BANK FOR INTERNATIONAL SETTLEMENTS

BIS Working Papers

No 619

Volatility risk premia and future commodities returns

by José Renato Haas Ornelas and Roberto Baltieri Mauad

Monetary and Economic Department

March 2017 (revised July 2017)

Paper produced as part of the BIS Consultative Council for the Americas Research Network project "The commodity cycle: macroeconomic and financial stability implications"

JEL classification: Q02, G15, G17, F37

Keywords: Commodity predictability, Volatility risk premium, Commodity currencies

BIS Working Papers are written by members of the Monetary and Economic Department of the Bank for International Settlements, and from time to time by other economists, and are published by the Bank. The papers are on subjects of topical interest and are technical in character. The views expressed in them are those of their authors and not necessarily the views of the BIS.

This publication is available on the BIS website (www.bis.org).

© *Bank for International Settlements 2017. All rights reserved. Brief excerpts may be reproduced or translated provided the source is stated.*

ISSN 1020-0959 (print)
ISSN 1682-7678 (online)

Volatility Risk Premia and Future Commodity Returns*

José Renato Haas Ornelas

Banco Central do Brasil

Roberto Baltieri Mauad

Banco Central do Brasil

Abstract

This paper extends the empirical literature on volatility risk premium (VRP) and future returns by analyzing the predictive ability of commodity currency VRP and commodity VRP. The empirical evidence throughout this paper provides support for a positive relationship of commodity currencies VRP and future commodity returns, but only for the period after the 2008 global financial crisis. This predictability survives the inclusion of control variables like equity VRP and past currency returns. Furthermore, gold VRP also has the ability to predict future commodity returns. However, this predictability is restricted to precious metals when control variables are considered.

JEL Classification: Q02, G15, G17, F37.

Keywords: Commodity predictability, Volatility risk premium, Commodity currencies

* This paper was prepared for the 3rd BIS CCA Research Network on "The commodity cycle: macroeconomic and financial stability implications". We would like to thank our discussant Torben Andersen, Robert Vigfusson, Deepa Datta, João Barata Ribeiro Barroso, Emanuel Kohlscheen, Pedro Vallocci, Fabrizio Zampolli and other participants of the BIS CCA Research Network as well as participants of an internal seminar at the Banco Central do Brasil for useful comments. The views expressed in this paper are those of the authors and do not necessarily reflect those of the Banco Central do Brasil.

I. Introduction

Predicting commodity price changes is an important issue for exporting and importing countries as well as for many companies. Given the interdependence of commodity and currency markets in producing countries (Cashin et al. 2004), many forecasting approaches rely on movements of exchange rates. It is well accepted that commodity prices move in the opposite direction of the nominal US Dollar exchange rate against a basket of currencies. Chen et al. (2014) perform factor analysis of 51 commodities and observe that the first common factor is inversely linked to this nominal exchange rate. Chen et al. (2010) find that commodity currencies[1] are able to predict commodity price movements. The explanation is that exchange rates are more forward-looking than commodity prices, so that expectations about future developments of these markets are reflected first in these currencies and later in commodity prices. However, recent papers support reverse causality: from commodities to exchange rates. This is the case of Zhang, Dufour and Galbaith (2016) and Kohlscheen, Avalos and Schrimpf (2016).

Another promising area for forecasting financial asset prices is to track the volatility (or variance) risk premium, i.e., the difference between implied volatility and realized volatility[2]. Bollerslev, Tauchen and Zhou (2009) and Bollerslev et al. (2014) find that the variance risk premium for developed equity markets can predict future equity index returns. Bollerslev, Tauchen and Zhou (2009) also propose a model to explain this result. The intuition of their model is that when risk aversion increases (decreases), equity prices are quickly discounted, resulting in high (low) future returns. Similar patterns can also be found for exchange rates. For instance, Londono and Zhou (2017) and Ornelas (2017) find that the volatility risk premium of exchange rate options can predict currency returns from a time-series perspective, although the empirical results of these papers do not match.

In this paper, we argue that commodities can be viewed as risky assets, so we can apply the model by Bollerslev, Tauchen and Zhou (2009) to commodity returns instead of equity returns. In this case, the intuition is similar: when risk aversion increases (decreases), risky assets (in our case, commodities) are quickly discounted, and later this discount is accrued, leading to high (low) future commodity returns.

This way, we empirically investigate whether several types of volatility risk premium (henceforth VRP) can predict future commodity returns as well as returns of other asset classes. The most straightforward idea is to analyze the use of VRP of commodities to predict commodity returns. However, good quality and readily available data needed to calculate commodity VRPs are only available as of 2007. For this reason, we also analyze the VRP of commodity currencies (henceforth CC), for which we can build longer time-series. Furthermore, this paper compares the predictive ability of these commodity-linked VRPs with those of US equity VRP and non-CC[3] VRP.

Our regression results find a positive and statistically significant relationship between VRP of CC and future commodity index returns, but only for the period after the 2008 global financial crisis. This result holds not only for the main broad spot commodity index, but also for sub-indexes like energy and metals, and also for other asset classes like equities, currencies and corporate bonds. Furthermore, the results hold for forecast periods of up to four months.

[1] The commodity currencies considered are the Australian Dollar, the Canadian Dollar and the New Zealand Dollar. See Chen and Rogoff (2003) for a discussion.

[2] Many papers define volatility risk premium as the realized minus the implied volatility.

[3] We use Euro, British Pound and Yen as our representative set of non-commodity currencies.

Gold VRP is also able to predict future returns of commodities, currencies and equities, with a positive relationship. However, when adding other VRPs as control variables in the regressions, the predictive ability of gold VRP is limited to precious metals.

Oil VRP also shows predictive power, with positive coefficients over future returns, but it is restricted to energy-related commodities. This result contrasts with those of Chevallier and Sevi (2014), who find a negative and statistically significant relationship between oil VRP and future returns. These different results can presumably be attributed to sample differences such as a longer time span and the use of intraday data.

We also perform a multivariate regression using all five VRPs as explanatory variables and the returns of several asset classes as dependent variables. The overall picture of this regression shows the CC and equity VRPs as the best predictors. Gold VRP's predictive ability in this context is confined to precious metals, while the oil VRP coefficients no longer have significance for energy commodities. These results are robust to the inclusion of control variables like the past returns of commodities and currencies.

Overall, this paper contributes to the literature by showing evidence that commodity-linked VRPs can predict future price movements not only of commodities but also of other asset classes. Nevertheless, this evidence is limited to the aftermath of the 2008 global financial crisis. Such predictive ability seems to be linked to varying risk aversion in financial markets.

In the following sections, we describe the VRP calculation method in section 0, and the sample in section 0. Empirical results for CC VRP are in section 0. Section 0 shows results for the gold VRP, while section 0 deals with oil VRP. Section 0 reports a multivariate analysis with all VRPs together. Finally, section 0 concludes the paper.

II. Volatility Risk Premium Calculation

The VRP calculation requires a measure of implied (risk-neutral) volatility of returns and a measure of realized (physical) volatility of returns. The realized volatility can be easily calculated if we have a time series of returns. Bollerslev, Tauchen and Zhou (2009) point out that realized volatility calculated with intraday data can provide better estimates of the true unobserved volatility than traditional measures based on daily data. This paper uses volatility based on 5-minute returns for the currency VRPs and daily returns for the other VRP variables.

The implied volatility can be harder to calculate. One simple way to measure it is just to take the implied volatility of at-the-money (ATM) options. The advantage of this method is the readily available data. Another way is to calculate the risk-neutral (implied) volatility from options with several strikes, and then take the square root. This is called a model-free implied volatility (henceforth MFIV) when no parametric model assumption is made. The VIX index, the most known volatility index, is calculated by CBOE using several options on the S&P500 index, with different strikes. In this paper we use MFIV for the VRP calculations.

To illustrate the calculation of the MFIV, we first present the continuous-strike equation frequently mentioned in the literature (see, for instance, Demeterfi et al., 1999):

$$\mathrm{E}^{\mathbb{Q}}\left[\sigma_{t,t+T}^2\right] = \kappa\left(\int_0^{F_{t,t+T}} \frac{1}{K^2} P_{t,t+T}(K)dK + \int_{F_{t,t+T}}^{\infty} \frac{1}{K^2} C_{t,t+T}(K)dK\right) \tag{1}$$

Where $P_{t,t+T}(K)$ and $C_{t,t+T}(K)$ are the put and call prices with strike price *K* and maturity date $t+T$, $F_{t,t+T}$ is the forward price matching the maturity options' dates; $\kappa = 2\exp\left(i_{t,t+T}(t+T)\right)$; and $i_{t,t+T}$ is the $t+T$-period domestic riskless rate.

As we do not have a continuum of strikes *K*, it is necessary to discretize equation 1. The method to calculate the VIX and other CBOE model-free implied volatility indexes uses the following discretization equation:

$$E^{\mathbb{Q}}\left[\sigma_{t,t+T}^2\right] = \frac{2e^{rT}}{T}\sum_{i=1}^{n}\frac{\Delta K_i}{K_i^2}\theta_{t,t+T}(K_i) - \frac{1}{T}\left[\frac{F}{K_0}-1\right]^2 \qquad (2)$$

Where
n is the number of options available for the calculation;
K_i is the strike of the i_{th} out-of-the-money option (it is a call if $K_i > F$ and a put if $K_i < F$);
K_0 is the first strike below the forward index level, F;
ΔK_i is the interval between previous strike and next strike, calculated as $\Delta K_i = (K_{i+1} - K_{i-1})/2$ (for the highest strike, ΔK_i is the difference for this strike and the second highest, while for the lowest strike, ΔK_i is the difference between second lowest and this strike); and
$\theta_{t,t+T}(K_i)$ is the price of an out-of-the-money option at time *t*, maturing at time *t* + *T*, with strike K_i.

For equity and commodity MFIV, we use the CBOE indexes, so that this formula (2) is used. For currency MFIV, we use essentially the same equation. The only difference is that our OTC (over-the-counter) options data always have a perfect at-the-money option, so that the last term of equation (2) disappears since F is equal to K_0.

The calls and puts that we use for the currency MFIV calculation (either CC or non-CC) are the ATM and those with deltas of 10 and 25. Therefore, we have only five options to calculate the MIFV, so that the discretization in equation (2) has lower precision than popular indexes like the VIX. Unlike exchange-traded options, there are not many strikes far out-of-money to be used to calculate the MFIV in the OTC currency market. This may cause underestimation of the MFIV, as emphasized by Andersen et al. (2015). However, this is the kind of data typically available for currency options. Della Corte et al. (2016), Londono and Zhou (2017) and Ornelas (2017) also use only five strikes when calculating the MFIV for currencies. Furthermore, this underestimation of the MFIV itself may be not an issue if the degree of underestimation does not vary over time, since our goal is to use the VRP for prediction. In fact, Londono and Zhou (2017) and Ornelas (2017) provide empirical results showing that VRPs calculated with MFIV are not much better than ATM implied volatilities for prediction.

In our base case, the period length *T* is one month or 30 calendar days. To adjust the period between implied and realized volatility, we convert both to a monthly basis, considering the actual number of trading days over the next 30 calendar days. When necessary, we consider a conventional measure of 250 working days to convert from annual to daily volatilities.

Having both risk-neutral and physical measures, one can calculate the volatility risk premium. Ideally, the volatility risk premium should be the difference of a risk-neutral measure $E^{\mathbb{Q}}[\sigma]$ and an expected physical measure $E^{\mathbb{P}}[\sigma]$, both for the same period:

$$VRP_t = E^{\mathbb{Q}}\left[\sigma_{t,t+T}\right] - E^{\mathbb{P}}\left[\sigma_{t,t+T}\right] \qquad (3)$$

Although the risk-neutral volatility can be estimated from option prices, the expected future volatility is not available. The traditional way in the literature (including Bollerslev, Tauchen and Zhou, 2009 and Della Corte et al, 2016) to address this issue is to use the current implied volatility and the past realized volatility with a period ending in the current date, i.e., a backwards volatility. This method implicitly assumes that $E^{\mathbb{P}}\left[\sigma_{t,t+T}\right] = \sigma_{t-T,t}$, i.e., that agents expect that volatility has a unit autocorrelation. However, realized volatility does not have a unit correlation, but rather behaves in clusters. In this setting, there is a mismatch between the period for which volatility was forecasted and the period of the realized volatility. The market may expect that the future volatility will be different from the past, but this approach ignores this issue. In this traditional approach, the formula for the VRP would be:

$$VRP_t = E^{\mathbb{Q}}\left[\sigma_{t,t+T}\right] - \sigma_{t-T,t} \tag{4}$$

Where $\sigma_{t-T,t}$ is the realized volatility from t - T to t.

