.***	68.743***	888.39***	−56.682***	−56.688***	0.1519	25.759***
Platinum	0.0179	7.4568	−9.6033	1.4282	−0.5286	3.6081	2209.***	53.335***	3154.9***	−57.710***	−57.691***	0.4403	59.160***
AUD	0.0098	7.7035	−8.212	0.8542	−0.6489	12.054	22972.***	101.12***	4452.5***	−65.041***	−65.041***	0.3573	137.16***
BRL	0.0107	7.5516	−9.6682	1.0681	−0.0669	8.8119	12139.***	94.055***	5053.0***	−62.709***	−62.701***	0.2729	180.73***
CAD	−0.0048	3.807	−5.0716	0.6097	−0.0853	5.0876	4050.0***	56.570***	3227.4***	−61.512***	−61.514***	0.2778	58.157***
CHF	−0.0129	8.8907	−13.022	0.7213	−1.2459	36.133	2.0502e + 005***	49.966**	85.641***	−60.993***	−60.995***	0.1646	6.9404***
DKK	−0.0044	3.068	−4.6108	0.6259	−0.1125	2.4793	968.64***	25.249	1477.3***	−61.324***	−61.326***	0.3041	30.219***
EURO	0.0044	4.6208	−3.0031	0.6256	0.1071	2.4326	932.03***	27.646	1429.0***	−61.174***	−61.177***	0.3090	29.448***
GBP	−0.0034	4.4349	−8.1694	0.6189	−0.8754	12.653	25503.***	89.651***	735.27***	−59.851***	−59.835***	0.3294	25.748***
IDR	0.0070	7.962	−5.1619	0.6111	0.8079	17.930	50653.***	141.69***	1697.2***	−25.627***	−66.868***	0.3506	53.412***
INR	0.0091	3.9383	−3.756	0.4795	0.1869	9.5028	14135.***	62.035***	1462.8***	−46.996***	−64.764***	0.3815	48.803***
JPY	−0.0039	3.3428	−5.2156	0.6556	−0.3302	4.2165	2846.***	28.992	509.76***	−62.229***	−62.234***	0.2949	13.730***
KRW	−0.0032	10.135	−13.222	0.7360	−0.5647	49.076	3.7661e + 005***	199.46***	2536.7***	−17.042***	−61.190***	0.1178	118.11***
MXN	0.0218	8.1141	−5.96	0.6924	0.8565	13.644	29554.***	72.107***	2690.7***	−60.459***	−60.475***	0.1477	137.71***
NOK	−0.0014	4.78	−6.444	0.8097	0.0864	3.5031	1922.7***	38.307	1789.2***	−62.719***	−62.858***	0.4335	33.107***
NZD	0.0139	5.9322	−6.1782	0.8720	−0.3736	4.6797	3510.0***	58.755***	2228.1***	−61.270***	−61.316***	0.2481	46.012***
RUB	0.0197	12.522	−10.710	0.8655	1.1011	38.911	170042.***	196.05***	4204.5***	−16.953***	−63.136***	0.4782	188.55***
SEK	−0.0029	5.4715	−5.3016	0.7864	−0.1191	3.8441	2318.5***	43.306	3068.6***	−63.560***	−63.649***	0.2169	59.378***
SGD	−0.0070	2.6949	−2.3849	0.3490	0.0021	4.8160	3625.0***	44.867**	1172.1***	−63.111***	−61.315***	0.3809	27.468***
THB	−0.0057	4.4702	−3.5252	0.3878	0.1544	13.142	27008.***	94.431***	1825.0***	−60.344***	−60.456***	0.2098	61.156***
TWD	−0.0025	2.4848	−3.423	0.3098	−0.4270	10.032	15843.***	63.026***	478.17***	−65.372***	−65.261***	0.1226	25.854***
ZAR	0.0028	7.924	−6.2975	1.1144	0.2489	2.9500	1398.9***	39.311	2270.5***	−60.954***	−60.993***	0.3353	61.901***

Notes: *** denotes the rejection of the null hypotheses of normality, no autocorrelation, unit root, stationarity for KPSS, and conditional homoscedasticity at the 1% significance level.

Table 2
Unconditional correlations of sample returns among the precious metal and currency market returns.

	Gold	Silver	Palladium	Platinum	AUD	BRL	CAD	CHF	DKK	EURO	GBP	IDR
Gold	1.000											
Silver	0.786	1.000										
Palladium	0.463	0.531	1.000									
Platinum	0.609	0.619	0.642	1.000								
AUD	0.339	0.417	0.392	0.415	1.000							
BRL	−0.154	−0.244	−0.242	−0.248	−0.484	1.000						
CAD	−0.317	−0.374	−0.348	−0.352	−0.660	0.402	1.000					
CHF	−0.396	−0.329	−0.214	−0.273	−0.396	0.142	0.352	1.000				
DKK	−0.404	−0.383	−0.298	−0.347	−0.576	0.286	0.503	0.766	1.000			
EURO	0.403	0.384	0.298	0.347	0.577	−0.287	−0.503	−0.765	−0.998	1.000		
GBP	0.299	0.329	0.252	0.301	0.557	−0.296	−0.482	−0.494	−0.651	0.653	1.000	
IDR	−0.110	−0.145	−0.120	−0.140	−0.198	0.089	0.153	0.118	0.147	−0.149	−0.129	1.000
INR	−0.194	−0.229	−0.219	−0.265	−0.343	0.252	0.282	0.163	0.246	−0.248	−0.238	0.191
JPY	−0.259	−0.143	−0.003	−0.067	−0.038	−0.091	0.013	0.409	0.302	−0.302	−0.120	0.047
KRW	−0.107	−0.173	−0.206	−0.246	−0.428	0.311	0.323	0.171	0.277	−0.280	−0.298	0.215
MXN	−0.150	−0.259	−0.283	−0.281	−0.524	0.571	0.463	0.131	0.279	−0.280	−0.315	0.093
NOK	−0.379	−0.398	−0.338	−0.386	−0.615	0.373	0.562	0.603	0.781	−0.780	−0.604	0.175
NZD	0.333	0.389	0.352	0.378	0.833	−0.410	−0.596	−0.408	−0.565	0.566	0.547	−0.162
RUB	−0.139	−0.200	−0.204	−0.204	−0.299	0.250	0.299	0.183	0.260	−0.260	−0.235	0.116
SEK	−0.358	−0.377	−0.339	−0.362	−0.616	0.343	0.547	0.624	0.835	−0.835	−0.607	0.144
SGD	−0.358	−0.370	−0.322	−0.377	−0.629	0.389	0.521	0.482	0.611	−0.612	−0.504	0.229
THB	−0.225	−0.237	−0.197	−0.190	−0.299	0.204	0.249	0.233	0.284	−0.284	−0.246	0.171
TWD	−0.145	−0.174	−0.200	−0.244	−0.369	0.247	0.306	0.227	0.287	−0.289	−0.283	0.188
ZAR	−0.290	−0.338	−0.306	−0.321	−0.586	0.459	0.497	0.314	0.464	−0.464	−0.426	0.140

(*continued on next page*)

Table 2 (*continued*)

	INR	JPY	KRW	MXN	NOK	NZD	RUB	SEK	SGD	THB	TWD	ZAR
Gold												
Silver												
Palladium												
Platinum												
AUD												
BRL												
CAD												
CHF												
DKK												
EURO												
GBP												
IDR												
INR	1.000											
JPY	−0.034	1.000										
KRW	0.319	0.007	1.000									
MXN	0.320	−0.139	0.359	1.000								
NOK	0.299	0.176	0.316	0.381	1.000							
NZD	−0.308	−0.071	−0.386	−0.451	−0.584	1.000						
RUB	0.237	−0.002	0.177	0.295	0.326	−0.262	1.000					
SEK	0.275	0.188	0.300	0.360	0.816	−0.587	0.284	1.000				
SGD	0.385	0.281	0.509	0.420	0.598	−0.599	0.316	0.592	1.000			
THB	0.263	0.186	0.266	0.215	0.278	−0.300	0.159	0.266	0.448	1.000		
TWD	0.311	0.106	0.495	0.284	0.317	−0.354	0.231	0.295	0.512	0.298	1.000	
ZAR	0.306	0.010	0.351	0.522	0.499	−0.524	0.282	0.497	0.507	0.272	0.319	1.000

Table 3
Estimation of the bivariate AR(1)-DECO-GARCH model.

