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Research article

Wavering interactions between commodity futures prices and us dollar exchange rates

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Abstract: This paper examines the intricate impact of commodity futures settlement prices on USD exchange rates. The daily data on changes in logs of futures prices and changes in logs of US dollar in euro and USD trade weighted exchange rate are tested with Bayesian VAR, multiple breakpoint regression and two-state Markov switching. Commodities include West Texas Intermediate and Brent crude oil, as well as copper and gold. The tests imply prevalence of an inverse relationship between changes in commodity futures prices and USD exchange rates, but their interactions become positive at stressful market conditions. Strengths, statistical significance and causal interactions between commodity futures prices and USD exchange rate depend on the type of commodities and market risk conditions. The relationship between WTI and USD exchange rates has been strengthening over time. Interactions between changes in gold prices and the exchange rate are very unstable.

Keywords: commodity futures prices; USD exchange rates; multiple breakpoint regression; Bayesian VAR; Markov switching

JEL Codes: C58, F31, G13

1. Introduction

Our study examines the interplay between returns on selected commodities (changes in logs of commodity futures prices) and the US Dollar exchange rates. The underlying hypothesis is that shocks in commodity futures settlement prices inversely affect US Dollar (USD) values in foreign currencies. In other words, rising commodity futures prices result in USD depreciation and declining prices in USD appreciation. Based on key findings in the prior literature, we assume that the impact of commodity futures prices on the exchange rate varies significantly in time. This causal impact is particularly sensitive to financial market risk conditions. Specifically, at normal market periods USD depreciation is associated with rising commodity prices, while at times of financial distress, i.e. under high market risk conditions, USD appreciation corresponds with higher commodity prices.

We focus our analysis on two crude oil and two metals one-month futures settlement prices that have been widely discussed in the literature as more or less significantly related to exchange rate movements. Specifically, the commodities included in our exercise are: West Texas Intermediate (WTI) and Brent crude oil, copper and gold. We use the USD value in EUR and USD Trade Weighted (TWEX) exchange rates. We test causal interactions and impulse responses between commodity futures prices and exchange rates. We employ linear multiple breakpoint regression to examine their changes over time. We assume that returns on crude oil futures and the exchange rates are very sensitive to market risk conditions. Our underlying assumption is that at normal, low market risk periods the two pairs of returns display an inverse relationship, while at turbulent times their relationship becomes positive. As suggested by several recent studies (Lizardo and Mollick, 2010; Ding and Vo, 2012; Reboredo, 2012), these relationships hold well for all examined commodity futures prices in relation to USD in EUR and TWEX, albeit mainly in the aftermath of the recent financial crisis, i.e. in the presence of massive liquidity injections to financial markets.

Our analytical assumption is based on key findings in several prior studies. The literature examining relationships between commodity spot and futures prices and exchange rates is extensive. We assume that there is a prevalent causal impact of changes in commodity futures prices on the USD exchange rate, which is consistent with a similar directional inference discussed by Lizardo and Mollick (2010), Ding and Vo (2012), and Fratzscher, et al. (2014).

We begin with a brief survey of pertinent literature in Section 2. Section 3 presents the data description and the analysis of bi-variate causal relationships between changes in logs (returns) to commodity prices and USD exchange rates by testing them with Bayesian vector autoregression (BVAR) with impulse response functions. The prevalent causal impact of changes in commodity prices on the USD exchange rates allows us to devise an underlying analytical model presented in Section 4. The model is empirically tested with Bai-Perron multiple breakpoint (MBP) regressions in Section 5. MBP enables us to identify discernible phases in the changeable relationships between commodity futures and the exchange rates. We gain insights on their time varying patterns by estimating Two-State Markov Switching Models (MSM) shown and discussed in Section 6. The concluding Section 7 summarizes key findings of our study and presents some policy recommendations.

2. Pertinent literature

The literature examining the relationships between commodity spot as well as futures prices and USD exchange rates is extensive and it seems to follow two research streams. The first of them is consistent with our analytical assumptions and empirical findings assuming a causal impact of changes in commodity prices on the exchange rate. The second stream follows reversed causal effects, assuming a prevalent impact of changes in the USD exchange rate on commodity prices.

In essence, our model and empirical tests are based on the first causal reaction, i.e. on the transmission of shocks in commodity futures prices on the exchange rate, as implied by the BVAR tests and impulse response functions discussed below. The causal effects of changes in commodity prices on exchange rates are evidenced among others by Lizardo and Mollick (2010). They show that crude oil prices significantly and continuously explain changes in the USD exchange rate. Reboredo (2012), Ding and Vo (2012) and Chiang, et al. (2014) expand this analysis by demonstrating that such causal impact became stronger during the recent financial crisis. We add to this debate by showing reversals in such inference. While at normal periods increasing commodity futures prices entail the USD depreciation, they result in the USD appreciation at times of financial distress. In our analysis, this direct relationship is transmitted via higher market risk during turbulent market conditions that lead to the USD appreciation.

There are several studies in the literature that assume a reverse causal relationship between commodity futures prices and exchange rates, i.e. a transmission of changes in the exchange rate onto commodity prices. Among others, Sadorsky (2000) shows that futures prices of crude oil, heating oil and gasoline are strongly co-integrated with the trade-weighted exchange rate. Based on a structural VAR analysis of 1990–2007 quarterly data, Akram (2009) argues that a weaker dollar leads significantly to higher commodity prices. Chen et al. (2010) show that exchange rates have a strong predictive power in forecasting changes in global commodity prices. They argue that the opposite causal reaction is notably less robust. Coudert and Mignon (2016) argue that there is a negative transmission of changes in the dollar exchange rate into real oil price, except for the mid-2000s when this transmission becomes positive.

There is a notable distinction between short-run and long-run effects of changes in commodity futures prices on the exchange rate. Among others, Bénassy-Quéré et al. (2005) argue that oil prices significantly and inversely affect the USD exchange rate in the short-run, but their relationship becomes direct in the long-run. Yet, their analysis is based on monthly data ending in 2004 and may not hold for the more recent period much affected by the recent global financial crisis and its resolution policies. In newer studies, Allegret et al. (2015, 2017) show that real currency appreciation following demand-driven rise in oil prices affects only selected countries and their exchange rates and they argue that the proportional role of individual macroeconomic and institutional factors affecting oil prices has changed over time.

There are several studies supporting the second stream of the literature that assumes prevalence of a causal impact of changes in the USD exchange rate on commodity prices. Based on historical evidence of co-movements between oil prices and exchange rates, Zhang et al. (2008) as well as Zhang (2013) show that changes in the USD exchange rate inversely affect changes in oil prices. However, they also show that sudden surges in exchange rate volatility have no impact on fluctuations in oil prices. Similarly, Wu et al. (2012) as well as Beckmann and Czudaj (2013) provide some evidence that the USD depreciation against major currencies results in a corresponding increase in oil prices, although this functional relationship is subject to right-skewness, i.e. prevalence of positive over negative shocks, as well as leptokurtosis (tail risks)[1]. In a similar vein, Sari et al. (2010) provide evidence of short run responses of changes in metal future prices and weaker response of oil prices to fluctuations in USD exchange rates.

[1] For the analysis of tail risks in various financial markets during the 2008–2010 financial crisis see Orlowski (2012).