Another approach is to use some volatility forecasting model for the expected realized volatility instead of simply assuming unit autocorrelation. Bollerslev, Tauchen and Zhou (2009) use this approach as a robustness test, and the volatility forecasting model used is the HAR (heterogeneous autoregressive) method of Corsi (2009). In this approach, the formula for the VRP would be:

$$VRP_t = E^{\mathbb{Q}}\left[\sigma_{t,t+T}\right] - \sigma_{HAR,t} \tag{5}$$

Where $\sigma_{HAR,t}$ is the realized volatility using Corsi's HAR method, with the usual windows of 1, 5 and 22 days for parameter estimation. As in Bollerslev, Tauchen and Zhou (2009), we use the full sample when estimating the HAR parameters, so that we are subject to look-ahead bias.

While this is an improvement over the traditional approach, it still measures the true $E^{\mathbb{P}}\left[\sigma_{t,t+T}\right]$ with noise, since it considers only information coming from prices, disregarding information coming from other sources. When market participants interpret some non-price information to induce a volatility rise, this measure underestimates the true VRP, and vice versa.

An alternative approach is to follow Mele et al. (2015) and Ornelas (2017) and compare the risk-neutral volatility forecasted between t - T and t with the (future) realized volatility also between t - T and t. Using this approach, we compare the risk-neutral volatility with realized volatility for the same period of the forecast, so there is no need to assume unit autocorrelation of realized returns. This VRP "forward" approach is calculated as follows:

$$VRP_t = E^{\mathbb{Q}}\left[\sigma_{t-T,t}\right] - \sigma_{t-T,t} \tag{6}$$

This approach has the drawback of using the risk-neutral volatility information lagged by T periods, in order to ensure that only information available at time t is used. Furthermore, it implicitly assumes $E^{\mathbb{P}}\left[\sigma_{t-T,t}\right] = \sigma_{t-T,t}$, which means perfect forecasting by agents. But in practice, the forecast error is not zero. Therefore, the measure of equation (6) is actually the ideal VRP measure of equation (3) plus the forecast error. It is possible that the forecast error can predict the returns on our empirical investigation instead of the volatility risk premium. However, we cannot disentangle these two components. In addition, it could be the case that forecast errors are correlated with the ideal VRP. When the actual volatility is unexpectedly high, it is likely that risk aversion and risk premia will increase, prices will go down and future returns will be positive, and vice versa.

Still on the forward approach, Mele et al. (2015) argue that an appealing feature of the VRP formula (6) is that it has the economic interpretation of the P&L at time t of a short position in a volatility swap contract originated at time t - T with a payoff equal to the difference of the MFIV at time t - T and the realized volatility from t - T to t. We can make a parallel with many empirical investigations in finance that approximate the expected returns by the past returns. Here, the expected VRP is approximated by the swap realized P&L.

All these three alternative approaches have measurement errors over the ideal way to calculate the VRP, given by equation 3. Thus, in this paper when intraday data is available, we use the HAR approach (equation 5) and the forward approach (equation 6) as a crosscheck. When intraday data are unavailable, we use the traditional approach (equation 4) instead of the HAR approach.

As we use the VRP as the independent variable, these measurement errors may create an error-in-variables problem. Thus, VRP coefficients may be underestimated due to the attenuation bias. By using different ways of measuring VRP, we try to decrease this problem. Nevertheless, these measurement errors can occasionally be very large, so that the estimated VRP can take some time to converge to the true VRP.

III. Sample

Our main variables consist of VRP data from currency and commodities. For currencies, we have data from options and intraday returns since 2003. For commodities, we use daily data for the realized volatility and the MFIVs are those calculated by CBOE, specifically the OVX (CBOE Crude Oil ETF Volatility Index) and the GVZ (CBOE Gold ETF Volatility Index). These indexes have shorter time-series.

Our currency VRP sample uses implied volatility from OTC (over-the-counter) exchange rate options. These are not actual trades, but estimates collected from JP Morgan's data query application. We use options with one-month maturity, and five moneyness levels: puts and calls with deltas of 10 and 25, and the ATM option. The OTC currency option market also has specific trading conventions. First, OTC options have a constant time to maturity, so that the expiration date is always being rolled over, instead of having a fixed expiration date, as in the case of exchange-traded options. This structure avoids the need to make interpolations in order to have a MFIV for a fixed maturity – for instance one month for the VIX. Another difference is that exchange-traded options are quoted at fixed strike prices, while OTC options are quoted at fixed deltas. Furthermore, while exchange-traded options are quoted in terms of option premia, the OTC currency options are quoted in terms of Garman and Kohlhagen implied volatilities.

Since inputs of equation (2) are strikes and options prices while our raw data consist of implied volatility and delta strikes, we need two intermediate steps. First, we need to convert deltas into strike prices following the conventions of the OTC currency markets (see Reiswich and Uwe, 2010). Specifically, we use the premium-adjusted delta convention for JPY and CAD and the regular delta convention for the remaining currencies (Exhibit 5 in Reiswich and Uwe, 2010). Second, we convert implied volatilities into option prices using the Garman and Kohlhagen option pricing formula[4].

The currency realized variance is based on the tick-by-tick exchange rate quotes provided by Gain Capital at their website[5]. We calculate 5-minute log returns by aggregating tick-by-tick ask quotes into a 5-minute time series, and then taking the first difference of the log. The 5-minute realized variance is calculated as the sum of these squared returns, including weekend returns[6]. In order to compare this measure with the MFIV, we multiply this realized variance by the number of trading days over the next 30 calendar days in order to match the option maturity's trading days. We then take the square root in order to compare it with the MFIV.

$$\sigma^2_{t-T,t} = bd \sum_{i=i}^{n} [\log(p_i / p_{i-1})]^2 \tag{7}$$

Where
$\sigma^2_{t-T,t}$ is the realized variance from *t* - *T* to *t*;
bd is the number of business days of both currencies over the next 30 calendar days;
p_i is the last ask quote (exchange rate) in the i^{th} 5-minute interval of the period [*t* - *T*, t]; and
n is the number of 5-minute intervals in the period [*t* - *T*, t].

Therefore, our realized volatility measure is expressed on a monthly basis, since we use *T* = 30 calendar days. In order to make the two variables of the VRP comparable, we convert the MFIV from annual to monthly by dividing it by the square root of (250 / *bd*).

We consider two types of VRP calculation: the HAR approach from equation (5) and the forward approach from equation (6). The sample time period goes from February 2003 to December 2014, so that we have approximately 12 years of overlapping daily data, since options have one-month maturities. The sample has data for five currency pairs, all against the US Dollar. The currencies are from developed countries: Australian Dollar (AUD), British Pound (GBP), Canadian Dollar (CAD), Euro (EUR) and Japanese Yen (JPY). This currency selection is based on data availability for the whole sample period. We divide these currencies into two groups: the commodity currencies (CC) – Australian and Canadian Dollars – and the non-commodity currencies – Euro, Pound and Yen.

Our commodity VRP samples are based on MFIV calculated by CBOE using the same method as the VIX. The options used are those written on two ETFs (exchange-traded funds) related to commodities. For gold, the underlying ETF is the SPDR Gold Shares, while for oil it is the United States Oil Fund. The realized volatility is calculated based on daily returns of these underlying ETFs, due to the lack of intraday data for these funds. We consider two types of VRP calculation: the traditional approach from equation 4 and the forward approach from equation 6.

[4] We use Libor-like interest rates for each country in order to convert deltas into strike prices and implied volatilities into option prices.
[5] http://www.gaincapital.com/.
[6] This measure of the realized variance defined by the sum of squared returns is also known as quadratic variation or integrated variance. Andersen et al. (2010) provide a literature review of the measurement methods and econometrics of realized variance.

We also use as a control variable an equity VRP, from the S&P500, the main large capitalization index in the US. This VRP is calculated using the VIX and realized volatility using daily observations, and is based on the traditional and forward approaches.

The main statistics are summarized in Table I. The equity and oil VRPs have a positive mean. However, the two currency VRPs have means near zero. This was already reported by Mueller, Stathopoulos and Vedolin (2013).

Figure 1 shows the behavior of the different VRPs, MFIV and realized volatilities through time. As we have daily observations, the times-series are considerably noisy. Thus, in some situations we have negative spikes of the VRP together with increases in the realized volatility, which is not intuitive. We believe this is a consequence of the biases in measuring the VRP mentioned in the last section. This can probably be explained by the different time dynamics of implied and realized volatilities. While implied volatilities capture new information faster, realized volatilities, which are based solely on past prices, need some time to embed new information. For gold and oil, the VRPs seem more volatile when compared to the other assets. It is worth mentioning that these spikes may hinder predictability of the VRP over future returns.

The pairwise correlations between the different volatility risk premia are relatively small, except between the two currency VRPs, as can be seen in Table II. The equity and CC VRPs have a positive correlation of 0.28, while oil and gold VRPs have very low correlations with other asset classes.

Since our data are overlapping, as we use daily information of one month to maturity options, the VRP has an autocorrelation by construction. As can be seen in Figure 2, the currency VRPs are autocorrelated up to one and a half months. Using the HAR method for the RV calculation, the autocorrelation of the VRP is lower from the beginning, and fades faster than the VRP obtained with the forward method (for the CC VRP, for instance, the autocorrelation dissipates within no more than 50 days).

Table I – Summary Statistics

Variable	Mean	Standard Deviation	25th Percentile	75th Percentile	Start Period	End Period
Equity VRP(Traditional)	1,00	1,33	0,46	1,68	03-2003	12-2014
CC VRP (HAR)	-0,07	0,45	-0,23	0,16	03-2003	12-2014
non-CC VRP (HAR)	0,17	0,34	-0,01	0,37	03-2003	12-2014
OIL VRP (Traditional)	1,52	1,80	0,65	2,54	05-2007	12-2014
Gold VRP (Traditional)	0,92	1,24	0,25	1,68	06-2008	12-2014