	Mean equation		Variance equation			Diagnostic tests	
	μ	ϕ	ω	α	β	Q(30)	$Q^2(30)$
Panel A: 1st step univariate GARCH model							
Gold	0.0376** (0.0174)	−0.0125 (0.0183)	0.0172** (0.0078)	0.0406*** (0.0120)	0.9469*** (0.0157)	32.061 [0.3646]	23.406 [0.7981]
Silver	0.0254 (0.0302)	0.0081 (0.0212)	0.0479* (0.0274)	0.0533*** (0.0174)	0.9369*** (0.0212)	27.298 [0.6075]	31.409 [0.3954]
Palladium	0.0195 (0.0306)	0.0877*** (0.0181)	0.0626** (0.0297)	0.0671*** (0.0146)	0.9192*** (0.0192)	17.784 [0.6015]	25.120 [0.1968]
Platinum	0.0229 (0.0208)	0.0495*** (0.0180)	0.0210** (0.0084)	0.0505*** (0.0098)	0.9388*** (0.0126)	9.4984 [0.9763]	26.001 [0.1657]
AUD	0.0154 (0.0108)	−0.0139 (0.0163)	0.0488*** (0.0158)	0.0569*** (0.0085)	0.9363*** (0.0076)	34.683 [0.2543]	27.272 [0.9209]
BRL	−0.0359*** (0.0128)	0.0082 (0.0182)	0.0157*** (0.0046)	0.1461*** (0.0187)	0.8476*** (0.0176)	22.553 [0.8331]	31.049 [0.4130]
CAD	−0.0077 (0.0081)	−0.0119 (0.0166)	0.0188*** (0.0637)	0.0477*** (0.0054)	0.9474*** (0.0052)	33.807 [0.2885]	33.803 [0.2887]
CHF	−0.0350 (0.0220)	−0.0361* (0.0218)	0.0074 (0.0053)	0.0436*** (0.0085)	0.9457*** (0.0057)	30.970 [0.4168]	0.9160 [1.0000]
DKK	−0.0082 (0.0087)	−0.0046 (0.0158)	0.0012 (0.0008)	0.0329*** (0.0042)	0.9639*** (0.0047)	15.601 [0.9858]	41.828 [0.0740]
EURO	0.0084 (0.0088)	−0.0035 (0.0158)	0.0012 (0.0008)	0.0326*** (0.0042)	0.9642*** (0.0047)	21.029 [0.8869]	32.572 [0.3413]
GBP	0.0066 (0.0082)	0.0018 (0.0177)	0.0282** (0.0121)	0.0615*** (0.0182)	0.9325*** (0.0173)	31.081 [0.4113]	32.743 [0.3337]
IDR	0.0034 (0.0064)	−0.0657** (0.0265)	0.0188 (0.0120)	0.2804*** (0.0965)	0.7077*** (0.1005)	55.544 [0.0031]	15.142 [0.9889]
INR	−0.0056 (0.0035)	−0.0654*** (0.0204)	0.0148** (0.0074)	0.0909*** (0.0174)	0.9214*** (0.0141)	29.594 [0.4865]	21.325 [0.8774]
JPY	0.0035 (0.0101)	−0.0088 (0.0178)	0.0048** (0.0021)	0.0379*** (0.0093)	0.9513*** (0.0120)	13.065 [0.9969]	22.093 [0.8506]
KRW	−0.0148** (0.0074)	−0.0243 (0.0179)	0.0030*** (0.0009)	0.0787*** (0.0093)	0.9162*** (0.0087)	33.507 [0.3009]	30.654 [0.4325]
MXN	−0.0013 (0.0082)	0.0271 (0.0178)	0.0033*** (0.0012)	0.0940*** (0.0165)	0.9032*** (0.0156)	21.546 [0.8700]	43.508 [0.0528]
NOK	−0.0049 (0.0115)	0.0047 (0.0168)	0.0036** (0.0015)	0.0385*** (0.0051)	0.9561*** (0.0058)	22.041 [0.8525]	14.923 [0.9901]
NZD	0.0210* (0.0122)	0.0099 (0.0161)	0.0059*** (0.0021)	0.0438*** (0.0079)	0.9480*** (0.0086)	30.651 [0.4326]	38.337 [0.1412]
RUB	−0.0010 (0.0038)	0.0266 (0.0186)	0.0290*** (0.0778)	0.1161*** (0.0143)	0.8966*** (0.0103)	20.446 [0.9044]{	35.704 (0.2178)
SEK	−0.0051 (0.0107)	−0.0235 (0.0160)	0.0034*** (0.0012)	0.0379*** (0.0056)	0.9559*** (0.0062)	21.436 [0.8737]	37.028 [0.1763]
SGD	−0.0112** (0.0048)	−0.0093 (0.0172)	0.0924*** (0.0031)	0.0479*** (0.0068)	0.9454*** (0.0070)	38.638 [0.1340]	22.419 [0.8383]
THB	−0.0081 (0.0050)	0.0160 (0.0199)	0.0298*** (0.0097)	0.1116*** (0.0172)	0.8705*** (0.0206)	57.594 [0.0017]	22.562 [0.8328]
TWD	−0.0058* (0.0035)	−0.0296 (0.0201)	0.0761** (0.0318)	0.0843*** (0.0173)	0.9146*** (0.0163)	58.846 [0.0012]	35.107 [0.2995]
ZAR	0.0013 (0.0160)	0.0121 (0.0168)	0.0117*** (0.0042)	0.0553*** (0.0089)	0.9356*** (0.0106)	26.942 [0.6262]	34.075 [0.2778]
Panel B: 2nd Step DECO							
	ρ	*a*	*b*	Student-df	Log *L*	AIC	BIC
	0.0256*** (0.0045)	0.0132*** (0.0038)	0.9816*** (0.0054)	5.6006*** (0.1098)	−81993	43.7842	43.9902

Notes: Q(30) and $Q^2(30)$ are the Ljung-Box test statistic applied to the standard residuals and the squared standardized residuals, respectively. The ρ coefficient is the dynamic equicorrelation coefficient. The p-values are reported in the brackets [.]. The standard error values are reported in the parentheses (.). The asterisks ** and *** indicate significance at the 5% and 1% levels, respectively.

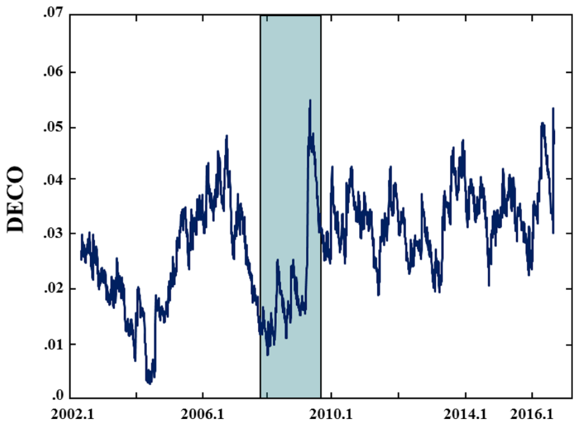

Fig. 1. Dynamic equicorrelation between the four precious metals and 20 currency markets. Note: The shaded area denotes the recent U.S. recession as defined by the NBER during the period 11/23/2007–5/22/2009.

Ruble (RUB), Singaporean Dollar (SGD), Thailand Baht (THB), Taiwan Dollar (TWD), South African Rand (ZAR).[3] Gold and silver futures are both traded on the Chicago Mercantile Exchange (CME), while platinum and palladium are traded on the New York Mercantile Exchange (NYMEX). The sample spans the period from January 3, 2000 to May 6, 2016 and covers several major economic and political events. The data are extracted from Datastream. The synchronization of the return series data is important to better understand the relationship among international markets when daily data is used. For this aim, we have synchronized data before our empirical exercise in order to avoid biases from time zone differences between the considered markets (that is, non-synchronous trading and short-term correlations from noise).