As a compromise to the discussion about prevalence of causal effects in the relationships between commodity (spot and futures) prices and USD exchange rate, Fratzscher et al. (2014) argue that there is a pronounced causality between oil prices and USD exchange rate in both directions. Nevertheless, they concur that the USD depreciation is brought about by positive shocks in oil prices and this directional effect has been prevalent. They further prove that the negative correlation between oil prices and USD exchange rates has become recently become stronger due to higher market risk triggered by the recent financial crisis. As a result, crude oil and its derivatives have gained importance as global financial assets. In an earlier study, Breitenfellner and Cuaresma (2008) also demonstrated an increasing association between oil prices and exchange rates, attributing it to improved accuracy of forecasts of both commodity prices and exchange rate. The strengthening impact of commodity prices on exchange rates and on other macroeconomic variables stemming from greater stability of their changes and improved forecast accuracy is also proven by Joëts, et al. (2015).

In sum, the literature seems to imply increasing inference of changes in commodity futures prices on the USD exchange rate. Under normal, low risk market conditions, this relationship is inverse, i.e. increasing commodity prices entail USD depreciation, and decreasing prices are associated with the USD appreciation. This functional relationship becomes direct during turbulent, high market risk times. We contribute to the literature by testing the causal effects, varied intensity and stability of these functional interactions between commodity futures prices and USD exchange rate in subsequent sections. While the majority of published empirical studies on this subject are based on low (quarterly or monthly) data frequency, we conduct our empirical tests on daily data. Moreover, we employ the multiple breakpoint regression and the Markov switching process to identify precise daily breakpoints and switching episodes in the tested series.

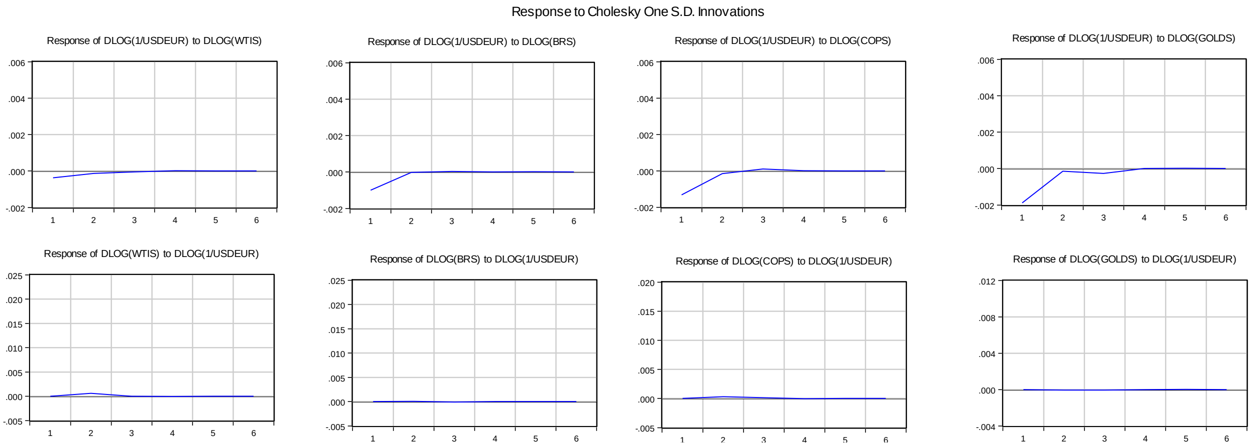
3. Data description and causal interactions

Before devising a model examining association between commodity futures prices and the USD exchange rates, we intend to analyze causal directions and transmission of shocks between these variables. For this purpose, we employ Bayesian vector autoregression (BVAR) analysis and the corresponding impulse reaction functions on our two crude oil and metal prices and separately, USD in EUR and trade weighted USD exchange rates.

As a basis for BVAR and subsequent tests in our study, we use daily data on futures settlement prices and average exchange rates for a sample period January 5, 1999–August 12, 2016 (4401 observations). The beginning of our sample period is determined by the inception of EUR in January 1999. The data are obtained from Bloomberg and Federal Reserve Bank of St. Louis—Federal Reserve Economic Data (FRED). All variables in our empirical exercises are stationary, as they are entered in changes in logs, i.e. captured as percent returns. The order of our BVAR tests is optimized for the number of response lags by minimizing the Akaike information criterion (AIC) at different lag specifications. AIC results suggest a BVAR optimization with 2 lagged terms in each of the examined cases. Our BVAR(2) tests assume Monte Carlo distribution of error terms. From BVAR(2) tests, we derive un-accumulated impulse responses that are shown in Figures 1a and 1b.

The results shown in Figure 1a indicate that the change in logs of USD value in EUR responds inversely to one-standard deviation shocks in commodity futures prices, as displayed in the upper-row diagrams. The opposite causal reactions of commodity prices to the exchange rate are indiscernible (the lower-row diagrams). Brent prices' response is stronger than that of WTI prices. The responses of metal futures, i.e. copper and gold, are stronger than those for crude oil futures. As shown by impulse response functions in Figure 1b, the causal reactions of futures prices to the USD trade weighted exchange rate are almost identical to the responses to USD in EUR.

1a. Responses between commodity futures prices and the USD in EUR exchange rate.



1b. Responses between commodity futures prices and the USD trade weighted exchange rate.

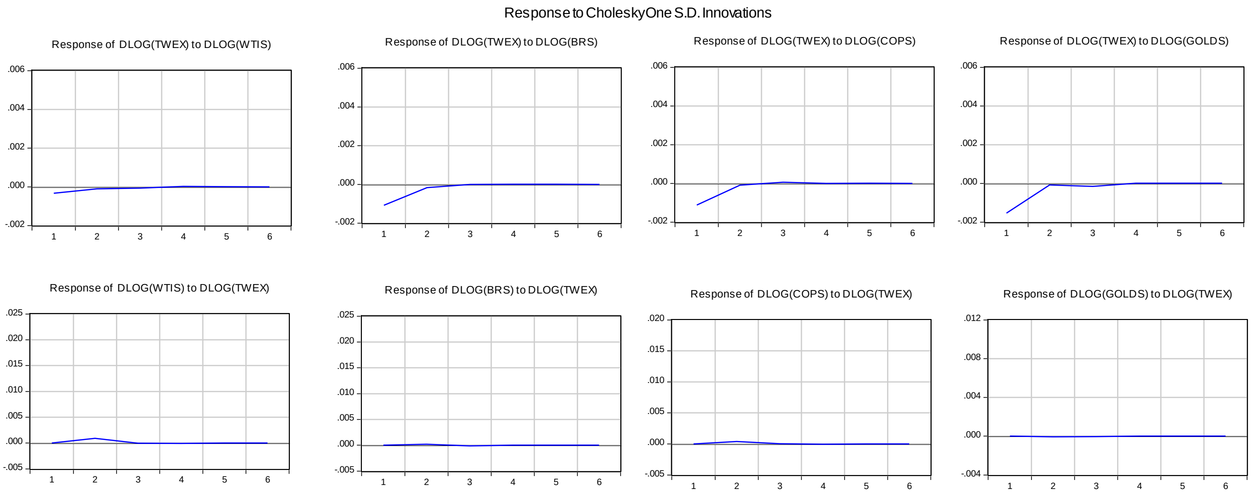


Figure 1. Impulse responses between commodity futures prices and exchange rates. Notes: un-accumulated responses to Cholesky one standard deviation shocks generated from BVAR(2). Daily data for a sample period January 5, 1999–August 12, 2016 (4401 observations). Source: authors' own estimation based on Bloomberg and the Federal Reserve Bank of St. Louis FRED data.