Figure 1 – Volatility Risk Premium x Realized Volatility

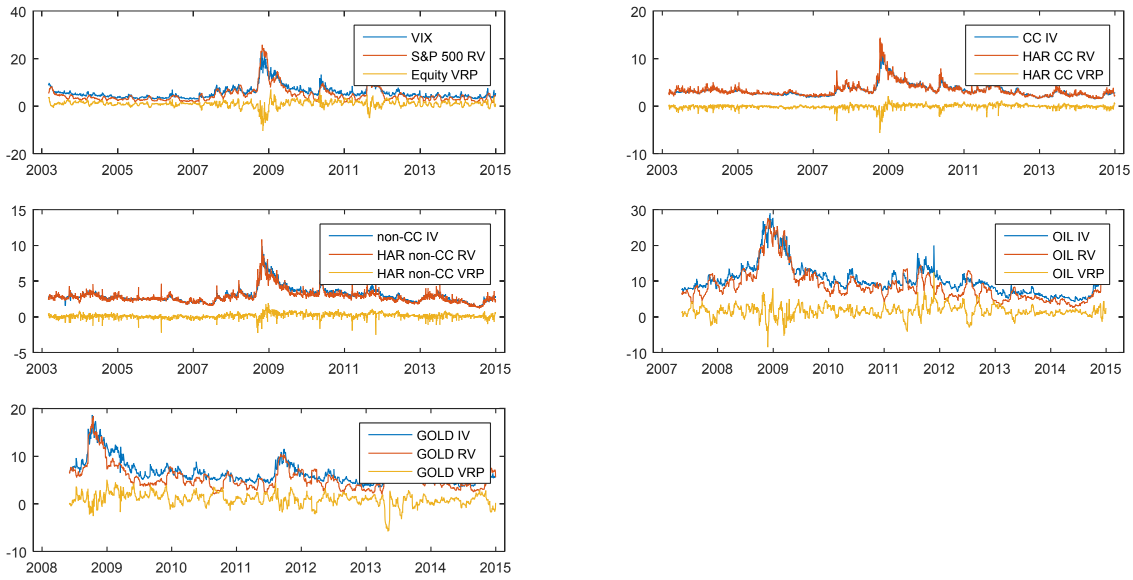
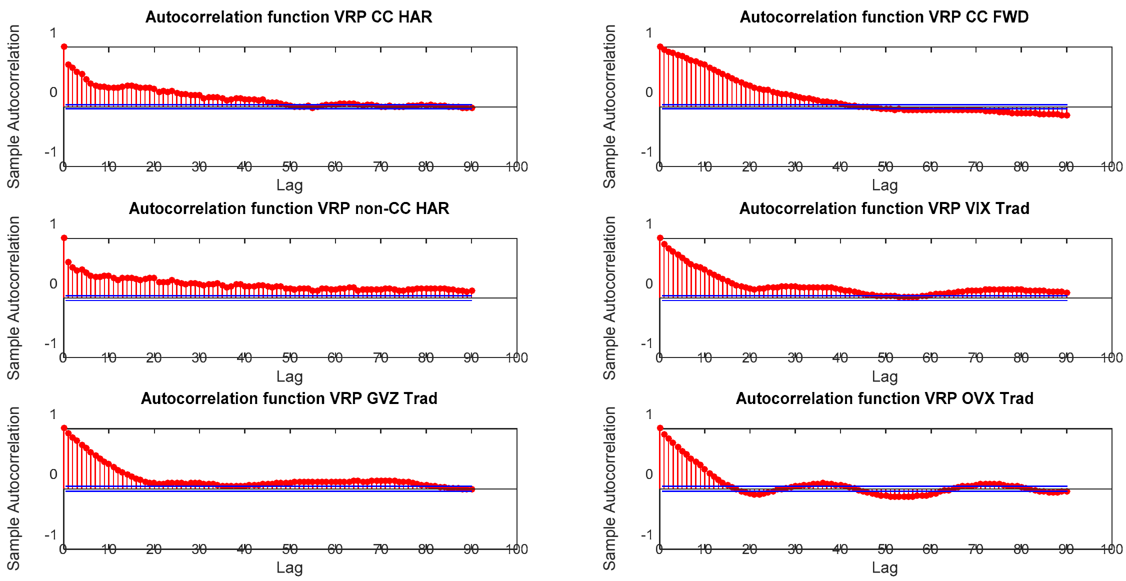


Table II – Correlations between Volatility Risk Premia

	Equity VRP (Traditional)	CC VRP (HAR)	non-CC VRP (HAR)	OIL VRP (Traditional)	Gold VRP (Traditional)
Equity VRP(Traditional)	1,00	0,28	0,03	0,01	-0,08
CC VRP (HAR)	0,28	1,00	0,62	-0,05	-0,10
non-CC VRP (HAR)	0,03	0,62	1,00	-0,08	0,02
OIL VRP (Traditional)	0,01	-0,05	-0,08	1,00	0,00
Gold VRP (Traditional)	-0,08	-0,10	0,02	0,00	1,00

Figure 2 – VRP Autocorrelation Functions



IV. Commodity Currency Volatility Risk Premium

We start by analyzing the predictive ability of VRP from commodity currencies. We calculate the VRP of two commodity currencies - Australian Dollar and Canadian Dollar[7] - and then take an equal-weight average. The advantage of using currency option data is having longer time series. In the next sections, we also use VRP from individual commodities: gold and crude oil VRP.

We consider two types of VRP calculation: the first uses equation 5, with the expected volatility using the HAR model; and the second uses the forward approach, which follows equation 6. In both cases, we use one-month MFIV for the risk-neutral component $E^{\mathbb{Q}}[\sigma_{t-T,t}]$, and 5-minute returns for the physical component $E^{\mathbb{P}}[\sigma_{t-T,t}]$, so that the time window *T* in these formulas is one month. As we use daily time series and options expiring in one month, we have an overlapping data structure. To cope with this issue, we use Hansen-Hodrick HAC t-statistics. The number of lags used is the number of overlapping periods plus one, as is usual in the literature. Our main dependent variables are commodity indexes' weekly returns. We use the Bloomberg Broad spot commodity index, and four sub-indexes. We also evaluate dependent variables from other asset classes, such as equity indexes, currency indexes and bond yields.

Our baseline regression specification (8) also includes a constant and the lagged dependent variable:

$$R_{t,t+h} = \alpha + \beta_1 R_{t-h,t} + \beta_2 VRP_{t-1} + \varepsilon_t \tag{8}$$

where

$R_{t,t+h}$ is the index monthly log return for commodities, currencies and equity indexes, and the yield or spread change for bond yields and corporate spreads. Both are in percentage points. We use returns with windows (*h*) of one, two and three months, assuming 21 business days for each month. Returns and changes are expressed on a monthly basis.

VRP_{t-1} is the commodity currency volatility risk premium. The CC VRP is the simple average of the VRP from the Australian Dollar and Canadian Dollar. We use two types of VRP: the HAR approach (equation 5) and the forward approach (equation 6). The latter is expressed on a monthly basis.

Results are in Table III. In Panel A, we analyze results for commodity returns, which comprise the Broad Indexes and the following sub-indexes: energy, agriculture, industrial metals and precious metals. Coefficients are positive, indicating that a high (low) risk premium leads to future positive (negative) commodity returns. The size of the coefficients usually decreases with the return window *h*. For the Broad Commodity index, the coefficient is statistically significant for just two cases.

The sub-index results show a different level of significance, although almost all coefficients are positive. While energy and industrial metals indexes are mainly significant, agriculture and precious metals are not. Point estimates for energy and industrial metals are around 2, while for agriculture and precious metals they are under 1. Thus, the sensitivity to the VRP of the different commodities varies depending on the type.

The adjusted R^2 of the forward VRP approach regressions are on average 5.8% in panel A, which is higher than the average of those of the HAR approach (4.6%). Point estimates and significance of the forward approach are also slightly better. Industrial metals have the best forecast performance. It is puzzling to see that the adjusted R^2 for the energy and industrial metals increase when we go from one month to three months, while for the others the forecast performance decreases with the return window size.

[7] We do not use the New Zealand Dollar due to lack of intraday data availability in the beginning of the sample period.

Panel B shows results using currency index returns as dependent variables. We use four indexes:

- Dollar index, which measures the value of the US Dollar against a basket of currencies weighted by trading volume. The higher this index is, the higher is the US Dollar value against this basket;
- MSCI EM currency index, which measures the strength of the most traded emerging market currencies against the US dollar. The higher this index is, the higher is the value of emerging market currencies against US Dollar;
- Bloomberg JP Morgan Latam currency index, which measures the strength of the most traded Latin American currencies against the US Dollar. The higher this index is, the higher is the value of Latin American currencies against US Dollar;
- Bloomberg JP Morgan Asia currency index, which measures the strength of the most traded Asian currencies against the US dollar. The higher this index is, the higher is the value of Asian currencies against US Dollar.

Note that while the Dollar Index measures the value of the Dollar against a basket (of mainly developed country) currencies, the other three indexes measure the value of a basket of currencies against the US Dollar, so that they are inversely correlated by construction.

Coefficient estimates of Panel B support that high risk premium leads to appreciation of the US Dollar and depreciation of the other currencies. This is consistent with the idea that the US Dollar is the strong currency, and the others are risky currencies or risky assets. The overall results for currencies are in line with those of Ornelas (2017), but contrast with those of Londono and Zhou (2017), possibly because the latter authors use VRP based on options with longer maturities and realized volatilities based on windows of six months. This way, their realized measure is more stable and probably tends to the unconditional volatility, except, perhaps, during very turbulent times.

The two CC risk premia have mainly statistically significant coefficients for all currency indexes, except for the Dollar Index. The coefficients for the Emerging Markets currencies and regional currencies are positive, consistent with the risk premia discounting model, while the negative coefficient of the Dollar Index means that the other currencies are discounted instead of the US Dollar. The CC VRPs have a stronger influence and predict better the Latin American currencies compared to the Asian currencies. This is expected, since these currencies are mainly from commodity exporting countries.

Results of Panel C show equity indexes as dependent variables. We use four capitalization-weighted indexes: MSCI World (developed countries), MSCI Emerging Markets, Russell 2000 (US small capitalization companies) and S&P500 (US large capitalization companies). The CC risk premia show good predictive ability over these equity indexes, with most of the coefficients significant. Curiously, the emerging market indexes show the weakest results. As in the equity index VRP literature, coefficients are positive, indicating that a high (low) risk premium leads to future positive (negative) returns.

Panel D tests the predictive ability of the VRP on bond yields and spreads. We use as dependent variables the change of Treasury bond yields and corporate bond spreads, measured in percentage points. The corporate bonds are those with ratings A and BBB from US companies. The US Treasury bonds are zero coupon bonds with maturity of 10 years. We also break down the US bond yield into expected short-term interest rate and term premia. This decomposition is based on the articles of Adrian et al. (2013, 2014) and data can be found at the NY Fed website[8]. Using this approach, we can distinguish between risk premiums and future monetary policy expectations. Coefficients in Panel D for dependent variables that represent a

[8] https://www.newyorkfed.org/research/data_indicators/term_premia.html. We have downloaded this time series on October, 2016.

premium – term premium and corporate spreads – are mainly negative. This is in line with the risk premium discounting model[9]. We have a positive influence of the volatility risk premium on future excess returns coming from risk premia. However, only corporate spreads have statistically significant coefficients. Term premia coefficients are largely insignificant, perhaps due to the various unconventional easing measures in the US after the crisis, which created a downward trend of the term premium.

The US 10-year expected short-term interest rate coefficients in Panel D are positive, meaning a conventional monetary policy tightening after VRP shocks. Note that this result is not necessarily inconsistent with the risk premium discounting model, since they are the base interest rate of the economy. We also tested this decomposition for shorter term bonds (one, three and five years), and the results (not reported) showed that the coefficients are largely insignificant for one-year maturity, but then start becoming positive and significant as maturity increases. It is interesting to see that the positive returns of risky assets documented in Panels A, B and C occur despite pressure coming from the increasing risk-free discount rate.

Overall, the CC VRP regressions have significant coefficients for a broad range of assets. We also performed three additional analyses, but we do not show detailed results for them. First, we calculated the CC VRP using longer-term options with maturities of three and six months, and the realized volatility using the HAR method. However, in these regressions the results are much weaker to predict commodities and currencies returns (not reported). Nevertheless, these longer-term options VRP are still able to predict equity indexes and yields.

Furthermore, we analyze the slope of the model-free implied volatility term structure for the commodity currencies. We calculate this slope using MFIV with maturities of one, three and six months for each day in the sample. This term structure slopes upward, as expected[10]. However, when we substitute the VRP by this slope in equation 8, it is not able to predict future commodity returns with horizons of one to six months, except for the precious metals index returns (not reported).

Finally, we have also tested the 10-delta risk reversal[11] for both the commodity currencies as predictor instead of the VRP in equation 8. The risk reversal is a gauge of the relative pricing of left and right tails. However, the results showed no predictive ability of this variable on commodity returns, except for the energy index with one-month maturity (not reported).

It is worth noting that, given the measurement errors on the VRP documented in section II, we may have a problem of error in variables in Table III, so that coefficients might be underestimated due to the so-called attenuation bias.

In the next subsections, we perform further robustness analyses with subsamples before and after the crisis, and use VRP calculated from other currencies and equities.

---

[9] Recall that we can have the following first-order approximation for the return of a bond: $Ret \approx -D \times \Delta y$, where *D* is the duration of the bond and Δy is the yield change. As the durations is constant and positive, we have a negative relationship between returns and yields.

[10] The idea is that the longer the maturity, the higher should be compensation for risk.

[11] The 10-delta risk reversal is the difference of a call and a put implied volatility with delta equal to ten. For the Canadian Dollar, we use the call implied volatility minus the put. For the Australian Dollar, we use the put minus the call implied volatility, since the quotation standard is reversed.