We calculate the continuously compounded daily returns by taking the difference in the log values of two consecutive prices. Table 1 provides the statistical properties for the considered returns series. Among the precious metal markets, gold yields the highest average return followed by silver, platinum and palladium. Silver is the highest volatile market, while gold is the least volatile. For currencies, the Mexican foreign exchange rate presents the highest returns, while that of Switzerland exhibits the lowest average returns. The South Africa currency market is the highest volatile, while that of Taiwan is the least volatile.

The skewness and kurtosis results show asymmetric and fat tails. In addition, the Jarque Bera test strongly rejects the hypothesis of normal distribution. We apply the Dickey and Fuller (1979), Phillips and Perron (1988) unit root tests and the Kwiatkowski, Phillips, Schmidt, and Shim (1992) stationarity test to check the stationarity/unit roots for selected precious metals and currency returns. The results indicate that all return series are stationary. We also check the presence of serial correlation in the residuals up to the 30th lag value (Box-Pierce Q(30) and $Q^2(30)$ tests) and the ARCH effect in the return series by applying the ARCH LM test. The results highlight the presence of both serial correlation and the ARCH effect in all cases. These results motivate us to extend our analysis by modeling the GARCH family models for both the precious metals and the FX spot rates under consideration.

Table 2 reports the unconditional correlations between the precious metal returns and the FX spot rates of the considered countries. The four precious metal markets exhibit a negative correlation with the FX spot rates for all cases with the exception of Australia, Eurozone, UK and New Zealand. This finding implies a presence of ample diversification opportunities for investors which seek to construct a portfolio consisting of precious metals and the currencies markets.

4. Empirical analysis

4.1. Results of the marginal model

The results of the DECO-GARCH (1,1) model between the precious metal and the foreign exchange markets are presented in Table 3.[4] Panel A reports the statistics for the univariate GARCH (1,1) model. The autoregressive parameter of the mean equation is statistically significant only for gold and for the FX spot rates of Brazil, Korea, New Zealand, and Singapore, suggesting an adjustment of past information to current return values. The components of the ARCH and the GARCH effects (see the variance equation) are statistically significant and indicate that all return series are persistent. The Ljung-Box test results of the standardized residuals and the standardized square residuals up to the 30th lag value (see the diagnostic tests) do not reject the null hypothesis of no serial correlation, and thus they provide no evidence of misspecification in our model.

The equicorrelation value results (Panel B) present a low value of the correlation (i.e. 0.025), indicating the presence of higher diversification opportunities between the precious metals and FX spot returns. The short-run parameter (a) is significant and highlights the presence of shocks between the FX spot and precious metal returns. Further, the long-run coefficient (b) possesses a

[3] The exchange rates are defined as the price of the dollar against that of a domestic currency (i.e., USD/local currency).

[4] This study considers different GARCH models with different combinations of the lag parameters for the values ranging from a lag zero to a maximum lag of 2. The best GARCH model that fits our series has the minimum Akaike information criteria (AIC) value.

Table 4
Total volatility spillovers.

	Gold	Silver	Palladium	Platinum	AUD	BRL	CAD	CHF	DKK	EURO	GBP	IDR
Gold	43.48	17.97	4.6	10.28	0.58	0.32	0.54	0.45	2.44	2.42	1.45	0.8
Silver	16.65	44.04	5.27	8.87	2.29	0.26	2.01	0.42	2.17	2.18	0.83	1.16
Palladium	5.23	6.96	56.66	14.75	1.28	0.27	2.29	0.18	1.47	1.43	0.43	0.28
Platinum	7.2	7.18	12.33	53.05	0.98	0.32	1.36	0.23	1.65	1.67	0.96	0.52
AUD	1.43	1.45	0.38	1.3	27.52	8.85	6.17	0.21	3.09	3.09	1.79	0.03
BRL	1.27	0.31	0.14	0.6	11.93	47.82	3.75	0.04	1.38	1.32	0.71	0.05
CAD	0.85	1.68	1.47	1.07	12.71	4.03	28.33	0.46	4.8	4.81	2.23	0.3
CHF	0.74	0.37	0.26	0.23	0.26	0.09	0.47	77.1	6.33	6.48	0.18	0
DKK	1.68	1.25	0.68	1.26	2.43	1.09	4.81	1.96	22.63	22.48	2.57	0.06
EURO	1.65	1.24	0.66	1.26	2.5	1.14	4.75	1.97	22.41	22.49	2.7	0.05
GBP	1.92	0.64	0.27	0.9	3.67	1.1	3.56	0.18	6.5	6.73	43.95	0.01
IDR	1.04	1.54	0.15	2.02	3.33	2.42	0.72	0	0.26	0.29	0.49	80.77
INR	0.58	0.24	0.08	1.25	1.15	0.41	0.61	0.03	0.74	0.75	0.29	0.03
JPY	2.12	0.65	0.26	1.84	9.08	3.03	0.97	0.18	4.81	4.9	5.08	0.43
KRW	1.33	0.76	0.35	1.97	23.78	8.09	1.94	0.07	1.22	1.28	1.42	0.14
MXN	1.18	0.37	0.23	0.68	15.44	11.87	3.62	0.07	0.97	0.96	1.19	0.1
NOK	2.7	1.62	0.54	2.09	3.67	1.47	5.26	0.69	12.9	12.8	3.29	0.01
NZD	1.75	1.76	0.61	1.37	16.83	4.74	5.42	0.51	5.56	5.57	2.63	0
RUB	0.11	0.2	0.03	0.06	0.03	0.05	0.21	1.42	0.27	0.27	0.07	0.05
SEK	1.62	1.4	0.84	1.44	4.42	1.31	7.13	0.63	12.81	12.78	3.07	0.18
SGD	1.6	1.64	0.55	1.43	3.94	2.62	4.69	1.07	7.14	7.34	1.24	0.27
THB	0.32	0.22	0.01	0.07	0.22	0.06	0.31	0.01	0.18	0.17	0.05	0.23
TWD	0.31	0.44	0.05	0.57	0.58	0.44	1.28	0.59	2.64	2.77	0.92	0.1
ZAR	1.39	1.51	1.21	1.83	10.12	5.74	6.92	0.27	3.65	3.61	2.37	0.05
To	54.7	51.4	30.9	57.2	131.2	59.7	68.8	11.6	105.4	106.1	36	4.9
All	98.2	95.4	87.6	110.2	158.8	107.6	97.1	88.7	128	128.6	79.9	85.6
Net	−1.8	−4.6	−12.4	10.3	58.7	7.5	−2.9	−11.3	28	28.6	−20	−14.3

(*continued on next page*)

Table 4 (*continued*)