We note that our BVAR tests and impulse response functions are consistent with the directional inference suggested by Lizardo and Mollick (2010), Ding and Vo (2012) and Reboredo (2012). We assume that there is a discernible transmission of market-implied inflation expectations onto commodity futures prices and ultimately to the exchange rate. The first "leg" of this transmission, i.e.

a strong causal impact of changes in the 5-year and the 10-year breakeven inflation to changes in commodity futures prices, is proven empirically by Orlowski (2017)[2]. Moreover, our causal interactions are reversed to those implied by Zhang et al. (2008), Wu et al. (2012) as well as Beckmann and Czekaj (2013), all of whom showing prevalence of a casual inference from nominal USD exchange rates to oil prices. They also demonstrate that these responses are sensitive to sample periods, market risk conditions and testing (data generating) specifications.

In sum, we detect pronounced and rather instantaneous inverse responses of exchange rates to changes in commodity futures prices. Specifically, positive shocks in all four commodity prices entail a USD depreciation, with a one-day lag. Recognizing the prevalence of such causal reactions, we devise an underlying analytical function for further, more specific empirical tests.

4. The underlying model

Taking into consideration the transmission of shocks from commodity futures prices to the USD exchange rates, we devise the following functional relationship that is a basis for the remainder of our analysis:

$$\Delta \log e_t = \beta_0 + \beta_1 \Delta \log(CP_t) + \varepsilon_t \tag{1}$$

with $\Delta loge_t$ representing changes in USD values in EUR or in the USD trade-weighted exchange rate and $\Delta \log(CP_t)$ reflecting percent changes in commodity futures settlement prices.

We fundamentally agree that the relationships between commodity futures prices and USD exchange rates are not uniform over time. They are particularly sensitive to market risk and market liquidity conditions, among other influential factors which in-depth examination is beyond the scope of our analysis[3]. In order to account for different patterns in the relationship prescribed by Equation 1 at tranquil vs. turbulent markets, we introduce the Chicago Board Options Exchange VIX market volatility variable into the examined functional relationship in the following form. We augment Equation 1 with a dummy variable $DVIX$ that assumes the value of 1 at turbulent market periods when VIX exceeds the threshold of 24 and 0 for the tranquil market days of VIX remaining below the threshold. We have identified the VIX threshold of 24 by running the Bai-Perron Threshold estimation of the stochastic VIX series for the entire sample period, permitting just one structural break. The threshold test has identified 3350 tranquil market days, i.e. VIX oscillating below the obtained threshold, and 1050 days of turbulent markets.

The modified functional relationship that accounts for market turbulence by adding the $DVIX$ variable is represented by:

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[2] Breakeven inflation reflects inflation expectations of government bond markets participants, as it is derived from the spread between yield on government bonds and the rates on the corresponding maturity TIPS (Treasury Inflation-Protected Securities).

[3] A number of studies examine a broad range of macroeconomic and institutional factors affecting commodity prices and exchange rates. Worth noting studies addressing these issues include Blanchard and Gali (2007), Fraetzscher et al. (2014), and Joëts et al. (2017).

$$\Delta \log e_t = \beta_0 + \beta_1 \Delta \log(CP_t) + \beta_2 DVIX + \beta_3 \Delta \log(CP_t) * DVIX + \varepsilon_t^{'} \quad (2)$$

The interactive term $\Delta \log(CP)_t * DVIX$ represents the impact of log changes in commodity prices on the exchange rates during elevated market risk periods. It is plausible to expect that at times of high market risk that might be exacerbated by increasing futures prices, there are significant capital inflows to USD denominated assets. As a result, rising commodity prices are associated with the USD appreciation at times of financial distress, thus the value of the estimated $\hat{\beta}_3$ is likely to be positive.

We have conducted a number of empirical tests of the functional relationships represented by Equation 2. The results of the linear MBP estimations as well as non-parametric MSM tests are shown and discussed in the subsequent sections. We choose only the most robust estimations that are optimized by minimizing the Akaike information criterion.

5. Multiple breakpoint tests

We tests the functional relationships between the exchange rates and futures price with the Bai-Perron multiple breakpoints (MBP) regressions in order to identify possible discernible phases in individual functional relationships. The estimation results for the tests of the USD in EUR as a function of commodity futures prices based on Equation 2 are shown in Tables 1a and 1b.

The results shown in Table 1a reflect the MBP estimation of the USD in EUR exchange rate as a function of crude oil prices. There are four discernible periods, separated by three breakpoints for both WTI and Brent prices. Incidentally, the timing of these breakpoints is almost identical in both cases and the results are quite similar. There is no significant relationship between crude oil prices and USD in EUR exchange rate in the early period, i.e. in Phase 1 that begins January 5, 1999 and end January 22 (for Brent) and January 23 (for WTI) of 2003. In Phase 2 capturing the period between late January 2003 and mid-March 2009, there is an inverse, statistically significant relationship between both crude oil prices and the USD in EUR exchange rate. Specifically, an increase in oil futures prices is associated with the USD depreciation, although the estimated values of $\hat{\beta}_1$ coefficients are both rather low. The same coefficient assumes a considerably higher absolute value in Phase 3 that covers the period of crisis resolution policies, notably, the vast liquidity injections by central banks to financial markets (Orlowski, 2015). There is a strong inverse relationship between crude oil prices and the USD value in EUR during this period. More recently in Phase IV, the same inverse relationship is considerably weaker, as suggested by lower estimated values of $\hat{\beta}_1$.

The interactive term is significant only during the most recent period, i.e. in Phase IV. Its estimated $\hat{\beta}_3$ coefficient is positive and equally strong for both WTI and Brent series implying that increasing oil prices at times of financial distress prescribed by VIX exceeding 24 are associated with USD appreciation. This suggests that rising oil prices tend to exacerbate global equity market risk that triggers capital flows to less risky USD denominated securities, thus leads to the USD appreciation. Similar effects are not detected for the preceding sample periods.

Table 1A. Phases in the relationship between changes in logs of USD in EUR exchange rate as a function of crude oil futures settlement prices—Bai-Perron multiple break-point regression estimation results of Equation 2.