Table III – Commodity Currency Regression Results

Dependent Variable	Coefficients						t statistics						Adjusted R^2					
	HAR VRP			Fwd VRP			HAR VRP			Fwd VRP			HAR VRP			Fwd VRP		
	1 Mo	2 Mo	3 Mo	1 Mo	2 Mo	3 Mo	1 Mo	2 Mo	3 Mo	1 Mo	2 Mo	3 Mo	1 Mo	2 Mo	3 Mo	1 Mo	2 Mo	3 Mo
Panel A																		
Broad Commodities	1,45	1,21	0,77	1,85	0,69	0,49	1,32	1,73	1,21	2,33	1,56	1,14	2,0%	9,9%	9,0%	6,3%	9,6%	9,0%
Energy	1,88	2,28	1,99	2,31	1,47	1,56	1,17	1,77	1,71	1,99	1,53	2,00	1,7%	9,5%	8,5%	4,4%	9,8%	10,0%
Agriculture	0,73	0,72	0,15	1,10	0,29	-0,07	0,66	0,87	0,23	1,45	0,56	-0,16	0,5%	1,4%	0,4%	1,8%	1,2%	0,4%
Industrial Metals	2,36	2,22	1,90	2,98	1,75	1,46	1,59	1,76	1,89	3,10	2,42	2,79	3,6%	9,0%	9,5%	9,0%	10,7%	11,2%
Precious Metals	1,00	0,70	-0,17	0,78	0,15	-0,44	1,08	1,72	-0,45	1,18	0,50	-1,30	2,2%	0,9%	0,2%	2,6%	0,4%	1,1%
Panel B																		
Dollar Index	-0,49	-0,07	0,02	-0,33	0,05	0,00	-1,18	-0,25	0,10	-0,96	0,25	0,02	0,8%	0,2%	1,9%	0,9%	0,2%	1,9%
MSCI EM Currency	0,44	0,33	0,30	0,50	0,20	0,23	1,47	1,40	1,83	1,97	1,01	2,29	2,1%	2,4%	2,5%	3,9%	2,2%	3,1%
Latam FX Index	0,78	0,67	0,61	0,77	0,40	0,43	2,16	2,06	2,36	2,22	1,43	2,46	4,0%	5,3%	3,4%	5,6%	4,9%	3,9%
Asia FX Index	0,34	0,18	0,16	0,35	0,11	0,12	1,81	1,53	2,34	2,50	1,14	2,05	1,9%	1,5%	2,7%	5,0%	1,4%	3,1%
Panel C																		
MSCI WORLD	1,53	1,10	0,99	1,68	0,75	0,63	1,67	1,48	3,48	1,87	1,33	3,88	2,4%	2,5%	8,1%	5,2%	2,7%	8,2%
MSCI EM	1,09	0,73	0,79	1,37	0,23	0,39	0,91	0,99	1,70	1,20	0,41	1,01	1,8%	3,5%	4,9%	2,7%	3,2%	4,7%
RUSSELL 2000	2,65	1,87	1,81	2,70	1,43	1,26	2,20	1,62	3,27	2,47	1,75	5,19	3,4%	3,7%	6,3%	8,2%	5,4%	7,8%
S&P 500	1,78	1,32	1,25	1,78	0,98	0,82	2,07	1,72	4,32	2,14	1,67	7,90	3,0%	3,4%	9,4%	6,3%	4,3%	9,9%
Panel D																		
10-year T-Bond US	0,56	1,43	1,69	1,83	1,90	1,60	0,41	1,09	1,80	1,42	2,02	3,62	0,1%	3,3%	3,0%	2,4%	7,4%	6,7%
US Term Premium	-5,06	-0,99	-1,54	-0,20	0,93	0,44	-0,97	-0,29	-0,61	-0,06	0,40	0,26	0,6%	0,1%	0,3%	0,4%	0,1%	0,3%
US Expected Short-term IR	2,03	1,81	1,74	2,08	1,50	1,36	1,08	1,21	1,54	1,75	2,15	2,54	1,9%	2,6%	2,8%	4,0%	4,0%	4,2%
US Corporate Spread (A)	-3,56	-3,16	-2,36	-2,51	-1,39	-0,68	-3,06	-5,21	-4,72	-2,35	-6,74	-1,95	11,3%	12,6%	13,3%	11,6%	10,2%	10,6%
US Corporate Spread (BBB)	-3,56	-3,82	-3,58	-2,81	-2,53	-2,19	-4,36	-5,22	-8,29	-3,99	-6,12	-11,92	18,2%	20,0%	20,8%	20,4%	20,9%	20,7%

This table shows results of 108 regressions: $R_{t,t+h} = \alpha + \beta_1 R_{t-h,t} + \beta_2 VRP_{t-1} + \varepsilon_t$. There are 19 dependent variables and 6 independent variables. Each regression has as independent variables: one risk premium, the lagged dependent variable (for one, two and three months) and a constant. The dependent variables in Panels A, B and C are the returns of: Broad Spot commodity index, the sub-indexes of energy, agriculture, industrial metals and precious metals; the Dollar index, the JP Morgan EM currency index, the Bloomberg JP Morgan Latam currency index, the Bloomberg JP Morgan Asia currency index, MSCI World, MSCI Emerging Markets, Russell 2000 and S&P500. The dependent variables in Panel D are the first difference of the bond yields from US 10-year Treasury bonds, US 10-year term premium, US 10-year expected short-term interest rate; and the first difference of corporate bond spreads from US companies with rating A and BBB. All the independent variables are lagged. The independent variables are commodity currency volatility risk premium for one, two and three months calculated using two different approaches: the HAR method for the realized volatility calculation (proposed by Corsi 2009) and the forward approach described in Section II. The commodity currencies are AUD and CAD, which are calculated with equal weights for each currency. Estimates of the constants and lagged dependent variable coefficients are omitted. The statistics marked in green are significant at least at 10%. The t-statistics are Hansen-Hodrick HAC with h+1 lags, where h is the size of the return window. The sample period is from February 2003 to December 2014, with 2955 daily overlapping observations. VRPs and returns are expressed on a monthly basis in percentage points. The maturity of the options is one month.

IV.1 Subsample analysis: Pre and post crisis

In this subsection, we analyze results of the baseline regression previously presented considering two subsamples: before and after the 2008 global financial crisis, which also delimits a major change in monetary policies from developed countries. We split our sample into two subsamples considering the date January 1, 2008 as the dividing point, and use only one-month returns, given the small subsample sizes. In the first subsample, we have conventional monetary policy, while in the second we have the phenomenon of zero interest rate lower bound, and the unconventional monetary policy measures.

As can be seen in Table IV, results are considerably different between these two subsamples. Before the crisis, the future returns of most variables analyzed seem unpredictable using the VRP as explanatory variable. After the crisis, however, most of the variable returns become significant, using either the HAR CC VRP or the forward CC VRP. The adjusted R^2 is also much higher after the crisis.

One possible explanation is that currency options prices became more informative through time, so that the VRP turns out to be an efficient predictor. In the case of commodities, it may be the case that the so-called financialization of commodity markets also made returns of this asset class more sensitive to investor sentiment and market volatility. As explained by Cheng and Xiong (2013), financial investors affect risk sharing and information discovery in commodity markets, and the futures market participation has changed lately. Basak and Pavlova (2017) show how financial markets transmit shocks not only to future prices but also to commodity spot prices and inventories.

The zero interest rate environment may also contribute. Before the crisis, the expected returns of risky assets used to come partly from the risk-free rate and partly as compensation for risk. After the crisis, the risky asset returns are almost exclusively for risk compensation, which can increase the sensitivity of returns to the VRP.

Another possible explanation is related to larger responses towards changes in risk in the post-crisis sample compared to before the crisis. The process called "search for yield", where investors need to move to riskier assets in order to achieve their target returns, may have contributed to this change. As these investors changed their usual habitat, they might have responded in a more intense way to positive innovations of the VRP. Furthermore, new investors in an asset class are likely to have more risk-averse behavior.

Table IV – Pre and Post crisis analysis

Dependent Variable	Coefficients				Adjusted R^2			
	Before Crisis		After Crisis		Before Crisis		After Crisis	
	HAR VRP	Fwd VRP	HAR VRP	Fwd VRP	HAR VRP	Fwd VRP	HAR VRP	Fwd VRP
Broad Commodities	-0,43	-0,06	2,43	2,39	4,7%	4,6%	5,8%	11,9%
Energy	1,06	0,25	2,51	2,66	0,8%	0,7%	5,4%	9,9%
Agriculture	-2,07	-1,69	2,05	1,82	2,6%	2,8%	2,1%	4,6%
Industrial Metals	-0,61	1,28	4,17	3,99	0,3%	0,8%	9,3%	17,4%
Precious Metals	-0,35	1,44	1,83	0,80	5,5%	6,6%	3,0%	2,1%
Dollar Index	0,15	-0,56	-0,96	-0,43	0,1%	1,1%	3,4%	1,9%
MSCI EM Currency	-0,29	-0,20	0,91	0,80	2,5%	2,3%	5,3%	8,0%
Latam FX Index	0,12	0,17	1,23	0,99	2,8%	2,9%	8,0%	9,6%
Asia FX Index	-0,19	-0,09	0,61	0,51	1,3%	0,9%	5,8%	10,0%
MSCI WORLD	-1,00	-0,35	2,70	2,35	1,1%	0,3%	5,6%	9,1%
MSCI EM	-2,21	-1,19	2,92	2,49	2,5%	1,6%	5,1%	6,6%
RUSSELL 2000	-0,64	0,15	3,98	3,46	0,2%	0,0%	7,2%	13,5%
S&P 500	-0,82	-0,46	2,72	2,28	1,3%	0,9%	6,1%	10,1%
10-year T-Bond US	-1,97	-3,37	1,43	2,62	1,2%	5,5%	0,5%	5,2%
US Term Premium	-7,45	-13,75	-2,69	2,09	0,7%	2,4%	1,1%	1,1%
US Expected Short-term IR	-0,90	-2,70	3,18	2,85	2,9%	5,9%	3,2%	7,3%
US Corporate Spread (A)	1,17	0,67	-4,85	-3,11	4,3%	4,1%	15,6%	15,3%
US Corporate Spread (BBB)	-0,44	-0,46	-4,21	-3,03	4,7%	4,7%	28,9%	31,4%

This table shows results of 72 regressions: $R_{t,t+h} = \alpha + \beta_1 R_{t-h,t} + \beta_2 VRP_{t-1} + \varepsilon_t$. There are 19 dependent variables and 4 independent variables. Each regression has as independent variables: one risk premium, the lagged dependent variable and a constant. The dependent variables are the returns of: Broad Spot commodity index, the sub-indexes of energy, agriculture, industrial metals and precious metals; the Dollar index, the JP Morgan EM currency index, the Bloomberg JP Morgan Latam currency index, the Bloomberg JP Morgan Asia currency index, MSCI World, MSCI Emerging Markets, Russell 2000 and S&P500. The six last dependent variables are the first difference of the bond yields from US 10-year Treasury bonds, US 10-year term premium and US 10-year expected short-term interest rate; and the first difference of corporate bond spreads from US companies. All the independent variables are lagged. The independent variables are commodity currency volatility risk premium calculated using HAR and forward methods described in Section II. The commodity currencies are AUD and CAD, which are calculated with equal weights for each currency. Estimates of the constants and lagged dependent variable coefficients are omitted. The statistics marked in green are significant at least at 10%. The t-statistics are Hansen-Hodrick HAC with n+1 lags, where n is the size of the return window. The sample period is from February 2003 to December 2007 for the pre-crisis period (1205 daily overlapping observations) and from January 2007 to December 2014 for the post-crisis period (1750 daily overlapping observations). VRPs and returns are expressed on a monthly basis in percentage points. The maturity of the options is one month.

IV.2 Comparison with other Volatility Risk Premia

In this subsection, we perform a test to assess the predictive ability of two other VRPs as dependent variables: the average VRP of three non-CC (Euro, British Pound and Japanese Yen) and the VRP of the S&P500, i.e., the VRP using the VIX index. We still use regression specification (8) so that we have only one VRP as independent variable. The VRP variable is the HAR CC VRP, the HAR non-CC VRP or the traditional equity VRP. We perform this analysis using returns up to six months so we can assess predictability over a longer horizon than in the previous section.

Overall, the coefficients in Table V for the other two VRPs show the same signs, although with different levels of significance. Panel A of Table V shows that the commodity index returns are better explained and more sensitive (as expected) by the CC VRP than the non-CC VRP. The CC VRP coefficients are larger and significant up to four months in the case of energy and industrial metals. The adjusted R^2 of the CC VRP is also higher on average.

When compared to the equity VRP, the CC VRP also shows larger coefficients. However, in terms of predictive power the equity VRP surprisingly performs better for the broad index, and sub-indexes of energy and agriculture, which are those with highest weights. A possible explanation for this result is the higher stock exchange liquidity of this index compared to the other commodity indexes. For the industrial metals and precious metals indexes, the CC VRP shows better predictive ability.