	INR	JPY	KRW	MXN	NOK	NZD	RUB	SEK	SGD	THB	TWD	ZAR	**From**
Gold	0.63	1.77	1.19	0.28	3.78	1.62	0.04	2.16	1.85	0.17	0.07	1.13	56.5
Silver	0.51	0.81	0.01	0.53	2.63	3.07	0.03	2.57	2.29	0.12	0.15	1.12	56
Palladium	0.29	0.36	0.06	0.41	1.24	1.72	0.03	1.82	0.72	0.06	0.01	2.05	43.3
Platinum	1.29	0.68	0.24	0.67	2.28	1.76	0.02	2.28	1.65	0.17	0.05	1.45	46.9
AUD	0.32	5.77	0.05	11.51	3.45	17.8	0.01	2.73	1.34	0.11	0.1	1.49	72.5
BRL	0.21	2.25	0.15	16.19	1.43	6.73	0.01	1.21	1.27	0.23	0.12	0.86	52.2
CAD	0.33	1.83	0.21	4.81	5.67	10.5	0.04	6.8	2.82	0.05	0.09	4.12	71.7
CHF	0.01	0.43	0	0.01	1.71	0.89	0.75	2.62	0.59	0.01	0.04	0.42	22.9
DKK	0.27	1.75	0.01	0.69	11.46	4.44	0.1	12.18	3.81	0.04	0.19	2.16	77.4
EURO	0.28	1.82	0.01	0.71	11.36	4.49	0.1	12.14	3.9	0.04	0.2	2.15	77.5
GBP	0.34	5.41	0.19	1.83	6.84	5.22	0.05	5.44	1.38	0.03	0.4	3.48	56
IDR	0.2	1.19	0.54	0.28	0.45	2.14	0.05	0.55	1	0.08	0.08	0.4	19.2
INR	80.73	1.02	2.22	0.6	1.48	1.63	0.04	1.01	3.24	0.22	1.11	0.52	19.3
JPY	0.3	41.68	0.36	2.44	4.85	10.03	0.05	2.73	1.61	0.54	0.29	1.76	58.3
KRW	0.18	5.08	20.91	12.99	1.77	11.94	0.04	0.84	1.92	0.03	0.74	1.21	79.1
MXN	0.21	2.17	0.25	47.06	1.22	7.91	0.03	1.18	1.6	0.02	0.02	1.66	52.9
NOK	0.58	2.67	0.04	1.23	22.36	6.28	0.12	13.08	3.7	0.07	0.35	2.46	77.6
NZD	0.41	5.96	0.03	5	6.02	24.79	0.05	5.35	2.77	0.39	0.12	2.32	75.2
RUB	0.08	0.04	0.08	0.18	0.42	0.03	95.71	0.34	0.26	0	0.01	0.07	4.3
SEK	0.43	1.7	0.27	0.85	12.68	6.32	0.14	24.17	2.95	0.02	0.21	2.61	75.8
SGD	0.97	1.65	1.17	2.59	6.01	5.96	0.08	5.9	33.95	0.48	2.73	5	66
THB	0.16	0.26	0.05	0.15	0.35	0.48	0	0.2	1.24	94.68	0.23	0.33	5.3
TWD	0.48	1.6	0.67	0.41	4.14	1.66	0.04	3.52	6.09	0.26	67.93	2.5	32.1
ZAR	0.2	2.21	0.59	9.92	3.69	7.22	0.02	4.46	3.34	0.18	0.23	29.28	70.7
To	8.7	48.4	8.4	74.3	94.9	119.8	1.8	91.1	51.3	3.3	7.6	41.3	1268.9
All	89.4	90.1	29.3	121.3	117.3	144.6	97.6	115.3	85.3	98	75.5	70.5	**Total:** 52.90%
Net	−10.6	−9.9	−70.7	21.4	17.3	44.6	−2.5	15.3	−14.7	−2	−24.5	−29.4	

Notes: Table 4 presents the results of total volatility spillover matrix. The i^{th} and j^{th} entry in each panel shows the estimated contribution to the forecast-error variance of market i coming from innovations to market j. The row sums excluding the main diagonal elements (termed 'From') and the column sums (termed 'To') present the total spillovers to (received by) and from (transmitted by) each volatility. The evolving net volatility spillover index is computed as the difference between directional 'To' spillovers and directional 'From' spillovers. The positive (negative) values indicate a transmitter (receiver) of return and volatility to (from) others. The underlying variance decomposition is based on a daily VAR of order 4 (as determined by the Schwarz information criterion), identified using a generalized VAR spillover framework as suggested by Diebold and Yilmaz (2012).

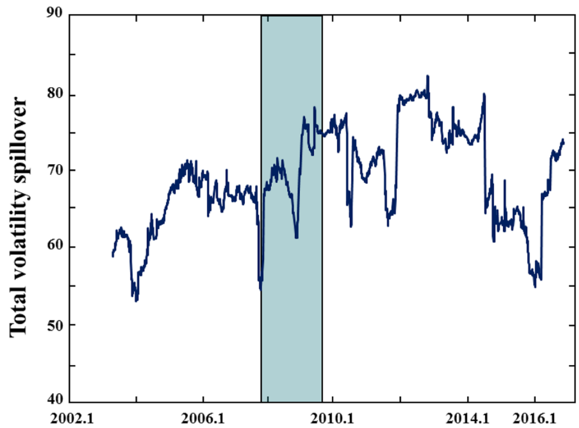

Fig. 2. The dynamics of the total volatility spillover index. Notes: The time-varying volatility spillovers are computed from the forecast error variance decompositions of the 10-step-ahead forecasts. The total spillover indices are estimated using 200-day rolling windows.

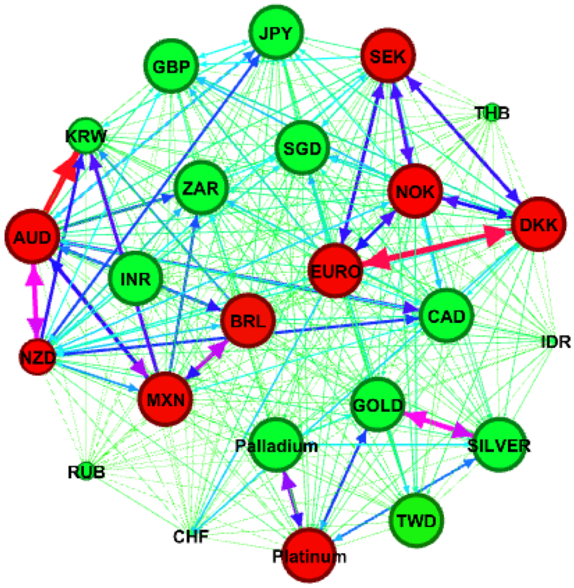

Fig. 3. Volatility network among the precious metals and FX markets.

high significant value of 0.9816 which indicates the presence of a higher persistence in volatility clustering across our sampled precious metals and FX returns. The significance of our short and long run parameters indicates appropriateness of the DECO model and the rejection of the assumption of constant conditional correlations (CCC) for all news to returns.

Fig. 1 shows the plots of the dynamic equicorrelation for the two groups of the precious metal and FX markets. The shaded area denotes the recent U.S. recession as defined by the National Bureau of Economic Research (NBER) during the period 11/23/2007–5/22/2009. As demonstrated, we observe a changing behavior of the dynamic equicorrelation, highlighting the restructuring of the portfolios between the precious metals and FX markets. Although we see a turbulent behavior in this moderate correlation throughout the sample period, the global financial crisis of 2008–09 had moved this correlation to its highest value of 0.055, underscoring the sensitivity of a such dynamic correlation to any extraneous crisis effect. This result supports the recoupling hypothesis (or the contagion effect), which can be particularly visible during periods of turmoil, that in turn diminishes the opportunities of international portfolio diversification for investors.

4.2. Rolling-sample volatility spillover analysis

4.2.1. For the precious metal markets

Table 4 presents the results of the net volatility spillovers, thereby highlighting the volatility spillovers between the precious metal-currency markets. For the sample of the precious metals, gold receives an almost 56.5 percent change from the other markets (palladium, platinum, silver, and 20 spot exchange returns). The Norwegian Krone induces a maximum spillover of 3.78 percent. In