Phases based on break points	Changes in the USD in EUR exchange rate as a function of changes in log of WTI price				Phases based on break points	Changes in USD in EUR exchange rate as a function of changes in log of Brent price			
	$\hat{\beta}_0$	$\hat{\beta}_1$	$\hat{\beta}_2$	$\hat{\beta}_3$		$\hat{\beta}_0$	$\hat{\beta}_1$	$\hat{\beta}_2$	$\hat{\beta}_3$
Phase I	*0.001*	0.015	−0.001	−0.001	**Phase I**	*0.001*	0.010	−0.001	0.016
1/05/1999 – 1/23/2003 (998 obs)	*(1.41)*	(1.29)	(−1.56)	(−0.07)	1/05/1999 – 1/22/2003 (986 obs)	*(1.42)*	(0.84)	(−1.45)	(0.94)
Phase II	*−0.001*	−0.042***	0.001	−0.010	**Phase II**	*−0.001*	−0.051***	−0.001	−0.019
1/24/2003 – 3/18/2009 (1535)	*(−0.78)*	(−4.88)	(0.22)	(−0.84)	1/23/2003 – 3/18/2009 (1547)	*(−0.71)*	(−5.64)	(−0.21)	(−1.46)
Phase III	*0.001*	−1.151***	−0.001	−0.006	**Phase III**	*0.002*	−0.149***	−0.001	−0.017
3/19/2009 – 3/22/2013 (1012)	*(0.52)*	(−10.82)	(−0.10)	(−0.32)	3/19/2009 – 3/22/2013 (1012)	*(0.74)*	(−9.56)	(−0.36)	(−0.91)
Phase IV	*0.002*	−0.035***	0.001	0.108***	**Phase IV**	*0.002*	−0.030***	0.001	0.115***
3/25/2013 – 8/12/2016 (855)	*(0.88)*	(−3.89)	(0.09)	(5.14)	3/25/2013 – 8/12/2016 (855)	*(0.90)*	(−3.16)	(0.49)	(5.06)
Diagnostic statistics:									
F-statistics	23.529				22.495				
Log likelh.	16166				16159				
AIC	−7.341				−7.338				
DW	1.981				1.984				

Notes: t-statistics in parentheses; *** denotes significance at 1%, ** at 5%, * at 10%. Daily data for a sample period January 5, 1999–August 12, 2016 (4401 observations). Source: Authors' own estimation based on Bloomberg and the Federal Reserve Bank of St. Louis FRED daily data.

Table 1B. Phases in the relationship between changes in logs of USD in EUR exchange rate as a function of copper and gold futures settlement prices—Bai-Perron multiple break-point regression estimation results of Equation 2.

Phases based on break points	Changes in USD in EUR exchange rate a function of changes in log of copper prices				Phases based on break points	Changes in USD in EUR exchange rate as a function of gold prices			
	$\hat{\beta}_0$	$\hat{\beta}_1$	$\hat{\beta}_2$	$\hat{\beta}_3$		$\hat{\beta}_0$	$\hat{\beta}_1$	$\hat{\beta}_2$	$\hat{\beta}_3$
Phase I 1/05/1999 – 5/24/2002 (835 obs)	*0.001* *(1.49)*	0.018 (0.75)	−0.001 (-0.95)	−0.056 (−1.51)	**Phase I** 1/05/1999 – 4/16/2002 (808 obs)	*0.001** *(1.87)*	−0.083** (−2.49)	−0.001 (−1.01)	−0.064 (−1.36)
Phase II 5/28/2002 – 5/19/2005 (736)	*−0.001* *(0.58)*	−0.121*** (−7.81)	−0.001 (−0.97)	0.267*** (6.82)	**Phase II** 4/17/2002 – 9/02/2005 (836)	*−0.001* *(−0.33)*	−0.441*** (−21.48)	−0.006 (−1.54)	0.114*** (2.89)
Phase III 5/20/2005 – 3/18/2008 (710)	*−0.001* *(−1.40)*	−0.023*** (−2.58)	−0.002 (−0.37)	−0.015 (−0.66)	**Phase III** 9/06/2005 – 11/02/2009 (1048)	*−0.001* *(−0.02)*	−0.178*** (−9.74)	0.001 (0.01)	−0.033 (−1.29)
Phase IV 3/19/2008 – 3/23/2013 (1266)	*0.001* *(0.78)*	−0.187*** (−11.68)	−0.001 (−0.17)	0.048** (2.55)	**Phase IV** 11/03/2009 – 8/12/2016 (1708)	*0.001* *(0.74)*	−0.208*** (−14.45)	0.001 (1.17)	0.164*** (5.72)
Phase V 3/27/2013 – 8/12/2016 (853)	*0.001* *(0.69)*	−0.093*** (−5.81)	−0.001 (−0.09)	0.265*** (5.58)					
Diagnostic statistics:									
F-statistics	27.893				59.471				
Log likelh.	16246				16403				
AIC	−7.375				−7.449				
DW	1.969				2.011				

Note: Source as in Table 1a.

Similar results are obtained in the MBP estimation of the relationship between the USD in EUR and metals prices shown in Table 1B. The MBP estimation identifies five discernible periods for the copper series and four for the gold series. The timing of breakpoints is different in this case.

Nevertheless, the absolute values of the estimated $\hat{\beta}_1$ coefficients are high during the post-crisis sub-periods. Notably, these inverse relationships were strong for both copper and gold series in Phase 2, i.e. during mid-April 2002 to early September 2005 period, which roughly corresponds with the monetary expansion pursued by the Federal Reserve at that time. Unlike in the case of crude oil, the interactive term for both metals was positive and very significant during the 2002–2005 period and also during the most recent period. Evidently, at times of elevated market risk, rising copper and gold prices lead to the USD appreciation, reflecting global risk mitigating efforts through investments in USD denominated assets.

Table 2A. Phases in the relationship between changes in logs of USD trade weighted exchange rate as a function of crude oil futures settlement prices—the Bai-Perron multiple break-point regression estimation results of Equation 2.

Phases based on break points	Changes in the USD trade weighted exchange rate as a function of changes in log of WTI price				Phases based on break points	Changes in USD trade weighted exchange rate as a function of changes in log of Brent price			
	$\hat{\beta}_0$	$\hat{\beta}_1$	$\hat{\beta}_2$	$\hat{\beta}_3$		$\hat{\beta}_0$	$\hat{\beta}_1$	$\hat{\beta}_2$	$\hat{\beta}_3$
Phase I 1/05/1999 − 1/23/2003 (998 obs)	*0.001* *(1.41)*	0.001 (0.07)	−0.001 (−0.44)	0.001 (0.08)	**Phase I** 1/05/1999 – 8/16/2007 (2134 obs)	*−0.001* *(−0.77)*	−0.025*** (0−4.61)	0.001 (0.44)	0.021** (2.28)
Phase II 1/24/2003− 3/18/2009 (1535)	*−0.001* *(−0.99)*	−0.042*** (−6.14)	0.001 (0.79)	−0.005 (−0.53)	**Phase II** 8/17/2007 – 3/18/2009 (2266)	*0.001* *(0.88)*	−0.073*** (−12.47)	−0.001 (−0.90)	−0.002 (−0.26)
Phase III 3/19/2009 − 10/04/2012 (896)	*−0.001* *(−0.33)*	−0.119*** (−11.00)	−0.001 (−0.16)	−0.016 (−1.11)					
Phase IV 10/05/2012 − 8/12/2016 (971)	*0.001* *(1.54)*	−0.051*** (−8.11)	0.001 (0.96)	0.074*** (5.01)					
Diagnostic statistics:									
F-statistics	33.829				50.526				
Log likelh.	17664				17594				
AIC	−8.022				−7.994				
DW	2.035				2.047				

Note: Source: as in Table 1a.