Panel B shows that the two currency VRPs have similar overall results. Except for the Dollar index, predictability lasts up to four months on average. The equity VRP has significant results, especially for Asian currencies, where the coefficients are significant up to six months.

Panel C shows results for equity indexes. Although the equity VRP shows good predictability up to six months, especially for US equities, the CC VRP has even better predictability. For the S&P500 returns, the average adjusted R^2 for the six regressions is 5.8% for the CC VRP, against 4.3% of the equity VRP. The non-CC VRP has weaker results, especially for short-term returns.

Fixed-income results in Panel D show that CC VRP has better predictive ability of Treasury bonds with longer horizons (3 to 5 months), and this is led by expected short-term interest rate and not the term premium. The other VRPs have limited predictability of US bonds. However, the non-CC VRP also predicts US corporate spreads, while the equity VRP shows positive coefficients, but they are significant only for some specific terms. The term premium coefficient for the non-CC VRP is negative, as expected, and the first month coefficient is significant. Overall, predictability of the term premium is very limited.

Table V - Other VRPs

Dependent Variable	Coefficients HAR CC VRP						Avg R^2	Coefficients HAR non-CC VRP						Avg R^2	Coefficients Traditional Equity VRP						Avg R^2
	1 Mo	2 Mo	3 Mo	4 Mo	5 Mo	6 Mo		1 Mo	2 Mo	3 Mo	4 Mo	5 Mo	6 Mo		1 Mo	2 Mo	3 Mo	4 Mo	5 Mo	6 Mo	
Panel A																					
Broad Commodities	1,45	1,21	0,77	0,93	0,88	0,59	5,0%	0,63	1,24	1,04	1,05	0,83	0,55	4,4%	0,65	0,25	0,25	0,37	0,38	0,35	5,4%
Energy	1,88	2,28	1,99	2,11	1,91	1,47	5,2%	-0,42	0,96	1,20	1,36	1,32	0,94	3,3%	0,86	0,66	0,69	0,81	0,78	0,64	5,7%
Agriculture	0,73	0,72	0,15	0,31	0,33	0,08	1,1%	1,43	1,54	1,06	0,93	0,69	0,50	1,7%	0,49	0,24	0,29	0,33	0,27	0,23	2,0%
Industrial Metals	2,36	2,22	1,90	1,70	1,26	0,74	5,3%	1,23	1,92	1,80	1,54	1,02	0,68	4,0%	0,62	0,39	0,27	0,23	0,13	0,11	3,5%
Precious Metals	1,00	0,70	-0,17	-0,42	-0,27	-0,31	0,8%	1,13	1,54	0,60	0,34	0,20	0,23	0,9%	0,55	-0,05	-0,11	-0,05	-0,03	-0,08	0,7%
Panel B																					
Dollar Index	-0,49	-0,07	0,02	-0,09	-0,07	-0,05	1,2%	-0,52	-0,21	0,02	-0,09	-0,09	-0,07	1,2%	-0,20	-0,03	-0,05	-0,07	-0,06	-0,05	1,5%
MSCI EM Currency	0,44	0,33	0,30	0,36	0,26	0,14	2,2%	0,62	0,55	0,37	0,37	0,32	0,24	2,2%	0,27	0,12	0,12	0,12	0,07	0,05	2,5%
Latam FX Index	0,78	0,67	0,61	0,59	0,43	0,26	3,2%	1,02	0,94	0,68	0,62	0,55	0,44	3,2%	0,38	0,20	0,18	0,16	0,10	0,09	3,0%
Asia FX Index	0,34	0,18	0,16	0,21	0,16	0,11	2,2%	0,35	0,30	0,20	0,20	0,17	0,13	1,8%	0,17	0,08	0,08	0,08	0,06	0,05	3,1%
Panel C																					
MSCI WORLD	1,53	1,10	0,99	1,19	1,10	0,80	4,3%	1,40	1,13	0,95	1,01	0,95	0,77	3,1%	0,57	0,32	0,32	0,29	0,23	0,22	3,3%
MSCI EM	1,09	0,73	0,79	1,00	0,81	0,35	2,4%	1,81	1,73	1,25	1,17	0,96	0,66	2,6%	0,66	0,14	0,14	0,13	0,05	0,01	2,1%
RUSSELL 2000	2,65	1,87	1,81	1,93	1,72	1,20	6,3%	2,24	1,84	1,54	1,49	1,42	1,21	3,2%	0,85	0,58	0,65	0,54	0,40	0,34	4,5%
S&P 500	1,78	1,32	1,25	1,36	1,21	0,90	5,8%	1,54	1,28	1,18	1,22	1,16	0,97	3,9%	0,62	0,46	0,43	0,34	0,26	0,24	4,3%
Panel D																					
10-year T-Bond US	0,56	1,43	1,69	1,38	1,09	0,67	2,9%	-2,41	-1,22	0,22	0,43	0,23	0,10	1,8%	1,00	0,31	0,20	0,10	0,11	-0,13	2,1%
US Term Premium	-5,06	-0,99	-1,54	0,47	0,37	-0,92	0,3%	-12,85	-2,73	-3,21	0,07	-0,22	-1,56	0,4%	1,51	0,37	-0,11	0,07	-0,27	-0,53	0,3%
US Expected Short-term IR	2,03	1,81	1,74	1,42	1,14	1,07	2,8%	-0,01	0,63	0,42	0,29	0,46	0,98	1,1%	0,41	0,16	0,24	0,17	0,15	-0,01	1,1%
US Corporate Spread (A)	-3,56	-3,16	-2,36	-2,43	-2,53	-2,44	10,1%	-4,44	-4,34	-3,91	-3,81	-4,06	-4,31	12,4%	0,19	0,53	0,61	0,32	0,14	0,08	6,4%
US Corporate Spread (BBB)	-3,56	-3,82	-3,58	-3,49	-3,38	-3,07	16,7%	-2,94	-3,67	-3,47	-3,55	-3,65	-3,89	13,9%	-0,34	-0,20	-0,16	-0,24	-0,29	-0,21	8,7%

This table shows results of 342 regressions: $R_{t,t+h} = \alpha + \beta_1 R_{t-h,t} + \beta_2 VRP_{t-1} + \varepsilon_t$, where VRP can be the HAR CC VRP, HAR non-CC VRP or the traditional equity VRP. There are 19 dependent variables with 6 return periods each. Each regression has as independent variables: one risk premium, the lagged dependent variable (for one to six months) and a constant. The dependent variables in Panels A, B and C are the returns of: Broad Spot commodity index, the sub-indexes of energy, agriculture, industrial metals and precious metals; the Dollar index, the JP Morgan EM currency index, the Bloomberg JP Morgan Latam currency index, the Bloomberg JP Morgan Asia currency index, MSCI World, MSCI Emerging Markets, Russell 2000 and S&P500. The dependent variables in Panel D are the first difference of the yields from 10-year Treasury bonds, US 10-year term premium and US 10-year expected short-term interest rate; and the first difference of corporate bond spreads from US companies. All the independent variables are lagged. The independent variables are commodity currency and non-commodity currency volatility risk premia for one to six months, besides the traditional equity VRP (whose realized volatility is calculated on a monthly basis as described in Section III). The commodity currencies are AUD and CAD, which are calculated with equal weights for each currency. Estimates of the constants and lagged dependent variables' coefficients are omitted. The statistics marked in green are significant at least at 10%. The t-statistics are Hansen-Hodrick HAC with n+1 lags, where n is the size of the return window. The sample period is from February 2003 to December 2014, with 2955 daily overlapping observations. VRPs and returns are expressed on a monthly basis in percentage points. The maturity of the options is one month. Adjusted R^2 shown are the average for the dependent variable of that line and the VRP above, i.e., an average of six regressions.

IV.3 Differential Analysis

In this subsection, we perform a test to verify the predictive ability of two differentials in the dependent variables: the difference between the VRP of CC (Australian and Canadian Dollars) and three non-CC (Euro, British Pound and Japanese Yen) and the difference between the US equity VRP and the CC VRP. Our expectation is that the difference of CC and non-CC VRP works better to predict the commodity index returns we are testing. For the second differential, we analyze whether the US equity VRP – CC VRP improves the predictability of the equity indexes and the other asset classes. Our regression specification in this case is the following:

$$R_{t,t+h} = \alpha + \beta_1 R_{t-h,t} + \beta_2 DifV_{t-1} + \varepsilon_t \qquad (9)$$

Where

$DifV$ represents the differentials CC VRP – non CC VRP or US equity VRP – CC VRP.

Table VI shows results for regression 9 using both these differentials. As can be seen in Panel A, indeed the commodity index returns have positive coefficients for the CC-non-CC differential, except for the agriculture sub-index. However, they are statistically significant only for the HAR VRP. When comparing with the equity VRP, we see that only the forward VRP coefficients are statistically significant. This means that both CC and equity VRP provide an additional predictability against the others.

In Panel B, coefficients of the differential CC VRP against non-CC are not significant, suggesting that the CC VRP has no special ability to predict currencies beyond that of the non-CC VRP, even for currencies more related to commodities, like those of Latin American countries. The equity VRP – CC VRP coefficients are significant, which means the equity VRP improves the results for these dependent variables.

Panel C shows that the CC VRP improves predictability of future equity returns over the two other VRPs. The only exception is the emerging market index, but this index was not significant when considering the VRP variables alone, in Table V. Even for the US equity returns, which do not have any currency exposure, the CC VRP is able to add predictability to the equity VRP.

Finally, Panel D shows the results for the group of corporate spreads and Treasury bonds. As in

Table V, the non-CC VRP was able to predict only the corporate spreads, so these are the only relevant estimates to analyze in this panel. In this regard, results show that the CC VRP is better than the non-CC VRP for the corporate spreads with rating BBB, but not for A-rated corporate bonds.

Table VI - Differential VRP

Dependent Variable	Coefficients				t statistics				Adjusted R^2			
	CC - non-CC		Equity - CC		CC - non-CC		Equity - CC		CC - non-CC		Equity - CC	
	HAR	Forward	HAR	Forward	HAR	Forward	HAR	Forward	HAR	Forward	HAR	Forward
Panel A												
Broad Commodities	1,67	1,22	0,46	0,21	1,71	1,20	1,99	2,29	1,7%	1,3%	1,8%	6,0%
Energy	3,39	2,71	0,64	0,25	2,29	1,62	1,26	1,68	2,7%	2,3%	1,6%	3,9%
Agriculture	-0,25	-0,30	0,41	0,12	-0,23	-0,26	1,10	1,62	0,3%	0,3%	1,0%	1,7%
Industrial Metals	2,55	2,11	0,33	0,27	1,83	1,62	0,84	2,08	3,0%	2,7%	1,9%	6,0%
Precious Metals	0,49	-0,34	0,44	0,15	0,47	-0,35	1,13	2,02	1,8%	1,8%	2,6%	4,2%
Panel B												
Dollar Index	-0,27	0,16	-0,15	-0,08	-0,61	0,30	-1,06	-1,90	0,1%	0,1%	0,6%	3,6%
MSCI EM Currency	0,06	-0,09	0,22	0,07	0,27	-0,23	1,86	2,09	1,2%	1,2%	3,4%	4,7%
Latam FX Index	0,17	0,22	0,30	0,07	0,49	0,47	1,95	1,75	2,4%	2,5%	4,6%	4,4%
Asia FX Index	0,19	0,14	0,13	0,04	1,09	0,48	1,83	2,63	0,4%	0,3%	2,7%	5,5%
Panel C												
MSCI WORLD	0,97	0,98	0,40	0,17	1,79	1,09	1,73	1,32	1,1%	1,2%	1,8%	3,3%
MSCI EM	-0,17	-0,58	0,54	0,17	-0,21	-0,50	1,59	1,24	1,3%	1,4%	2,3%	2,7%
RUSSELL 2000	1,93	2,29	0,57	0,31	2,15	1,75	1,73	1,84	1,1%	2,0%	1,5%	5,9%
S&P 500	1,23	1,43	0,43	0,17	2,40	1,72	1,97	1,46	1,0%	1,6%	1,8%	3,4%
Panel D												
10-year T-Bond US	3,10	3,91	0,97	0,21	1,96	2,37	1,47	1,54	1,6%	3,5%	2,1%	2,3%
US Term Premium	4,24	2,53	2,14	0,09	0,84	0,48	1,40	0,23	0,5%	0,5%	0,7%	0,4%
US Expected Short-term IR	3,18	2,90	0,18	0,18	1,95	1,94	0,42	0,95	2,6%	2,9%	0,7%	2,5%
US Corporate Spread (A)	-0,87	-0,22	0,58	-0,32	-1,08	-0,17	1,53	-3,32	8,1%	7,9%	8,7%	12,3%
US Corporate Spread (BBB)	-2,76	-2,88	0,11	-0,37	-3,13	-2,40	0,33	-4,46	15,3%	16,0%	13,6%	22,0%