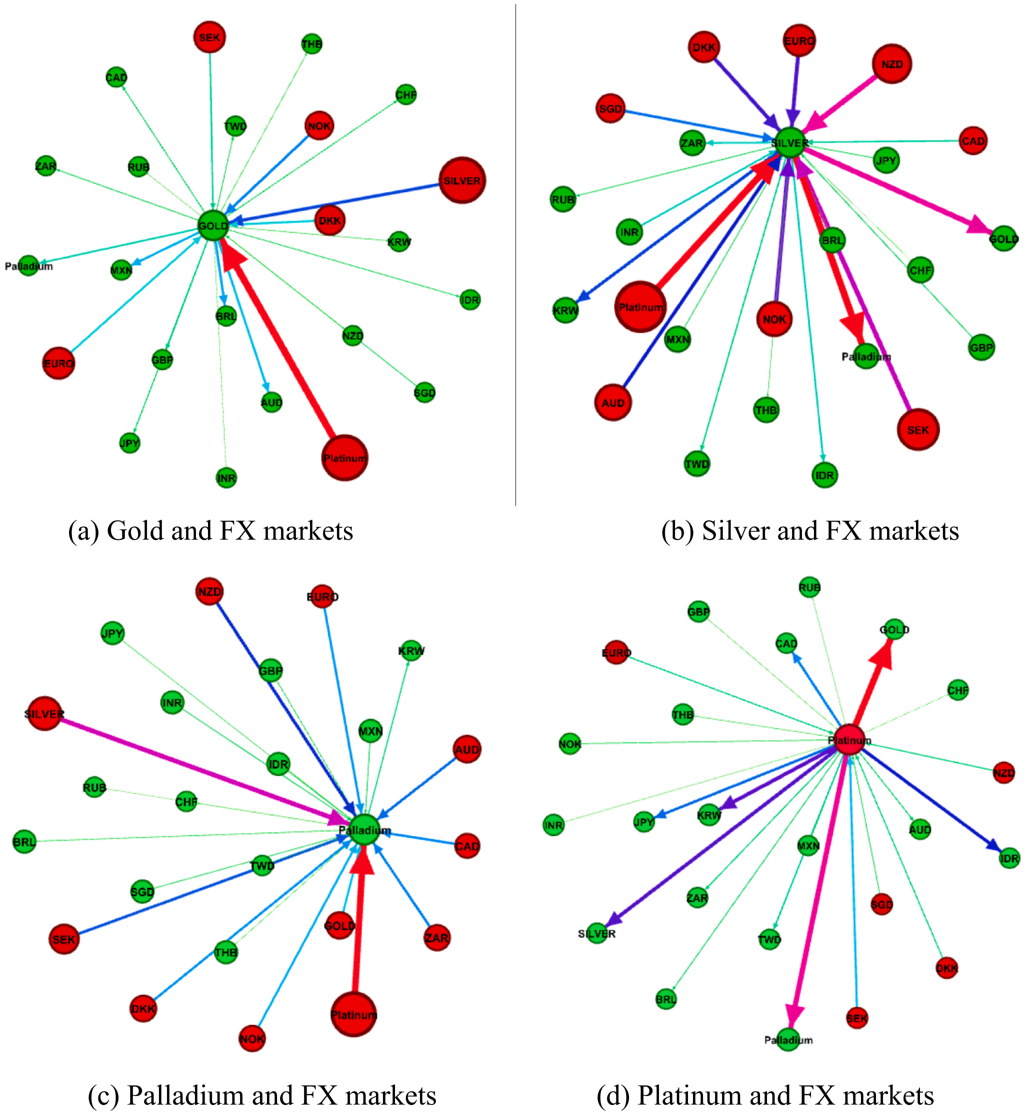

Fig. 4. Net pairwise network from precious metals to FX markets. Notes: This figure shows the net-pairwise directional network connectedness within the precious metals and FX markets. The red (green) color of a node shows the most significant net-pairwise transmitter (receiver) and the size of the node shows the magnitude of the net pairwise directional connectedness. The edge arrow thickness also indicates the strength of the net-pairwise directional connectedness. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

the case of silver, the New Zealand spot rate currency induces a change of 3.07 percent in this gray metal. The Canadian dollar remains at the top in inducing a maximum change of 2.29 percent in Palladium, while the Norwegian currency transmits a 2.28 percent change to the error forecast variance of platinum. More importantly, the platinum (palladium) market is the strongest (weakest) receiver of risk from the other precious metals and currency markets.

Gold and platinum induce, respectively, a change of a 2.7 and 2.09 percent in the Norwegian Krona, which suggests that the spillover effect between the Norwegian FX market and gold is bidirectional. Silver transmits a change of 1.76 percent towards the New Zealand FX market. Palladium induces a change of 1.47 percent in the Canadian FX returns.

4.2.2. For the foreign exchange markets

For the sample of foreign exchange markets, gold remains in the top position as a transmitter of risk to eleven out of the eighteen FX spot returns (i.e., Brazil, Switzerland, Denmark, Eurozone, UK, Mexico, Japan, Norwegian, New Zealand, Swedish, and Thailand). Among the precious metals, silver transmits the maximum spillover towards the AUD, CAD, NZD, RUB, SGD, and TWD spot returns. The Indonesia, Korea, India, and South Africa FX markets receive more shocks from the platinum market. Among all the currencies, the Australian dollar remains the dominant transmitter of shocks towards the remaining markets, while the Russian markets is the

Table 5
Risk evaluations for different Gold-FX portfolios.

	Portfolio	AUD	BRL	CAD	CHF	DKK	EURO	GBP	IDR	INR	JPY
RiskRed.	PII	0.86645	**0.98556**	0.73517	0.91025	0.67240	0.82012	0.81991	**0.99562**	**0.84888**	**0.71497**
	PIII	0.10794	0.00693	0.00367	0.00387	0.01903	0.00248	0.00357	0.77158	0.11896	0.24036
	PIV	**0.96530**	0.98274	**0.96280**	**0.96648**	**0.92507**	**0.96764**	**0.97063**	0.61647	0.71284	0.03837
VaRRed.	PII	0.01200	**0.02640**	0.01067	0.00853	0.00640	0.01440	0.01440	**0.01560**	**0.01867**	**0.05060**
	PIII	**0.01387**	0.01387	**0.01387**	0.01387	0.01387	0.01387	0.01387	0.00720	0.01360	0.01360
	PIV	0.00453	0.00181	0.00586	**0.04427**	**0.04187**	**0.03787**	**0.04081**	0.00906	0.00213	0.00746
SV Red.	PII	0.05630	**0.04979**	0.02552	0.03246	0.01902	0.03604	0.03595	**0.11246**	**0.03820**	**0.01880**
	PIII	0.00715	0.00709	0.00713	0.00712	0.00701	0.00714	0.00713	0.01291	0.00621	0.00543
	PIV	**0.14759**	0.03257	**0.12226**	**0.11968**	**0.05571**	**0.14359**	**0.42434**	0.02366	0.00760	0.00503
ReRed	PII	0.02373	**0.07518**	0.01603	0.01795	0.01359	0.01901	0.01900	**0.08647**	**0.01988**	**0.01361**
	PIII	0.00852	0.00851	0.00852	0.00850	0.00843	0.00854	0.00852	0.00364	0.00798	0.00741
	PIV	**0.03654**	0.05084	**0.03392**	**0.03326**	**0.02354**	**0.03621**	**0.03591**	0.00493	0.00876	0.00705
	IDR	KRW	MXN	NOK	NZD	RUB	SEK	SGD	THB	TWD	ZAR
RiskRed.	PII	**0.68997**	**0.94267**	0.80936	0.86933	**0.94533**	0.80111	0.39812	**0.84653**	**0.73517**	0.94076
	PIII	0.61081	0.03201	0.02129	0.00126	0.08011	0.02408	0.00438	0.09172	0.08058	0.02723
	PIV	0.62668	0.92173	**0.93513**	**0.96625**	0.64394	**0.92828**	**0.96265**	0.75796	0.56069	**0.94858**
VaRRed.	PII	0.04534	**0.07522**	0.01680	0.01440	**0.02640**	0.01173	0.01867	**0.02427**	**0.02293**	**0.02000**
	PIII	**0.05014**	0.05814	0.01707	0.01733	0.01707	0.01707	0.01707	0.01707	0.01707	0.01707
	PIV	0.04081	0.02640	**0.02800**	**0.02267**	0.01600	**0.02027**	**0.02213**	0.00266	0.00426	0.01093
SV Red.	PII	**0.01062**	**0.08336**	0.03241	0.04595	**0.01271**	0.03098	0.01162	**0.03105**	**0.01757**	**0.10564**
	PIII	0.00191	0.00760	0.00698	0.00707	0.00656	0.00698	0.00712	0.00651	0.00658	0.00696
	PIV	0.00164	0.05695	**0.06333**	**0.13878**	0.01173	**0.05647**	**0.09882**	0.01143	0.00886	0.08481
ReRed	PII	**0.01018**	**0.02816**	0.01788	0.02133	**0.01127**	0.01753	0.01083	**0.01789**	**0.01331**	**0.03297**
	PIII	0.00433	0.00834	0.00839	0.00850	0.00817	0.00840	0.00855	0.00811	0.00817	0.00842
	PIV	0.00404	0.02369	**0.02450**	**0.03630**	0.01089	**0.02359**	**0.01707**	0.01051	0.00936	0.02812

Notes: This table reports the results of risk-reduction effectiveness and downside risk gains for portfolios composed of the currency and precious metal futures with respect to the reference portfolio composed exclusively of the currency. Portfolio II is a risk-minimizing currency-precious metal portfolio, Portfolio III has equal weights and Portfolio IV whose weights are determined according to a variance minimization hedging strategy). The VaR Red.is the reduction in the VaR portfolio with respect to Portfolio I (where positive values indicate a VaR reduction). ES is the expected shortfall while SV Red and Re Red are respectively the semi variance and the regret reduction. The bold values indicate the portfolio that has the best risk reduction among the three portfolios for each FX-precious metal pair.

lowest transmitter of risk towards the rest of the markets.