Table 2B. Phases in the relationship between changes in logs of USD trade weighted exchange rate as a function of copper and gold futures settlement prices—Bai-Perron multiple break-point regression estimation results of Equation 2.

Phases	Changes in USD trade weighted ex. rate as a function of copper prices				Phases	Changes in USD trade weighted ex. rate as a function of gold prices			
	$\hat{\beta}_0$	$\hat{\beta}_1$	$\hat{\beta}_2$	$\hat{\beta}_3$		$\hat{\beta}_0$	$\hat{\beta}_1$	$\hat{\beta}_2$	$\hat{\beta}_3$
Phase I 1/05/1999 – 8/05/2002 (881 obs)	*0.001* *(0.45)*	0.010 (0.78)	0.001 (0.05)	−0.037* (−1.89)	**Phase I** 1/05/1999 – 4/16/2002 (808 obs)	*0.001* *(1.11)*	−0.048*** (−2.65)	0.001 (0.20)	−0.065*** (−2.56)
Phase II 8/06/2002 – 5/18/2005 (690)	*−0.001* *(−0.64)*	−0.111*** (−9.39)	−0.001 (−0.76)	0.221*** (7.00)	**Phase II** 4/17/2002 – 9/02/2005 (836)	*−0.001* *(−0.69)*	−0.357*** (−22.90)	−0.001 (−0.99)	0.126*** (4.31)
Phase III 5/19/2005 – 3/18/2008 (710)	*−0.001* *(−1.69)*	−0.020*** (−2.94)	0.001 (0.09)	−0.007 (−0.39)	**Phase III** 9/06/2005 – 11/02/2009 (1048)	*0.001* *(0.02)*	−0.150*** (−10.27)	0.001 (0.07)	−0.024 (−1.19)
Phase IV 3/19/2008 – 11/23/2012 (1183)	*0.001* *(0.22)*	−0.150*** (−12.46)	0.001 (0.06)	0.026* (1.84)	**Phase IV** 11/03/2009 – 8/12/2016 (1708)	*0.001* *(0.73)*	−0.192*** (−19.27)	0.001 (1.48)	0.132*** (6.69)
Phase V 11/26/2012 – 8/12/2016 (936)	*0.001* *(1.32)*	−0.089*** (−7.95)	0.001 (0.01)	0.163*** (4.73)					
Diagnostic statistics:									
F-statistics	40.691				84.596				
Log likelh.	17781				17983				
AIC	−8.073				−8.167				
DW	2.021				2.078				

Note: Source as in Table 1a.

In order to insulate the factors specific to the euro and the euro-denominated assets from our analytical framework, we examine the relationship between commodity prices and the USD trade weighted exchange rate. The results of the MBP regression tests for changes in logs of USD trade weighted exchange rate as a function of WTI and Brent crude oil prices are shown in Table 2A.

The tests identify three breakpoints (four distinctive phases) for WTI series and just one breakpoint (two phases) for Brent. Phase I for the WTI series, capturing a January 5, 1999–January 23, 2003 subperiod, shown no relationship of crude oil prices and the USD exchange rate. In Phases II and III, we observe an inverse relationship between the tested variables. This relationship is stronger in Phase III than in the preceding period, suggesting a strong association between decreasing WTI prices (from their peak in early July 2008) and USD appreciation. During the most recent period of October 5, 2012–August 12, 2016 (Phase IV), this inverse relationship becomes somewhat weaker, as implied by the lower estimated absolute value of $\hat{\beta}_1$. The interactive term $\hat{\beta}_3$ is significant only in the most recent period. Its positive value suggests a combination of rising (declining) WTI prices and USD appreciation (depreciation) at times of financial distress.

It is worth noting that the $\hat{\beta}_3$ for the Brent series is significant only in the early period (Phase I, i.e. a January 5, 1999–August 16, 2007 sub-period). There is no discernible impact of turbulent market conditions on the association between the Brent price and the USD trade weighted exchange rate during the second sub-period. The estimated $\hat{\beta}_3$ coefficients for WTI and Brent show an opposite directional influence during the entire sample period, with the impact of stressful market conditions on the examined relationship becoming stronger for WTI and weaker for Brent over time.

The results of the MBP estimations of Equation 2 for USD trade weighted exchange rate as a function of copper and gold futures settlement prices are shown in Table 2B. The relationship between copper prices and the exchange rate is not significant during the earliest sub-period, i.e. in Phase I. It is statistically significant with a negative sign during the remaining sub-periods, indicating a pronounced inverse relationships in Phases II (August 6, 2002–May 18, 2005) and IV (March 19, 2008–November 23, 2012) and a weaker association in Phases III and V. Turbulent market conditions have a significant positive effect on the relationship between copper and USD trade weighted exchange rate in Phases II and V and these results are fully consistent with the MBP estimation of the USD in EUR exchange rate series in Table 1B. A similar consistency takes place in estimation of gold prices and exchange rates. However this time, in the case of the USD trade weighted exchange rate, there is a statistically significant reversal in the impact of turbulent markets on the examined relationship between Phases I and II. During the episodes of high market risk, higher gold prices were associated with the USD depreciation in Phase I, while they became linked with the USD appreciation in Phase II and again in Phase IV, but not during the eve and the peak of the financial crisis captured by Phase III.

In sum, our tests show prevalence of an inverse relationship between commodity prices and USD exchange rates. However, during the most recent period, i.e. in the aftermath of global financial crisis, their relationships switches from negative to significantly positive during episodes of high market risk, i.e. when VIX exceeds the obtained threshold of 24. The normal inverse relationship between increasing (decreasing) commodity prices and USD depreciation (appreciation) switches to their positive co-movement at times of financial distress, with a reversed interaction between gold price and USD trade weighted exchange rate during the early sample period of 1999–2002. We recognize that it is not possible to consider and find a unified phase division in the tested relationships, since we include diversified (energy and metal) commodity futures that react differently to changes in economic fundamentals and exchange rates. Therefore, the breakpoints remain intrinsically heterogeneous.

6. Two-State Markov Switching tests

In order to examine stability and the exact time pattern of the multiple breakpoint regression estimation for the USD exchange rates as a function of commodity prices, we employ a Two-State Markov Switching Model. Its estimation also enables us to show directional changes and stability of either direct or inverse relationships between both pairs of variables during the entire examined sample period.

A two-state Markov switching process to simulate is specified as follows:

The process in State 1 is specified as:

$$\Delta \log e_{t|St=1} = c_1 + \gamma_1 \Delta \log CP_t + \varepsilon_{1t} \qquad \varepsilon_{1t} \to N(0,1) \tag{3}$$

We expect the process estimated for State (or ”Regime”) 1 to follow a seemingly different relationship between the returns to the exchange rate and commodity futures prices during the examined sample period to that obtained for State (”Regime”) 2. The process reflecting State or Regime 2 is prescribed by

$$\Delta \log e_{t|St=2} = c_2 + \gamma_2 \Delta \log CP_t + \varepsilon_{2t} \qquad \varepsilon_{2t} \to N(0,1) \tag{4}$$

The corresponding transition probability matrix is specified as:

$$P = \begin{bmatrix} p_{11} p_{21} \\ p_{12} p_{22} \end{bmatrix} \tag{5}$$

The results of the Markov switching estimation for change in log of the USD in EUR exchange rate as a function of changes in log of WTI and Brent futures prices are shown in Table 3. The estimations are augmented with a log sigma as a common term.