This table shows results of 76 regressions. We estimate the regressions $R_{t,t+h} = \alpha + \beta_1 R_{t-h,t} + \beta_2 DifV_{t-1} + \varepsilon_t$. $DifV$, which represent the two differentials we are testing: the difference between commodity currency volatility risk premium and non-commodity currency volatility risk premium and the difference between the equity VRP and the CC VRP. The dependent variables in Panels A, B and C are the monthly returns of: Broad Spot commodity index, the sub-indexes of energy, agriculture, industrial metals and precious metals; the Dollar index, the JP Morgan EM currency index, the Bloomberg JP Morgan Latam currency index, the Bloomberg JP Morgan Asia currency index, MSCI World, MSCI Emerging Markets, Russell 2000 and S&P500. The dependent variables in Panel D are the first difference of the bond yields from US 10-year Treasury bonds, US 10-year term premium and US 10-year expected short-term interest rate; and the first difference of corporate bond spreads from US companies. All the independent variables are lagged. The commodity currencies are AUD and CAD. The non-commodity currencies are EUR, GBP and JPY. The CC and non-CC VRP are calculated with equal weights for each currency. Estimates of the constants and lagged dependent variables' coefficients are omitted. The statistics marked in green are significant at least at 10%. The t-statistics are Hansen-Hodrick HAC with n+1 lags, where n is the size of the return window. The sample period is from February 2003 to December 2014, with 2955 daily overlapping observations. VRPs and returns are expressed on a monthly basis in percentage points. The maturity of the options is one month.

V. Gold Volatility Risk Premium

In this section, we evaluate the predictive ability of the gold volatility risk premium (GVRP) over commodity, currency and equity index returns. We omit results for bonds, as they are mainly insignificant, and include as dependent variables silver and gold indexes, which compose the precious metals index. The regression specification is the following:

$$R_{t,t+h} = \alpha + \beta_1 R_{t-h,t} + \beta_2 GVRP_{t-1} + \varepsilon_t \tag{10}$$

Where $GVRP_{t-1}$ is the lagged gold VRP, defined as the difference between the MFIV index GVZ calculated by CBOE and the realized volatility (using daily data) of the SPDR Gold Shares ETF.

We do not use the HAR method in this section to calculate the realized volatility, as we do not have intraday data for the gold ETF returns. Therefore, we have the VRP calculated via the traditional way and forward way. As seen before, the gold VRP time series is shorter, starting in June 2008. Thus, we consider returns of one to three months, as longer windows would make the number of non-overlapping periods too small.

Results in Table VII show mainly positive coefficients, in line with those of the other VRPs. There is a strong statistical significance for commodities and currencies, especially for the three-month returns. For equities, results are strong for the emerging markets, but weaker for developed markets. Furthermore, the forward approach has better explanatory power, with an adjusted R^2 roughly two times higher than the traditional approach.

Precious metals index and its sub-indexes display the highest coefficients; and coefficients for commodities are generally higher than for currencies. This is expected as gold VRP would capture risks more specific to its own market.

Table VII – Gold Volatility Risk Premium Regressions

Dependent Variable	Coefficients						t statistics						Adjusted R^2					
	Traditional GVRP			Fwd GVRP			Traditional GVRP			Fwd GVRP			Traditional GVRP			Fwd GVRP		
	1 Mo	2 Mo	3 Mo	1 Mo	2 Mo	3 Mo	1 Mo	2 Mo	3 Mo	1 Mo	2 Mo	3 Mo	1 Mo	2 Mo	3 Mo	1 Mo	2 Mo	3 Mo
Panel A																		
Broad Commodities	0,67	0,36	0,47	0,86	0,62	0,57	1,82	1,78	2,01	1,93	2,41	2,51	4,3%	15,6%	10,1%	10,0%	22,2%	15,7%
Energy	0,86	0,40	0,48	0,85	0,66	0,69	1,49	1,05	1,25	1,40	1,53	1,74	3,8%	16,9%	10,5%	5,8%	20,4%	14,8%
Agriculture	0,67	0,49	0,59	0,80	0,61	0,50	1,65	2,03	3,82	1,87	2,52	3,47	1,9%	3,0%	3,3%	5,1%	6,9%	5,0%
Industrial Metals	0,86	0,64	0,72	1,23	1,09	1,00	1,75	2,01	1,68	2,04	2,86	2,60	4,9%	11,0%	8,6%	11,7%	21,9%	19,4%
Precious Metals	0,96	0,54	0,55	1,04	0,73	0,52	1,84	2,01	5,15	3,10	5,06	6,11	4,7%	2,5%	3,9%	10,2%	10,0%	7,7%
Gold	0,93	0,51	0,47	0,85	0,57	0,38	2,06	2,18	5,82	3,07	4,66	6,71	7,6%	3,4%	4,5%	11,9%	9,5%	6,6%
Silver	1,01	0,59	0,75	1,51	1,17	0,91	1,33	1,40	3,09	2,79	4,79	4,70	1,4%	1,1%	2,4%	7,0%	8,7%	7,6%
Panel B																		
Dollar Index	-0,22	-0,11	-0,07	-0,37	-0,20	-0,12	-1,21	-0,99	-0,61	-2,06	-1,85	-1,26	1,3%	1,7%	3,6%	7,5%	5,6%	5,4%
MSCI EM Currency	0,22	0,18	0,20	0,37	0,30	0,25	1,68	1,64	2,22	2,58	3,38	3,78	3,3%	2,8%	3,5%	10,3%	11,4%	10,7%
Latam FX Index	0,38	0,31	0,35	0,49	0,43	0,39	2,53	2,14	2,98	2,89	4,20	4,54	6,7%	5,7%	4,9%	12,1%	14,0%	12,9%
Asia FX Index	0,11	0,10	0,09	0,19	0,15	0,11	1,50	1,91	2,65	2,39	3,25	4,04	1,3%	2,2%	3,9%	8,3%	10,4%	9,3%
Panel C																		
MSCI WORLD	0,35	0,21	0,29	0,65	0,45	0,35	0,96	0,91	1,31	1,34	1,36	1,78	1,6%	1,7%	10,0%	5,2%	5,3%	12,5%
MSCI EM	0,77	0,56	0,63	1,25	0,88	0,73	1,68	1,49	1,61	2,09	2,92	2,58	4,5%	5,8%	7,9%	11,1%	11,7%	12,7%
RUSSELL 2000	0,38	0,12	0,25	0,74	0,49	0,36	0,76	0,37	0,89	1,18	0,98	1,32	0,5%	0,2%	2,0%	3,8%	3,6%	4,4%
S&P 500	0,27	0,14	0,26	0,51	0,34	0,30	0,76	0,67	1,44	1,13	1,05	1,67	0,9%	0,9%	9,4%	3,5%	3,5%	11,7%

This table shows results of 90 regressions of the form: $R_{t,t+h} = \alpha + \beta_1 R_{t-h,t} + \beta_2 GVRP_{t-1} + \varepsilon_t$. GVRP is the gold volatility risk premium, which is calculated using the traditional forward approaches described in Section II. The reference maturity of the GVRP is one month. The dependent variables in Panels A, B and C are the monthly returns of: Broad Spot commodity index, the sub-indexes of energy, agriculture, industrial metals, precious metals, gold and silver; the Dollar index, the JP Morgan EM currency index, the Bloomberg JP Morgan Latam currency index, the Bloomberg JP Morgan Asia currency index, MSCI World, MSCI Emerging Markets, Russell 2000 and S&P500. All the independent variables are lagged. Estimates of the constant and lagged dependent variables are omitted. The statistics marked in green are significant at least at 10%. The t-statistics are Hansen-Hodrick HAC with n+1 lags, where n is the size of the return window. The sample period is from June 2008 to December 2014, with 1658 daily overlapping observations. VRPs and returns are expressed on a monthly basis in percentage points.

VI. Oil Volatility Risk Premium

In this section, we test the predictive ability of the oil volatility risk premium (OVRP) on the dependent variables evaluated in the previous section, but replacing silver and gold indexes by energy sub-indexes (WTI crude oil, petroleum, natural gas and unleaded gasoline). The regression specification is the following:

$$R_{t,t+h} = \alpha + \beta_1 R_{t-h,t} + \beta_2 OVRP_{t-1} + \varepsilon_t \qquad (11)$$

Where $OVRP_{t-1}$ is the lagged oil VRP, defined as the difference between the MFIV index OVX calculated by CBOE and the realized volatility (using daily data) of the United States Oil Fund ETF.

As in the previous section, we do not use the HAR method due to the lack of intraday data for the oil ETF. Instead, we use the traditional and forward approaches. As seen before, the oil VRP time-series is shorter, starting in May 2007. Thus, we also consider returns of only one to three months.

The results in Table VIII show few statistically significant coefficients. Signs are mainly positive for the forward VRP and statistically significant in the case of energy, petroleum and unleaded gas indexes. When using the traditional VRP, signs are mainly negative when commodity indexes are the dependent variable, but the energy-related indexes are not statistically significant. Thus, we are not able to draw general conclusions for commodities.

These results contrast with those of Chevallier and Sevi (2014), who find a statistically negative relationship between oil VRP and future returns. These different results can presumably be attributed to sample differences such as a longer time span and the use of intraday data. Furthermore, the way VRP is calculated may also explain these differences

Table VIII – Oil VRP

Dependent Variable	Coefficients						t statistics						Adjusted R^2					
	Traditional OVRP			Fwd OVRP			Traditional OVRP			Fwd OVRP			Traditional OVRP			Fwd OVRP		
	1 Mo	2 Mo	3 Mo	1 Mo	2 Mo	3 Mo	1 Mo	2 Mo	3 Mo	1 Mo	2 Mo	3 Mo	1 Mo	2 Mo	3 Mo	1 Mo	2 Mo	3 Mo
Panel A																		
Broad Commodities	0,00	-0,29	-0,29	0,18	-0,04	-0,02	-0,02	-1,92	-2,29	1,03	-0,40	0,68	1,5%	16,1%	11,1%	2,1%	14,8%	9,4%
Energy	0,38	-0,18	-0,20	0,53	0,20	0,25	1,63	-0,83	-0,94	1,67	0,94	1,85	3,6%	18,7%	10,8%	4,9%	19,0%	11,4%
Agriculture	-0,22	-0,35	-0,28	-0,11	-0,17	-0,14	-0,87	-1,88	-1,63	-0,56	-1,22	-1,39	0,5%	2,9%	1,9%	0,3%	2,2%	1,3%
Industrial Metals	-0,07	-0,49	-0,45	0,44	0,19	0,21	-0,28	-1,90	-1,96	1,86	1,11	1,59	1,8%	7,8%	5,3%	3,4%	6,3%	4,0%
Precious Metals	-0,32	-0,34	-0,39	-0,03	-0,15	-0,26	-1,18	-1,92	-3,95	-0,13	-1,07	-2,11	1,6%	1,7%	3,4%	0,9%	0,6%	2,8%
Panel B																		
WTI Crude Oil	0,39	-0,35	-0,17	0,60	0,21	0,38	1,13	-1,16	-0,54	1,55	0,81	1,51	5,8%	15,8%	7,7%	7,0%	15,7%	8,9%
Petroleum	0,37	-0,32	-0,19	0,60	0,19	0,34	1,06	-1,17	-0,65	1,66	0,80	1,64	6,3%	15,6%	6,7%	7,6%	15,4%	7,6%
Natural Gas	0,32	-0,12	-0,25	0,14	0,14	0,10	0,78	-0,28	-0,71	0,40	0,37	0,30	0,3%	2,0%	2,2%	0,1%	2,1%	2,0%
Unleaded Gas	0,35	-0,30	-0,21	0,72	0,29	0,37	0,95	-1,18	-0,72	1,99	1,12	2,10	6,7%	7,2%	1,2%	8,6%	7,5%	2,3%
Panel C																		
Dollar Index	0,17	0,18	0,16	-0,07	0,05	0,02	1,36	3,16	2,87	-0,63	0,88	0,40	1,3%	4,2%	7,5%	0,4%	1,8%	4,5%
MSCI EM Currency	-0,09	-0,11	-0,06	0,01	0,01	0,05	-0,84	-1,34	-0,82	0,23	0,18	1,48	2,0%	2,3%	1,1%	1,5%	1,1%	1,3%
Latam FX Index	0,03	-0,09	-0,05	0,04	0,03	0,11	0,20	-0,83	-0,51	0,41	0,45	1,95	3,9%	3,7%	1,1%	4,0%	3,4%	2,3%
Asia FX Index	-0,07	-0,06	-0,03	0,02	0,01	0,02	-0,90	-1,94	-1,02	0,55	0,26	0,85	0,9%	1,8%	1,9%	0,1%	0,2%	1,7%
Panel D																		
MSCI WORLD	-0,05	-0,18	-0,07	0,07	-0,05	0,07	-0,16	-0,97	-0,29	0,45	-0,47	0,64	0,6%	1,1%	6,2%	0,7%	0,7%	6,3%
MSCI EM	-0,28	-0,33	-0,16	-0,13	-0,20	0,03	-0,74	-1,16	-0,54	-0,56	-0,87	0,16	1,9%	3,5%	4,0%	1,7%	3,1%	3,7%
RUSSELL 2000	0,05	-0,11	0,02	0,24	0,08	0,19	0,12	-0,53	0,09	1,13	0,48	1,95	0,1%	0,2%	1,2%	0,6%	0,2%	2,3%
S&P 500	0,04	-0,12	-0,02	0,11	-0,01	0,10	0,14	-0,74	-0,08	0,73	-0,14	1,01	0,3%	0,7%	6,8%	0,4%	0,4%	7,3%