As transmitters of shocks to the precious metals, Denmark, Euro, UK, Indonesia, Japan, Korea, Norwegian and Thailand currency markets are active throughout our sample period and transmitted the maximum change to gold. In the case of silver, the AUD, CAD, CHF, IDR, NZD, SEK, SGD, and TWD transition of change to this grey metal. Palladium remains isolated from any major spillover and no currency acts as a transmitter of change to it. However, platinum receives spillovers from BRL, INR, MXN, THB, and ZAR. More importantly, we conclude that the developed currency markets of Asia and Europe are more influential towards the daily returns of gold, whereas the American currency market (including Canada) acts as a major transmitter to silver. Palladium shows insensitivity to any FX spot rate changes, but platinum shows sensitivity of the FX spot rates only.

The row of Table 4 presents the net effect of the transmission and reception of information for all sampled precious metals and FX spot markets. We see that, except the platinum which acts as a net transmitter of change, all the precious metals exhibit the property of a net receiver of change. Among the currencies, Australia, Brazil, Denmark, Eurozone, Mexico, Norwegian, New Zealand, and Swedish currency markets exhibit the property of a net transmitter of change, while the remaining FX markets are net receivers of risk. Taking the case of the Australian currency, the Australian economy is a net exporter of gold, and this precious metal constitutes a significant percentage of its national exports, making the value of the Australian dollar susceptible to fluctuations in gold prices. The UK currency is a net receiver of risk from other foreign exchange and precious metal markets.

Fig. 2 highlights the time-varying volatility spillover underscoring that the spillover remains consistent and at a moderate level from the start until the financial crisis period of 2008–09. However, we see a sharp drop in the total volatility spillover index during the 2008–09 financial crisis period where the foreign exchange transaction costs increased substantially, followed by a consistent turbulence in volatility transmission thereafter. This result may be due to the investor reactions by hedging their risk exposure using the appropriate risk control strategy (including safe haven assets in portfolios) and legislative and regulatory reactions by establishing

Table 6
Risk evaluations for different Silver-FX portfolios.

	Portfolio	AUD	BRL	CAD	CHF	DKK	EURO	GBP	IDR	INR	JPY
RiskRed.	PII	**0.74752**	**0.69045**	**0.76857**	**0.41362**	0.36686	**0.74788**	**0.93501**	**0.99574**	**0.94852**	**0.91267**
	PIII	0.63960	0.27541	0.16810	0.16381	0.51127	0.14430	0.18416	0.91625	0.56047	0.90621
	PIV	0.41609	0.44088	0.10440	0.38774	**0.91477**	0.10038	0.53555	0.89840	0.91859	0.76296
VaRRed.	PII	**0.02213**	**0.02427**	**0.02187**	**0.02160**	0.01893	0.01893	0.01867	**0.01813**	**0.02002**	**0.02293**
	PIII	0.02107	0.02053	0.01893	0.01067	0.01013	0.01493	0.01467	0.01653	0.01227	0.01781
	PIV	0.01520	0.00400	0.01333	0.01493	**0.01973**	**0.02213**	**0.02213**	0.00240	0.01440	0.01493
SV Red.	PII	**0.03469**	**0.08075**	**0.02597**	**0.02962**	**0.21943**	**0.02595**	**0.02848**	**0.05449**	**0.02703**	**0.07900**
	PIII	0.02071	0.01651	0.01871	0.01912	0.10716	0.01955	0.01841	0.00131	0.00151	0.00237
	PIV	0.01204	0.00773	0.00413	0.00704	0.00205	0.00509	0.02399	0.00193	0.00088	0.00234
ReRed	PII	**0.01856**	**0.02874**	**0.01611**	**0.01705**	**0.01491**	**0.01600**	0.01729	**0.16212**	**0.01664**	**0.02861**
	PIII	0.01452	0.01296	0.01383	0.01393	0.01035	0.01398	0.01357	0.00381	0.00389	0.00236
	PIV	0.01094	0.00875	0.00642	0.00841	0.00454	0.00711	**0.04653**	0.00440	0.00297	0.00483

		IDR	KRW	MXN	NOK	NZD	RUB	SEK	SGD	THB	TWD	ZAR
RiskRed.	PII	**0.96591**	**0.89764**	**0.86172**	**0.32259**	0.50542	**0.86992**	**0.90334**	**0.96603**	**0.97863**	**0.73892**
	PIII	0.88227	0.69658	0.54491	0.07749	0.81065	0.57665	0.19611	0.56468	0.11302	0.59678
	PIV	0.87593	0.51021	0.58046	0.01381	**0.83604**	0.64195	0.26414	0.87850	0.86988	0.61451
VaRRed.	PII	**0.01733**	**0.01893**	**0.01760**	**0.02267**	**0.01760**	**0.01867**	**0.02240**	**0.01973**	**0.02001**	**0.01920**
	PIII	0.01333	0.01707	0.01707	0.01707	0.01680	0.01867	0.01200	0.01360	0.02000	0.01813
	PIV	0.01147	0.00693	0.01413	0.01493	0.01413	0.01333	0.02001	0.01840	0.01787	0.01013
SV Red.	PII	**0.34631**	**0.02213**	**0.14783**	**0.03425**	**0.03312**	**0.02165**	**0.02428**	**0.03187**	**0.02391**	**0.02029**
	PIII	0.00164	0.00664	0.00983	0.02104	0.00354	0.00911	0.01814	0.00238	0.00251	0.00909
	PIV	0.00185	0.00189	0.00325	0.01529	0.00177	0.00312	0.00138	0.00066	0.00045	0.00613
ReRed	PII	**0.05319**	**0.01489**	**0.01548**	**0.01841**	**0.01807**	**0.01471**	**0.01566**	**0.01787**	**0.01547**	**0.01425**
	PIII	0.00408	0.00815	0.01472	0.01462	0.00599	0.00953	0.01366	0.00490	0.00504	0.00953
	PIV	0.00430	0.00431	0.00571	0.01235	0.00444	0.00557	0.00370	0.00256	0.00211	0.00784

Notes: See the notes of Table 5.

financial and economic reforms. The US has passed the Dodd-Frank Wall Street Reform and Consumer Protection Act in July 2010.[5]

Fig. 3 presents the network diagram highlighting the transmission and the reception of the volatility spillover between the four precious metals and twenty U.S. foreign exchange rate returns. The graphical observation shows that one precious metal (platinum) and eight currencies for Australian, Brazil, Denmark, European, Mexican, New Zealand, Norwegian, and Swedish act as a strong transmitter of spillover to other precious metal and currency markets. It is worth noting that the magnitude of the spillover is low towards the precious metals than to the other currency markets. Gold, silver and palladium act as receivers of spillovers from currency markets, while platinum which acts as a transmitter of shocks. The platinum, the most expensive metals, contributes to the risk of the remaining precious metals (gold, silver and palladium) and the foreign exchange rates more than it receives. It is worth noting that the considered four precious metals are not from the same class, thus having divergent abilities in the hedging risk function.

Note: The size of a node shows the magnitude of a net transmission/reception To or From other variables. The red (green) color of a node shows the most significant transmitter (receiver). The edge size shows the magnitude of the pair-wise spillover, while the edge magnitude is also reflected through the color type (green (weak), light blue (medium), blue and red (strong)).