The obtained States or Regimes from the Markov switching estimations for the WTI and Brent series are somewhat different. In the case of WTI futures prices, Regime I indicates a rather weak, positive relationship (a low $\hat{\gamma}_1$) between changes in logs of the USD in EUR exchange rate and changes in logs in these prices. Regime II reflects episodes of a strong positive relationship between these two variables, as implied by a high, positive value of $\hat{\gamma}_2$. The obtained regimes suggest that most of observed daily changes in WTI and USD in EUR are directly related, switching between mild and strong positive co-movements. The constant transition probabilities and the expected daily durations indicate that Regime I (i.e. a milder relationship) dominates the process. The probability of staying in this stage on any given day is 78 percent and switching to Regime II is only 22 percent. The expected duration of Regime I is 4.6 days, longer than just 2 days expected for Regime II. In hindsight, the relationship between WTI futures prices and USD in EUR exchange rate is predominantly positive, although not very strong.

Table 3. Estimations of Two-State Markov Switching for changes in logs of USD in EUR in relation to changes in WTI and Brent prices (Equations 3, 4 and 5).

	Changes in USD in EUR ex. rate as a function of changes in WTI price	Changes in USD in EUR ex. rate as a function of changes in Brent price
Regime I	$\hat{c}_1$ = 0.001 (0.50)	$\hat{c}_1$ = 0.001 (0.17)
	$\hat{\gamma}_1$*100 = 1.86** (2.14)	$\hat{\gamma}_1$*100 = -0.54 (-0.86)
Regime II	$\hat{c}_2$ = -0.002 (-0.83)	$\hat{c}_2$ = -0.001 (-0.80)
	$\hat{\gamma}_2$*100 = 19.79*** (10.50)	$\hat{\gamma}_2$*100 = 15.13*** (13.56)
Common terms:		
Log Sigma		
	−5.144*** (−419.9)	−5.102*** (−457.0)
Diagnostic tests:	Log likelihood = 16140	Log likelihood = 16142
	Akaike Info. Criterion = −7.333	Akaike Info. Criterion = −7.334
	Durbin Watson stats. = 1.977	Durbin Watson stats. = 1.994
Constant transition probabilities,		
Probability of staying (switching):		
Regime I	0.78 (0.22)	0.99 (0.01)
Regime II	0.49 (0.51)	0.01 (0.99)
Constant expected durations:		
Regime I	4.6 days	205 days
Regime II	2.0 days	105 days

Notes: as in Table 1, z-statistics in parentheses. Source: as in Table 1.

The regimes for Brent futures are more divergent. Regime I is prescribed by an inverse, albeit statistically insignificant co-movement. Regime II reflects a strong, positive relationship. However, the more ambiguous relationship prescribed by Regime I overwhelmingly dominates the process with its 99 percent probability of remaining in it on any given day and its expected duration of 205 days. Evidently, the co-movement between Brent futures and USD in EUR exchange rate is normally not robust, although it becomes stronger and significant at less prevalent times prescribed by Regime II.

Estimations of Markov switching processes for changes in (logs of) USD in EUR exchange rate as a function of changes in (logs of) copper and gold futures prices are shown in Table 4. The relationship between copper futures prices and the exchange rate is mainly positive. Regime I depicts a weaker and Regime II considerably stronger positive interactions. Both $\hat{\gamma}_1$ and $\hat{\gamma}_2$ coefficients are statistically significant. Regime I dominates the process with a low 23 percent probability of switching and the longer expected duration of 3.6 days. In the case of gold, Regime I reflects a negative, although statistically insignificant co-movement with the exchange rate. Regime II represents a significant, positive relationship between both variables and this relationship dominates the process with a longer expected duration of 49 days. The switching probabilities for both regimes are very low—only 3 percent for Regime I and 2 percent for Regime II. It can be therefore argued that both copper and gold futures prices are positively related to the USD value in EUR and this direct co-movement is stronger for gold.

One of the key, rather unexpected findings of our study are observed in Table 5 that shows relationships between changes in (logs of) USD trade weighted exchange rate and changes in (logs of) crude oil futures prices. Somewhat contrary to the results in Table 3, this relationship is mainly inverse for both WTI and Brent. In both cases Regime I reflects a milder inverse co-movement, while Regime II shows considerably stronger inverse relationships. All regime trajectories are statistically significant. The dispersion of results found in Tables 3 and 5 implies a significant negative impact of crude oil futures prices on USD values transmitted via other currencies included in the USD trade weighted basket, primarily via the British Pound. In both WTI and Brent cases, Regimes I, i.e. those reflecting somewhat milder inverse interactions, dominate the process with their longer expected duration and lower switching probability.

Table 4. Estimations of Two-State Markov Switching for changes in logs of USD in EUR in relation to changes in copper and gold prices (Equations 3, 4 and 5).

	Changes in USD in EUR ex. rate as a function of changes in copper price	Changes in USD in EUR ex. rate as a function of changes in gold price
Regime I	$\hat{c}_1$ = −0.001 (−0.61)	$\hat{c}_1$ = −0.001** (−2.27)
	$\hat{\gamma}_1$*100 = 2.59*** (2.66)	$\hat{\gamma}_1$*100 = −2.85 (1.35)
Regime II	$\hat{c}_2$ = 0.001 (0.34)	$\hat{c}_2$ = 0.001 (0.85)
	$\hat{\gamma}_2$*100 = 28.11*** (12.37)	$\hat{\gamma}_2$*100 = 36.53*** (13.56)
Common terms: Log Sigma	−5.140*** (−424.2)	−5.102*** (−457.0)
Diagnostic tests:	Log likelihood = 16185 Akaike Info. Criterion = −7.354 Durbin Watson stats. = 1.989	Log likelihood = 16142 Akaike Info. Criterion = −7.334 Durbin Watson stats. = 1.994
Constant transition probabilities, Probability of staying (switching):		
Regime I	0.72 (0.23)	0.97 (0.03)
Regime II	0.16 (0.83)	0.98 (0.02)
Constant expected durations:		
Regime I	3.6 days	32 days
Regime II	1.2 days	49 days

Notes: as in Table 1, z-statistics in parentheses. Source: as in Table 1.

Table 5. Estimations of Two-State Markov Switching for changes in logs of USD trade weighted exchange rate in relation to changes in WTI and Brent prices (Equations 3, 4 and 5).

	Changes in USD trade weighted ex. rate as a function of changes in WTI price	Changes in USD trade weighted ex. rate as a function of changes in Brent price
Regime I	$\hat{c}_1$ = −0.001 (−0.65)	$\hat{c}_1$ = 0.001 (1.16)
	$\hat{\gamma}_1$*100 = −0.94** (−2.31)	$\hat{\gamma}_1$*100 = −1.20** (−2.42)
Regime II	$\hat{c}_2$ = 0.001 (0.98)	$\hat{c}_2$ = −0.001 (−1.35)
	$\hat{\gamma}_2$*100 = −15.71*** (−14.18)	$\hat{\gamma}_2$*100 = −20.03*** (15.07)
Common terms:		
AR(1)	−0.021 (−1.32)	NA
Log Sigma	−5.469*** (−413.0)	−5.483*** (−447.4)
Diagnostic tests:	Log likelihood = 17665	Log likelihood = 17641
	Akaike Info. Criterion = −8.029	Akaike Info. Criterion = −8.015
	Durbin Watson stats. = 1.980	Durbin Watson stats. = 2.040
Constant transition probabilities,		
Probability of staying (switching):		
Regime I	0.98 (0.02)	0.85 (0.15)
Regime II	0.95 (0.05)	0.31 (0.69)
Constant expected durations:		
Regime I	54 days	6.5 days
Regime II	21 days	1.5 days

Notes: as in Table 1, z-statistics in parentheses. Source: as in Table 1.