This table shows results of 102 regressions of the form: $R_{t,t+h} = \alpha + \beta_1 R_{t-h,t} + \beta_2 OVRP_{t-1} + \varepsilon_t$. *OVRP is the oil volatility risk premium, which is calculated using the traditional forward approaches described in Section II. The reference maturity of the OVRP is one month. The dependent variables in Panel A are the monthly returns of Broad Spot commodity index, and the sub-indexes of energy, agriculture, industrial metals and precious metals. In Panel B, we have the WTI crude oil, petroleum, natural gas and unleaded gasoline, while Panel C shows the Dollar index, the JP Morgan EM currency index, the Bloomberg JP Morgan Latam currency index and the Bloomberg JP Morgan Asia currency index. Finally, in Panel D we present MSCI World, MSCI Emerging Markets, Russell 2000 and S&P500. All the independent variables are lagged. Estimates of the constant and lagged dependent variables are omitted. The statistics marked in green are significant at least at 10%. The t-statistics are Hansen-Hodrick HAC with n+1 lags, where n is the size of the return window. The sample period is from May 2007 to December 2014, with 1926 daily overlapping observations. VRPs and returns are expressed on a monthly basis in percentage points. The maturity of the options is one month.*

VII. Multivariate Analysis with all Volatility Risk Premia

In this section, we test the prediction power of VRPs by regressing all of them against index returns. As seen in Table II, the various VRPs have small correlation, except for the two currency VRPs. Thus, multicollinearity concerns are restricted to this pair. The regression specification is the following:

$$R_{t,t+h} = \alpha + \beta_1 R_{t-h,t} + \mathbf{\Gamma}\, \boldsymbol{VRP}_{t-1} + \varepsilon_t \qquad (12)$$

Where

VRP is a vector with the time series of the volatility risk premia. We consider the currency VRPs using the HAR approach, and the equity, oil, gold VRPs using the traditional approach.

As the gold VRP time series starts in June 2008, this regression is calculated from this date to the end of the sample, in December 2014, in the post crisis period. Results are in Table IX.

Panel A results indicate that CC VRP and equity VRP perform well as predictors. In this multivariate setting, gold VRP is able to predict only precious metals. Intriguingly, oil VRP does not help predicting energy indexes, but helps predicting precious metals. The agriculture commodity index is the only one with no significant coefficients, and has the lowest adjusted R^2 (6%). For the other commodities, adjusted R^2 values are over 10%.

For currency indexes as dependent variable (Panel B), the equity VRP has significant coefficients in all cases expect for the Dollar index, but the two currency VRPs have few significant coefficients. This puzzle comes from the high pairwise correlation between these measures. When we use only the CC VRP in the regression (not reported), its coefficients for currency indexes as dependent variables become significant.

For equity indexes (Panel C), both the CC and equity VRPs show statistical significance for almost all coefficients. The CC VRP has a statistically positive coefficient even for the S&P500, improving predictability in comparison with the VIX risk premium.

For the analysis of bonds and corporate spreads, in turn, the better coefficients are also those of the CC VRP, indicating robust predictive power for this measure. Corporate bond spreads show the highest adjusted R^2 values, from 20% to 30%.

Overall, the results indicate that CC VRP and equity VRP are the strongest predictors. Given the co-movement reported in the literature on the US Dollar nominal value (Chen et al, 2014) and also of past commodity currencies (Chen et al, 2010) with commodity prices, regression (13) adds these past returns to specification (12) in order to assess if they help to forecast commodity returns:

$$R_{t,t+h} = \alpha + \beta_1 R_{t-h,t} + \mathbf{\Gamma}\, \boldsymbol{VRP}_{t-1} + \delta\, RFX_{t-h,t} + \varepsilon_t \qquad (13)$$

Where

$RFX_{t-h,t}$ is the monthly lagged return of an exchange rate index. Two indexes are used: the Dollar index, which measures the value of the US Dollar against a basket of currencies weighted by trading volume; and an equally weighted index with the returns of the commodity currencies: Australian Dollar and Canadian Dollar. These are two of the three classic commodity currencies as defined by Chen and Rogoff (2003).

We include these variables to test if they have explanatory power beyond that of the CC VRP. The results in Panel A of Table X show that in fact the coefficients for the CC VRP are smaller when CC lagged returns are included, indicating the variable indeed captures some of the predictive ability of CC VRP. However, coefficients for the CC VRP remain significant even after the inclusion of CC returns.

The analysis of Panel B in Table X shows that the inclusion of the Dollar index as explanatory variable has a similar effect on the CC VRP coefficients (most of them are still significant, but their values are lower). The coefficients for the Dollar index, in turn, are mostly significant with a negative sign, as this index measures the US Dollar against a basket of other currencies (for the main US trading partners), as opposed to our other FX measures, which reflect the value of the foreign currency against the US Dollar.

Table IX – Analyzing all Volatility Risk Premia Together

Dependent Variable	Coefficients					t statistics					Adjusted R^2
	GOLD VRP	OIL VRP	CC VRP	non CC VRP	Equity VRP	GOLD VRP	OIL VRP	CC VRP	non CC VRP	Equity VRP	
Panel A											
Broad Commodities	0.50	-0.31	2.03	0.55	0.75	1.43	-1.39	2.90	0.39	2.55	12.9%
Energy	0.51	-0.04	2.85	-1.57	1.02	0.86	-0.11	2.94	-0.84	2.21	10.1%
Agriculture	0.55	-0.38	0.99	1.98	0.44	1.37	-1.32	1.06	1.12	0.99	6.0%
Industrial Metals	0.62	-0.36	3.60	1.01	0.79	1.28	-1.04	3.74	0.59	1.89	14.7%
Precious Metals	0.89	-0.59	0.36	2.30	0.65	1.80	-2.28	0.41	1.77	1.41	11.0%
WTI Crude Oil	0.25	0.04	3.61	-0.58	1.17	0.34	0.08	2.42	-0.29	1.83	12.1%
Petroleum	0.29	0.01	3.91	-0.16	1.12	0.44	0.01	2.93	-0.08	1.75	13.9%
Natural Gas	0.89	-0.16	0.82	-4.89	0.80	1.29	-0.36	0.60	-2.32	2.56	4.8%
Unleaded Gas	0.60	-0.08	5.82	0.36	0.92	0.99	-0.16	4.03	0.16	1.24	18.9%
Gold	0.88	-0.45	0.29	1.70	0.41	2.02	-2.02	0.34	1.45	1.10	12.2%
Silver	0.89	-1.03	0.25	4.18	1.28	1.24	-2.63	0.18	2.10	1.76	9.2%
Panel B											
Dollar Index	-0.19	0.28	-0.43	-0.86	-0.21	-1.05	2.27	-1.17	-1.66	-1.25	9.4%
MSCI EM Currency	0.15	-0.21	0.18	1.15	0.33	1.10	-1.76	0.49	1.80	2.18	14.1%
Latam FX Index	0.25	-0.12	0.26	1.52	0.43	1.45	-0.79	0.42	1.39	2.18	15.9%
Asia FX Index	0.07	-0.12	0.33	0.39	0.18	0.89	-1.51	1.95	1.26	1.96	14.1%
Panel C											
MSCI WORLD	0.10	-0.24	1.70	1.49	0.61	0.26	-0.68	2.00	0.74	1.79	9.3%
MSCI EM	0.58	-0.62	0.58	4.03	0.85	1.22	-1.61	0.62	1.93	1.96	12.9%
RUSSELL 2000	-0.02	-0.19	2.95	1.29	0.81	-0.05	-0.43	3.79	0.57	1.76	10.7%
S&P 500	-0.04	-0.10	1.95	0.96	0.62	-0.10	-0.31	2.39	0.50	1.92	9.6%
Panel D											
10-year T-Bond US	-0.91	-0.23	2.76	-4.11	1.18	-1.05	-0.42	1.87	-2.29	1.81	6.5%
US Term Premium	-3.75	3.57	2.71	-11.93	0.92	-0.93	1.43	0.44	-1.45	0.49	2.9%
US Expected Short-term	0.33	-0.28	4.21	-2.05	0.55	0.77	-0.82	2.69	-1.34	0.96	6.9%
US Corporate Spread (A)	-0.17	-0.12	-2.97	-4.05	0.28	-0.37	-0.38	-2.63	-1.64	0.64	20.5%
US Corporate Spread (BBB)	0.16	0.16	-3.81	-0.95	-0.39	0.46	0.60	-6.10	-0.68	-1.04	30.2%

This table shows results of 25 regressions: $R_{t,t+h} = \alpha + \beta_1 R_{t-h,t} + \mathbf{\Gamma}\,\boldsymbol{VRP}_{t-1} + \varepsilon_t$. There are 25 dependent variables and 6 independent variables (only 5 reported). Each regression has as independent variables, besides the lagged dependent variable and a constant, the volatility risk premium of five different asset classes: gold, oil, commodity currencies (equally weighted), non-commodity currencies (also equally weighted) and US equities. We consider the currencies VRPs using the HAR approach, and the equity, oil, gold VRPs using the traditional approach. The dependent variables in Panel A are the returns of: Broad Spot commodity index, the sub-indexes of energy, agriculture, industrial metals and precious metals; WTI crude oil, petroleum, natural gas, unleaded gasoline, gold and silver. In Panel B, we test returns of the Dollar index, the JP Morgan EM currency index, the Bloomberg JP Morgan Latam currency index and the Bloomberg JP Morgan Asia currency index. In Panel C, we have returns of the MSCI World, MSCI Emerging Markets, Russell 2000 and S&P500. Finally, Panel D shows the first difference of yields from US 10-year Treasury bonds, US 10-year term premium and US 10-year expected short-term interest rate; and the first difference of corporate bond spreads from US companies with ratings A and BBB. All the independent variables are lagged. The commodity currencies are AUD and CAD, which are calculated with equal weights for each currency. Estimates of the constants and lagged dependent variables are omitted. The t-statistics marked in green are significant at least at 10%. The t-statistics are Hansen-Hodrick HAC with h+1 lags, where h is the size of the return window. The sample period is from June 2008 to December 2014, with 1658 daily overlapping observations. VRPs and returns are expressed on an annualized basis in percentage points. The maturity of the options is one month.