4.3. Net-pairwise volatility spillover

We present the results of the net pairwise spillover of the precious metals with all the FX spot markets in Fig. 4. Gold exhibits the property of an active receiver of risk from the platinum, silver and currency markets of Norwegian, Swedish, Denmark and Eurozone. The gold itself acts as a transmitter of spillover towards the remaining currency markets as well as the palladium market. However, the magnitude of these interconnectivities is low. Compared with gold, silver, the most volatile precious metal market, acts as a more active receiver of risk from only the platinum precious metal market. Eight out of the twenty currencies transmit risk to silver (see the red node) with low magnitude. Palladium also exhibits its role as a receiver of risk from all precious metal market returns with different magnitude. More precisely, platinum is the most transmitter of risk to its cousin palladium followed by silver and gold. For currencies, AUD, CAD, ZAR, NOK, DKK, SEK, NZD, and Euro also transmit volatility towards palladium. Moreover, platinum among

[5] For more information see http://www.ftijournal.com/article/the-impact-of-global-financial-reforms and https://corpgov.law.harvard.edu/2010/11/20/the-financial-panic-of-2008-and-financial-regulatory-reform/.

Table 7
Risk evaluations for different Pallidum-FX portfolios.

	Portfolio	AUD	BRL	CAD	CHF	DKK	EURO	GBP	IDR	INR	JPY
RiskRed.	PII	0.20828	0.87032	0.20459	0.60922	0.17885	0.18455	0.28474	**0.99055**	0.31973	0.10134
	PIII	0.32422	0.01644	0.00817	0.07774	0.03862	0.06962	0.18416	0.91899	0.24210	0.39902
	PIV	**0.86614**	**0.94368**	**0.87741**	**0.90050**	**0.60359**	**0.87256**	**0.70499**	0.89456	**0.78339**	**0.87021**
VaRRed.	PII	0.01733	0.00320	0.01227	0.01653	0.01680	0.01627	**0.02187**	**0.02400**	**0.01973**	**0.01913**
	PIII	0.01920	0.01413	0.01413	**0.01920**	0.01867	0.01720	0.02053	0.01600	0.01840	0.01840
	PIV	**0.01973**	**0.01893**	**0.01947**	0.01867	**0.01930**	**0.01973**	0.01360	0.01707	0.01387	0.01547
SV Red.	PII	0.03877	0.15724	0.02876	0.03423	0.02761	0.02776	**0.02863**	**0.01585**	**0.03217**	**0.02589**
	PIII	0.02368	0.02279	0.02291	0.02301	0.02233	0.02294	0.01841	0.00133	0.01768	0.01402
	PIV	**0.18267**	**0.22813**	**0.14053**	**0.15527**	**0.03817**	**0.13787**	0.00465	0.00191	0.00204	0.00295
ReRed	PII	0.01966	0.04013	0.01681	0.01824	0.01649	0.01655	**0.01682**	**0.10134**	**0.01761**	**0.01591**
	PIII	0.01528	0.01513	0.01518	0.01518	0.01495	0.01525	0.01357	0.00371	0.01335	0.01188
	PIV	**0.04275**	**0.04484**	**0.03701**	**0.03923**	**0.01971**	**0.03716**	0.06818	0.00439	0.00454	0.00541
	IDR	KRW	MXN	NOK	NZD	RUB	SEK	SGD	THB	TWD	ZAR
RiskRed.	PII	0.57498	0.49133	0.37018	0.45436	**0.66528**	0.49089	0.39682	0.39156	0.42777	0.67516
	PIII	0.87183	0.07548	0.04404	0.03379	0.17580	0.05046	0.09882	0.19137	0.17335	0.56326
	PIV	**0.87334**	**0.51256**	**0.67589**	**0.90789**	0.28003	**0.61000**	**0.84352**	**0.71666**	**0.78093**	**0.71275**
VaRRed.	PII	**0.01900**	**0.02133**	0.01840	0.01950	**0.02107**	0.01760	0.01760	**0.01867**	**0.02053**	**0.02427**
	PIII	0.01787	0.01947	**0.01893**	0.01820	0.01867	**0.01920**	0.01920	0.01920	0.01947	0.01947
	PIV	0.01307	0.00906	0.01760	**0.02027**	0.00880	0.01893	**0.02267**	0.00746	0.00826	0.01840
SV Red.	PII	**0.03478**	**0.04112**	0.03316	0.03802	**0.05611**	0.03096	0.02365	**0.03316**	**0.02449**	**0.05751**
	PIII	0.00251	0.02143	0.02231	0.02313	0.01929	0.02198	0.02266	0.01879	0.01929	0.02193
	PIV	0.00174	0.02122	**0.04707**	**0.19933**	0.00543	**0.03884**	**0.08514**	0.00280	0.00202	0.05225
ReRed	PII	**0.03439**	**0.04102**	0.01801	0.01926	**0.02377**	0.01785	0.01539	**0.01825**	**0.01573**	**0.02398**
	PIII	0.00251	0.02151	0.01498	0.01528	0.01397	0.01492	0.01516	0.01379	0.01397	0.01485
	PIV	0.01307	0.02106	**0.02160**	**0.04418**	0.00748	**0.01967**	**0.02887**	0.00530	0.00451	0.02285

Notes: See the notes of Table 5.

all the precious metals acts as a major receiver of risk from all the precious metal markets and transmit risk only to four currencies (Euro, New Zealand, Swedish, Denmark, and Singapore).

5. Portfolio design and hedging strategy analysis

Using the results in Section 4, we assess the usefulness of the four precious metals for portfolio risk management by comparing the risks for three different portfolios against the benchmark portfolio (Portfolio I) composed of currencies. We can evaluate the potential reduction in the portfolio risk by including precious metal in the expanded portfolios of Portfolio I. First, to minimize risk without reducing expected returns, we consider the extended risk-minimizing portfolio composed of the currency-precious metals futures (denoted as Portfolio II). To do this, we assume an investor is holding a set of precious metal assets and wishes to hedge the position against unfavorable effects by including FX returns. Second, we consider a portfolio where the weights are exogenously determined (denoted as Portfolio III), that is, an equally weighted portfolio. Finally, we consider a portfolio whose weights are determined according to a variance-minimization hedging strategy (Portfolio IV). This is a hedged portfolio obtained from a variance-minimization hedging strategy constructed by holding a short position in a beta precious metal and a long position in the currency spot market. For mathematical specifications, the reader can refer to Mensi, Hammoudeh, and Kang (2015).

Table 5 presents the results of risk evaluations at the 1 percent significance level for gold and currency markets returns. The Risk Red statistics suggest that the optimally weighted Portfolio II and Portfolio IV (based on variance-minimization hedging strategy) helps the investor in reducing risk and downside risk, compared to equally weighted portfolios.

For example, Portfolio IV reduces risk at the significant levels by including gold with the North American, European and Australian FX markets (i.e., AUD, CAD, CHF, DKK, EURO, GBP, NOK, NZD, SEK, SGD, and ZAR). The VaR Red measure highlights a reduction in the VaR portfolio, compared to the benchmark Portfolio I. The Indonesian currency markets present the highest risk reduction by including gold compared to the remaining currencies. The downside risk measures (semi variance, regret and value at risk) yields results similar to the risk reduction effectiveness of portfolios by including gold with currency, however, excluding the South African FX spot market returns.

Table 6 reports results of downside risk measures for silver with currency markets in a set of portfolios. The Risk Red statistics are similar to the results like those of gold except for the major European and South African markets. More precisely, all currency markets combined with the silver exhibit a reduced risk for optimally diversified portfolio (i.e., Portfolio II) except for the Danish Krone and Russian ruble yielding the best risk reductions for Portfolio IV that is based on the variance- minimization hedging strategy. Silver

Table 8
Risk evaluations for different Platinum-FX portfolios.