A similar reversal from positive to inverse interactions is observed in estimations of changes in USD trade weighted exchange rate as a function of copper and gold futures prices shown in Table 6. Both regimes in the case of copper futures prices in relation to the USD trade weighted exchange rate indicate prevalence of an inverse relationship, in contrast to the direct relationship for the USD in EUR series. Regime II implies a milder inverse co-movement and Regime I a considerably stronger inverse relationship. However, Regime II is dominant with its longer expected duration and a bit higher probability of remaining in it. The Markov switching relationship for gold futures prices is dominated by Regime I reflecting a milder inverse relationship. All obtained estimated $\hat{\gamma}$ coefficient in Table 6 are statistically significant.

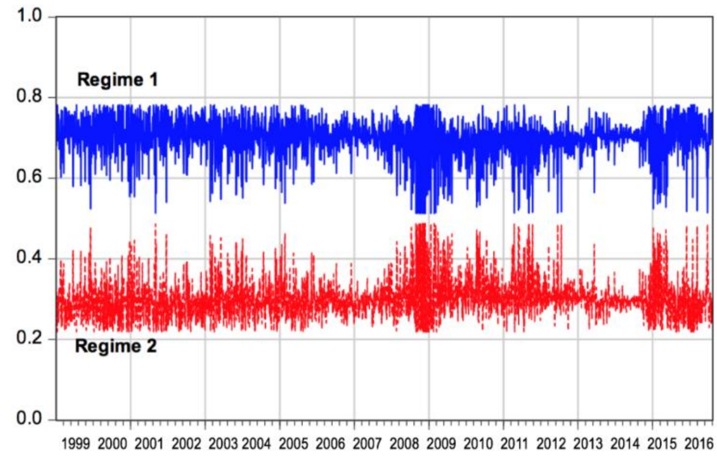
Table 6. Estimations of Two-State Markov Switching for changes in logs of USD trade weighted in relation to changes in copper and gold futures prices (Equations 3, 4 and 5).

	Changes in USD trade weighted ex. rate as a function of changes in copper price	Changes in USD trade weighted ex. rate as a function of changes in gold price
Regime I	$\hat{c}_1$ = −0.001 (−0.25)	$\hat{c}_1$ = 0.001 (1.47)
	$\hat{\gamma}_1$*100 = −25.76*** (12.24)	$\hat{\gamma}_1$*100 = −7.28*** (−6.25)
Regime II	$\hat{c}_2$ = 0.001 (0.49)	$\hat{c}_2$ = 0.001 (0.01)
	$\hat{\gamma}_2$*100 = −3.06*** (−4.13)	$\hat{\gamma}_2$*100 = −40.05*** (−15.67)
Common terms:		
Log Sigma	−5.507*** (−448.2)	−5.579*** (−452.8)
Diagnostic tests:	Log likelihood = 17733	Log likelihood = 18051
	Akaike Info. Criterion = −8.057	Akaike Info. Criterion = −8.202
	Durbin Watson stats. = 2.036	Durbin Watson stats. = 2.077
Constant transition probabilities, Probability of staying (switching):		
Regime I	0.75 (0.25)	0.95 (0.05)
Regime II	0.79 (0.21)	0.92 (0.08)
Constant expected durations:		
Regime I	1.3 days	19 days
Regime II	4.8 days	12 days

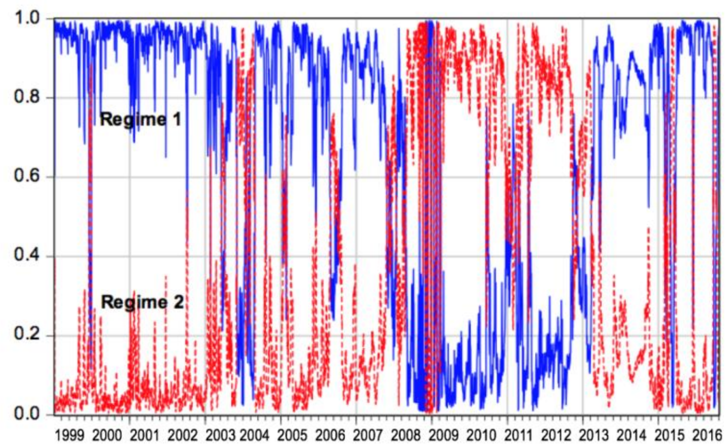
Notes: as in Table 1, z-statistics in parentheses. Source: as in Table 1.

Further insights in stability and reliability of the obtained Markov switching regimes can be derived from Figures 2a-d and 3a-d showing one-step ahead regime probabilities for the USD in EUR and USD trade weighted exchange rates respectively. The regime probabilities path shows in Figure 2a implies an orderly pattern of both regimes in the relationship between WTI futures and USD in EUR exchange rate. There are only minor discernible switching episodes around the peak of the financial crisis at the end of 2008 and the instability of the euro stemming from the sovereign debt crisis in the euro area in 2012–2013. The switching pattern for Brent futures prices vis-à-vis USD in EUR exchange rate two regimes is rather disorderly, as shown in Figure 2b. The regimes were rather stable only at the early stage of the sample period in 1999–2002. Time distribution of predicted regime probabilities for crude oil futures prices as a function of the USD trade weighted exchange rate shown in Figures 3a and 3b is exactly reverse for WTI and Brent. Both identified regimes for WTI series in relation to USD trade weighted exchange rate are very unstable (Figure 3a), while the regimes for Brent show a remarkable stability (Figure 3b).

2a. for WTI series (in conjunction with results in Table 3).



2b. for Brent series (in conjunction with results in Table 3).



2c. for copper series (in conjunction with results in Table 4).

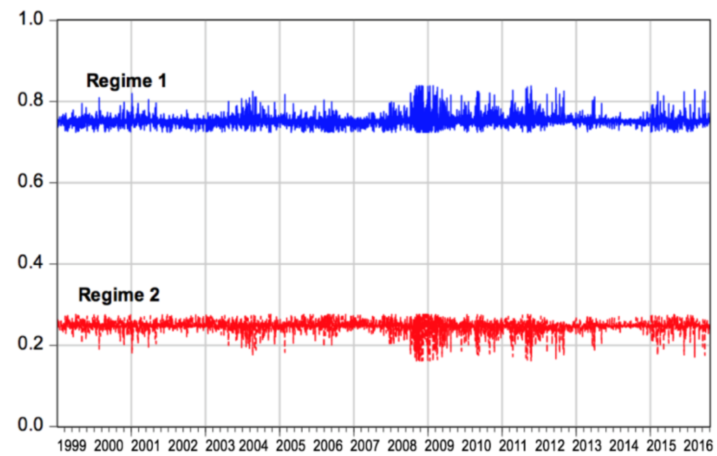


Figure 2. Markov switching one-step ahead predicted regime probabilities for the USD in EUR series as a function of commodity futures prices. Source: authors' own estimation.