Table X – Using Past Commodity Currency Returns and Dollar Index as Control Variables

Dependent Variables	Coefficients						t statistics						Adjusted R^2
	GOLD VRP	OIL VRP	CC VRP	non CC VRP	Equity VRP	CC Ret	GOLD VRP	OIL VRP	CC VRP	non CC VRP	Equity VRP	CC Ret	
Panel A													
Broad Commodities	0.45	-0.29	1.61	0.69	0.81	28.91	1.29	-1.31	2.05	0.50	3.38	1.87	14.2%
Energy	0.45	-0.01	2.47	-1.45	1.04	16.09	0.76	-0.02	2.19	-0.78	2.32	0.70	10.3%
Agriculture	0.50	-0.36	0.54	2.20	0.42	20.80	1.25	-1.24	0.54	1.25	1.02	0.97	6.6%
Industrial Metals	0.53	-0.29	2.93	1.32	0.89	36.43	1.08	-0.81	2.80	0.79	2.33	2.23	16.0%
Precious Metals	0.90	-0.55	-0.07	2.52	0.63	13.73	1.80	-2.07	-0.07	1.94	1.40	1.10	11.4%
WTI Crude Oil	0.13	0.12	2.91	-0.36	1.21	31.31	0.18	0.25	1.72	-0.18	1.98	0.99	12.7%
Petroleum	0.16	0.09	3.12	0.09	1.18	37.04	0.25	0.19	2.09	0.05	1.96	1.25	14.8%
Natural Gas	1.03	-0.29	2.25	-5.53	0.86	-42.83	1.45	-0.63	1.59	-2.44	2.43	-1.97	6.0%
Unleaded Gas	0.50	0.00	4.93	0.71	1.02	42.19	0.82	0.00	3.31	0.30	1.47	1.51	19.9%
Gold	0.88	-0.42	-0.05	1.87	0.40	10.25	2.00	-1.83	-0.06	1.60	1.07	1.10	12.4%
Silver	0.89	-0.99	-0.12	4.38	1.27	13.21	1.25	-2.54	-0.08	2.18	1.77	0.50	9.3%
Panel B													
Dependent Variables	GOLD VRP	OIL VRP	CC VRP	non CC VRP	Equity VRP	Dollar Index	GOLD VRP	OIL VRP	CC VRP	non CC VRP	Equity VRP	Dollar Index	Adjusted R^2
Broad Commodities	0.43	-0.35	1.77	0.69	0.86	-38.75	1.28	-1.70	2.38	0.53	3.39	-2.44	15.0%
Energy	0.41	-0.04	2.41	-1.37	1.09	-34.08	0.70	-0.13	2.35	-0.75	2.51	-1.81	11.0%
Agriculture	0.48	-0.41	0.61	2.23	0.48	-34.88	1.25	-1.49	0.64	1.31	1.20	-1.29	7.3%
Industrial Metals	0.52	-0.37	3.16	1.30	0.93	-45.56	1.10	-1.08	3.03	0.82	2.35	-2.34	16.5%
Precious Metals	0.90	-0.58	0.01	2.53	0.67	-21.36	1.81	-2.25	0.01	1.97	1.43	-1.23	11.5%
WTI Crude Oil	0.11	0.05	3.04	-0.32	1.27	-47.32	0.15	0.11	1.89	-0.17	2.15	-1.94	13.1%
Petroleum	0.15	0.01	3.32	0.12	1.25	-51.75	0.22	0.02	2.35	0.06	2.12	-2.13	15.3%
Natural Gas	0.92	-0.17	1.03	-5.00	0.80	11.30	1.34	-0.37	0.79	-2.29	2.46	0.37	4.8%
Unleaded Gas	0.48	-0.09	5.15	0.74	1.07	-56.44	0.78	-0.18	3.70	0.33	1.60	-1.75	20.3%
Gold	0.88	-0.45	0.11	1.81	0.42	-10.28	2.02	-2.01	0.12	1.54	1.11	-0.82	12.3%
Silver	0.90	-1.01	-0.43	4.64	1.34	-46.68	1.26	-2.55	-0.29	2.42	1.78	-1.41	10.1%

This table shows results of 22 regressions: $R_{t,t+h} = \alpha + \beta_1 R_{t-h,t} + \mathbf{\Gamma}\,\boldsymbol{VRP}_{t-1} + \delta\ RFX_{t-h,t} + \varepsilon_t$. There are 11 dependent variables and 7 independent variables (6 reported). In Panel A, the independent variables are, besides the lagged dependent variable and the lagged CC returns, the volatility risk premium of five different asset classes: gold, oil, commodity currencies (equally weighted), non-commodity currencies (also equally weighted) and US equities. We consider the currency VRPs using the HAR approach, and the equity, oil, gold VRPs using the traditional approach. The dependent variables are the returns of: Broad Spot commodity index, the sub-indexes of energy, agriculture, industrial metals and precious metals; WTI crude oil, petroleum, natural gas, unleaded gasoline, gold and silver. In Panel B, we have all the aforementioned independent variables, but instead of the lagged CC returns, we use the Dollar index. The commodity currencies are AUD and CAD, which are calculated with equal weights for each currency. Estimates of the constants and lagged index returns are omitted. The statistics marked in green are significant at least at 10%. The t-statistics are Hansen-Hodrick HAC with h+1 lags, where h is the size of the return window. The sample period is from June 2008 to December 2014, with 1658 daily overlapping observations. VRPs and returns are expressed on an annualized basis in percentage points. The maturity of the options is one month.

VII. Final Remarks

This paper extends the empirical literature on VRP and future returns by analyzing the predictive ability of CC VRPs and commodity VRPs. The empirical evidence throughout this paper provides support for a positive relationship of commodity-related VRPs and future commodity returns, but only for the period after the 2008 global financial crisis. This relationship is robust to the use of control variables such as equity VRP and currency lagged returns.

Future research might investigate whether the finding of a positive relationship post-crisis stems (in part) from the zero interest rate environment. Another interesting path for future research would be to analyze the volatility risk premia of Treasury bonds. This might shed light on whether unconventional monetary policy has a relevant influence on investors' risk appetite.

IX. References

Adrian, Tobias, Richard Crump, Benjamin Mills, and Emanuel Moench (2014) Treasury Term Premia: 1961-Present. *Liberty Street Economics*, May 12, 2014.

Adrian, Tobias, Richard Crump, and Emanuel Moench (2013) Pricing the Term Structure with Linear Regressions. *Journal of Financial Economics* 110, no. 1, pp. 110-138.

Andersen, Bordarenko and Gonzalez-Perez (2015) Exploring Return Dynamics via Corridor Implied Volatility. *Review of Financial Studies* v. 28 (10), pp 2902-2945.

Andersen, Torben, Tim Bollerslev, Francis Diebold (2010) Parametric and Nonparametric Measurements of Volatility. In: Aït-Sahalia Yacine, Lars Peter Hansen (Eds.), *Handbook of Financial Econometrics, Tools and Techniques*, Vol. 1. North Holland, pp. 67–137.

Basak, Suleyman, and Anna Pavlova (2016). A model of financialization of commodities. *Journal of Finance* Volume 71, Issue 4, Pages 1511–1556.

Bollerslev, T., G. Tauchen, and H. Zhou (2009). Expected Stock Returns and Variance Risk Premia. *The Review of Financial Studies* v. 22, n. 11, pp. 4463-4492.

Bollerslev, T., James Marrone, Lai Xu, and Hao Zhou (2014) Stock Return Predictability and Variance Risk Premia: Statistical Inference and International Evidence. *Journal of Financial and Quantitative Analysis* Vol. 49, No. 3, June 2014, pp. 633–661.

Cashin, Paul, Luis F. Céspedes and Ratna Sahay (2004) Commodity currencies and the real exchange rate. *Journal of Development Economics* 75, pp. 239– 268.

Chen, Yu-chi and Kenneth Rogoff (2003) Commodity currencies. *Journal of International Economics* v. 60 pp. 133–160.

Chen, Yu-chi, Kenneth Rogoff and Barbara Rossi (2010) Can Exchange Rates Forecast Commodity Prices?, *Quarterly Journal of Economics* v. 125(3), pp. 1145–1194.

Chen, Shu-Ling, John D. Jackson, Hyeongwoo Kim and Pramesti Resiandini (2014) What Drives Commodity Prices?, *American Journal Agriculture Economics* 96(5), pp. 1455-1468.

Cheng, I. H., & Xiong, W. (2013). The financialization of commodity markets. *National Bureau of Economic Research.* No. w19642.

Chevallier, Julien and Benoit Sevi (2014). A fear index to predict oil futures returns. *IPAG Working Paper 2014-333*.

Della Corte, P. and T. Ramadorai, and L. Sarno (2016) Volatility Risk Premia and Exchange Rate Predictability. *Journal of Financial Economics,* Volume 120, Issue 1, pp. 21–40.

Demeterfi, Kresimir, Derman, Emanuel, Kamal, Michael and Zou, Joseph (1999) A Guide to Volatility and Variance Swaps, *Journal of Derivatives*, 6, pp. 9–32.

Kohlscheen, Emanuel, Fernando Avalos and Andreas Schrimpf (2016) When the Walk is not Random: Commodity Prices and Exchange Rates. *BIS Working Papers* No 551.

Londono, Juan and Zhou, Hao (2017) Variance Risk Premiums and the Forward Premium Puzzle, *Journal of Financial Economics*.

Mele, Antonio, Yoshiki Obayashi and Catherine Shalen (2015) Rate fears gauges and the dynamics of fixed income and equity volatilities, *Journal of Banking & Finance* 52, pp. 256–265

Mueller, Philippe, Andreas Stathopoulos and Andrea Vedolin (2013) International Correlation Risk. *LSE Financial Markets Group Discussion Paper N.* 716.

Ornelas, Jose R. H. (2017) Expected Currency Returns and Volatility Risk Premium. *Central Bank of Brazil Working Paper* N. 454.

Reiswich, Dimitri and Wystup Uwe (2010) A Guide to FX Options Quoting Conventions. *Journal of Derivatives*. Winter 2010, 58-68.

Zhang, Hui Jun, Jean-Marie Dufour and John W. Galbraith (2016) Exchange rates and commodity prices: Measuring causality at multiple horizons. *Journal of Empirical Finance* 36, pp. 100–120.

Previous volumes in this series

No	Title	Author
618 March 2017	Business cycles in an oil economy	Drago Bergholt, Vegard H. Larsen and Martin Seneca
617 March 2017	Oil, Equities, and the Zero Lower Bound	Deepa Datta, Benjamin K. Johannsen, Hannah Kwon, and Robert J. Vigfussony
616 March 2017	Macro policy responses to natural resource windfalls and the crash in commodity prices	Frederick van der Ploeg
615 March 2017	Currency wars or efficient spillovers? A general theory of international policy cooperation	Anton Korinek
614 March 2017	Changing business models in international bank funding	Leonardo Gambacorta, Adrian van Rixtel and Stefano Schiaffi
613 February 2017	Risk sharing and real exchange rates: the role of non-tradable sector and trend shocks	Hüseyin Çağrı Akkoyun, Yavuz Arslan and Mustafa Kılınç
612 February 2017	Monetary policy and bank lending in a low interest rate environment: diminishing effectiveness?	Claudio Borio and Leonardo Gambacorta
611 February 2017	The effects of tax on bank liability structure	Leonardo Gambacorta, Giacomo Ricotti, Suresh Sundaresan and Zhenyu Wang
610 February 2017	Global impact of US and euro area unconventional monetary policies: a comparison	Qianying Chen, Marco Lombardi, Alex Ross and Feng Zhu
609 February 2017	Revisiting the commodity curse: a financial perspective	Enrique Alberola and Gianluca Benigno
608 January 2017	Redemption risk and cash hoarding by asset managers	Stephen Morris, Ilhyock Shim and Hyun Song Shin
607 January 2017	The real effects of household debt in the short and long run	Marco Lombardi, Madhusudan Mohanty and Ilhyock Shim
606 January 2017	Market volatility, monetary policy and the term premium	Sushanta K Mallick, M S Mohanty and Fabrizio Zampolli
605 January 2017	Wage and price setting: new evidence from Uruguayan firms	Fernando Borraz, Gerardo Licandro and Daniela Sola
604 January 2017	Endogenous wage indexation and aggregate shocks	Julio A Carrillo, Gert Peersman and Joris Wauters
603 January 2017	Multiplex interbank networks and systemic importance – An application to European data	Iñaki Aldasoro, Iván Alves
602 January 2017	The globalisation of inflation: the growing importance of global value chains	Raphael Auer, Claudio Borio and Andrew Filardo

All volumes are available on our website www.bis.org.