	Portfolio	AUD	BRL	CAD	CHF	DKK	Euro	GBP	IDR	INR	JPY
RiskRed.	PII	0.68177	0.96809	0.54906	0.88269	0.52929	0.53082	0.73409	**0.99177**	**0.72124**	**0.55647**
	PIII	0.26432	0.05173	0.25040	0.02333	0.12307	0.01934	0.02599	0.84864	0.09086	0.16630
	PIV	**0.94288**	**0.98051**	**0.99432**	**0.95760**	**0.91094**	**0.94891**	**0.95680**	0.76021	0.60087	0.24082
VaRRed.	PII	**0.02053**	**0.02960**	0.01947	0.01307	0.01307	0.01280	0.01867	0.00026	**0.01707**	**0.01627**
	PIII	0.01947	0.01947	0.01360	0.00266	0.01280	0.01280	0.01947	0.01627	0.01280	0.01360
	PIV	0.01307	0.00453	**0.02080**	**0.02107**	**0.01520**	**0.01520**	**0.01947**	**0.01707**	0.00373	0.01200
SV Red.	PII	0.04302	**0.40064**	0.02333	0.03269	0.02149	0.02138	0.03027	**0.55417**	**0.03139**	**0.02128**
	PIII	0.01165	0.01168	0.01163	0.01163	0.01152	0.01165	0.01164	0.00128	0.01054	0.00983
	PIV	**0.15714**	0.29197	**0.14121**	**0.14545**	**0.07822**	**0.13758**	**0.15392**	0.00216	0.00912	0.00596
ReRed	PII	0.02069	**0.06357**	0.01524	0.01799	0.01460	0.01463	0.01734	**0.07439**	**0.01779**	**0.01455**
	PIII	0.01084	0.01078	0.01081	0.01082	0.01074	0.01083	0.01081	0.00358	0.01032	0.00993
	PIV	**0.03959**	0.05389	**0.03757**	**0.03805**	**0.02796**	**0.03700**	**0.03918**	0.00464	0.00954	0.00772

	IDR	KRW	MXN	NOK	NZD	RUB	SEK	SGD	THB	TWD	ZAR
RiskRed.	PII	0.28953	0.84936	0.70022	0.76736	**0.89294**	0.68120	0.21440	**0.77150**	0.30775	0.89735
	PIII	0.71871	0.25304	0.14423	0.09227	0.06551	0.16192	0.02938	0.26432	0.05869	0.20404
	PIV	**0.74594**	**0.92360**	**0.92206**	**0.95514**	0.81597	**0.91365**	**0.95275**	0.72183	**0.60727**	**0.93648**
VaRRed.	PII	**0.01680**	0.00640	0.01467	0.01813	**0.02747**	0.01813	0.01787	**0.01973**	**0.02293**	0.01147
	PIII	0.01600	0.01947	0.01947	0.01947	0.01920	0.01947	0.01947	0.01947	0.01973	0.01947
	PIV	0.01307	**0.02880**	**0.02053**	**0.02267**	0.01920	**0.02240**	**0.02720**	0.00266	0.00533	**0.02053**
SV Red.	PII	**0.01019**	0.05659	0.03053	0.03932	**0.04326**	0.02914	0.01431	**0.03153**	**0.01725**	0.08546
	PIII	0.00291	0.01137	0.01149	0.01166	0.01086	0.01145	0.01162	0.01088	0.01093	0.01137
	PIV	0.00165	**0.07077**	**0.08162**	**0.15747**	0.02093	**0.07652**	**0.03431**	0.01427	0.01017	**0.09921**
ReRed	PII	**0.01006**	0.02383	0.01739	0.01979	**0.02929**	0.01695	0.01195	**0.01779**	**0.01315**	0.02920
	PIII	0.00540	0.01067	0.01075	0.01081	0.01047	0.01072	0.01082	0.01047	0.01053	0.01066
	PIV	0.00407	**0.02643**	**0.02855**	**0.03964**	0.01441	**0.02759**	**0.03430**	0.01194	0.01009	**0.03143**

Notes: See the notes of Table 5.

provides the highest risk reduction for Indonesian currency market followed by Australian market.

The value at risk reduction (VaR Red) measure yields similar results like risk reduction effectiveness statistics for all pairs. However, an exception is the combination of silver with euro and GBP FX spot rates (Portfolio IV) which seems to provide the best downside risk reductions. The semi variance and Regret (ReRed) measure results indicate that silver offers a downside risk for currency markets. For Palladium (see Table 7), results show an overall picture of the suitability of portfolio IV in general as the best in offering minimum downside risk as reported by our four measures. This precious metal market offers best risk and downside reductions for the Brazilian market. Regarding the risk evaluation for currency-platinum pairs (Table 8), Portfolio IV remains the most promising in terms of the risk reduction effectiveness compared to the benchmark Portfolio I together with other portfolios (II and III); however, with the exception of Indonesia, India, Japan, Russia and Thailand which exhibit minimum risk for Portfolio II.

To sum up, Portfolio IV offers the best downside risk reduction together with precious metals. More interestingly, gold offers best diversification opportunity compared to the remaining precious metal markets (silver, palladium and platinum).

6. Conclusions

Portfolio diversification has been an important topic of discussion among academic researchers, policy makers and finance, which are also equally interested in the composition of portfolios. The current literature discusses various techniques to combine equities with each other, stocks with bonds and currencies with stocks and bonds, resulting in portfolios yielding better performance for investors. However, the role of precious metals (gold, silver, platinum, and palladium) is sporadically investigated with respect to the formulation of different sets of portfolios that include many exchange rates of economies located in different regions of the world. The precious metals as commodities are considered as active participants in modern portfolio diversification strategies, particularly because of their low correlations with other financial assets and their insensitivity to major financial and economic events. Because of these reasons, those assets are considered as hedgers and/or safe havens for other assets during the periods of extreme market turmoil.

Our paper takes the lead in investigating the role of precious metals along with a broad set of currency markets in the formulation of four portfolio combinations namely a benchmark currency Portfolio (Portfolio I), a risk-minimizing without reducing the expected returns portfolio (Portfolio II), an equally weighted portfolio (Portfolio III), and a variance-minimization hedging strategy (Portfolio IV). We proceed by initially investigating conditional equicorrelations followed by volatility spillovers between the four major precious and 20 currency market returns. We witness significant reception and transmission behaviors of the precious metals and currency markets, implying a network. Finally, we compare different downside risk measures in various combinations of portfolios (i.e., a benchmark currency portfolio, a risk-minimizing precious metals and currency return portfolio, an equally weighted portfolio, and a hedged portfolio).

Our results highlight a weak average conditional equicorrelation between precious metal and currency markets. Furthermore, a moderate correlation is observed during the GFC, thereby indicating diversification opportunities. Using the Diebold and Yilmaz spillover index, only platinum is a transmitter for risk while the rest precious metals are net receivers of risk from a currency and a precious metal. The risk evaluation analysis shows strong evidence of risk reductions and downside risk reductions after the inclusion of precious metals. The variance-minimization hedging strategy portfolio and optimally weighted portfolios reveal the best downside risk reductions. Finally, among four precious metals, gold provides the highest risk reductions and downside risk.

Our paper has important economic implications for precious metal traders, portfolio managers and policy makers. For investors, and portfolio managers this study suggests that they should use precious metals with currency markets in a portfolio that provides the best risk minimization strategy. On the other hand, analysts can provide a comparative analysis for different mixes of portfolios based on the different risk evaluation measures. These measures can guide investors to make optimal portfolio combinations based on the level of risk (i.e., from the inclusion of pure spot markets such as in the benchmark currency portfolio (Portfolio IV) to a combination of assets based on variance-minimization hedging strategy (Portfolio IV) in a given portfolio. The economic implications that can be inferred from this study highlights the role that precious metals combined with certain sets of currency spot markets may play in portfolio diversification and investment protection against the downside risk.

Monetary authorities should watch the platinum market the most as this metal greases the movements (transmission of risks) of the foreign exchange markets and the other precious metals gold, silver and palladium. Central banks and governments can thus implement better policies that can serve as a cushion against net transmitters of risk including platinum and the currency markets of Brazil, Switzerland, Denmark, Eurozone, UK, Mexico, Japan, Norwegian, New Zealand, Swedish, and Thailand), particularly in periods of high inflation and economic and political instability. Further, the directional information on the exchange rate (net receivers and net contributors of risk) can help governments to implement policies in order to monitor their exchange rates and control inflation. To conclude, country size, exchange rate regime, and regular operations in the foreign exchange market are key determinants of risk spillovers between the currency and precious metal markets.

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Appendix A. Supplementary data

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