2d. for gold series (in conjunction with results in Table 4).

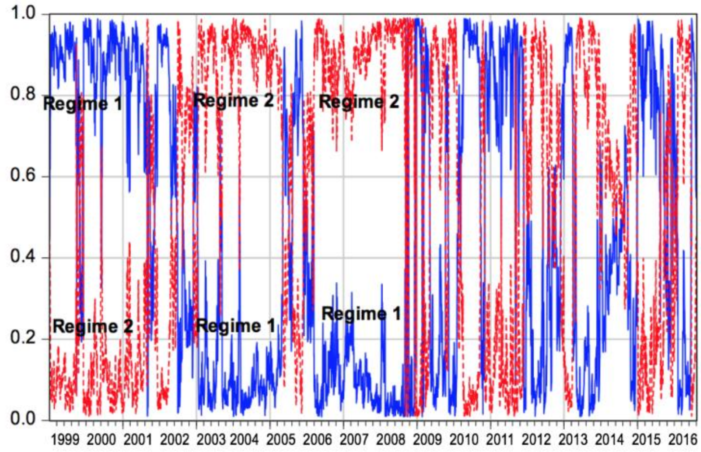


Figure 2. *Continued.*

3a. for WTI series (in conjunction with results in Table 5).

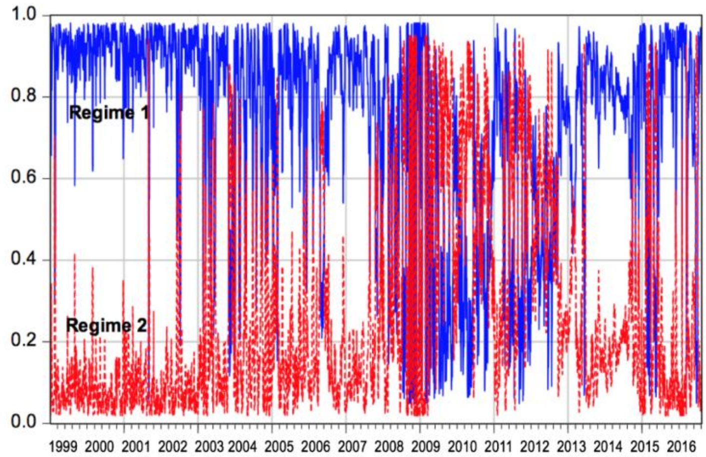
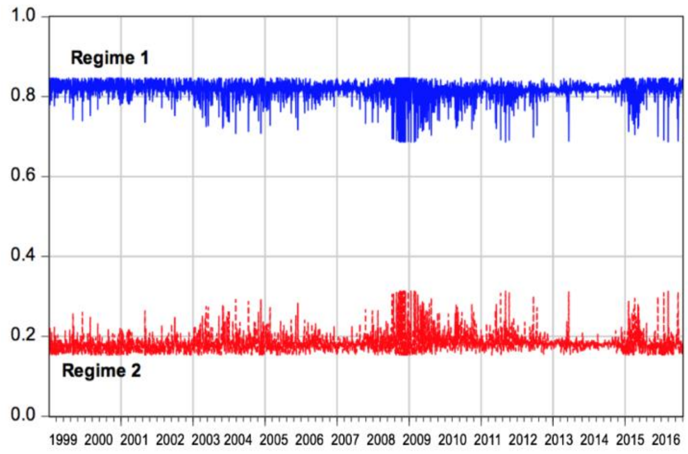
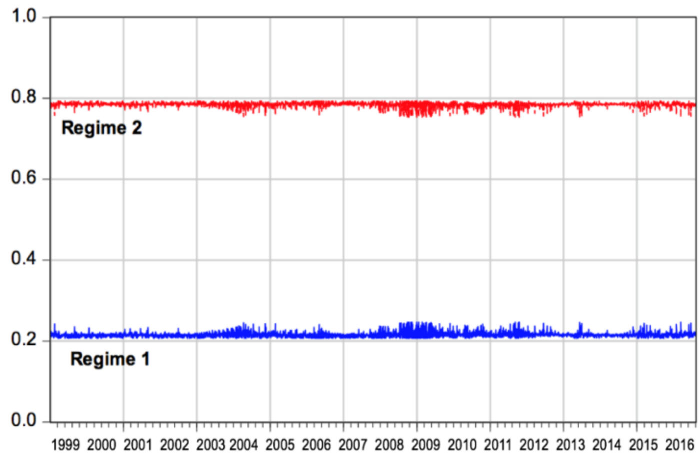


Figure 3. Markov switching one-step ahead predicted regime probabilities for the USD trade weighted exchange rate series as a function of commodity futures prices. Source: as in Figure 2.

3b. for Brent series (in conjunction with results in Table 5).



3c. for copper series (in conjunction with results in Table 6).



3d. for gold series (in conjunction with results in Table 6).

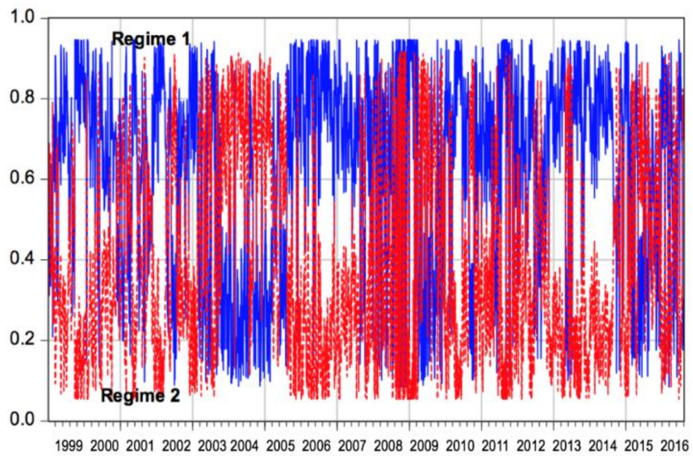


Figure 3. *Continued.*

The patterns of predicted regime switching probabilities for copper and gold futures prices in relation to USD in EUR exchange rate (Figures 2c and 2d) and USD trade weighted exchange rate (Figures 3c and 3d) are very similar. The switching patterns in the case of copper are rather orderly. There are minor switching episodes only in the case of the USD and EUR exchange rate series (Figure 2c) around the peak of the recent crisis and the timing of the euro area sovereign debt crisis. No discernible switching episodes are observed for the copper series as a function of the USD trade weighted exchange rate. In contrast, the patterns for gold series are very unstable in relation to both exchange rates. There are several regime reversals in the case of gold and USD in EUR exchange rate series, particularly during the first half of the entire sample period, i.e. between 1999 and 2007. The pattern for gold in relation to USD trade weighted exchange rate (Figure 3d) is very unsettled through the entire sample period.

In sum, the Markov switching estimations indicate rather unstable interactions between crude oil as well as gold futures prices and USD exchange rates. Stability of the identified regimes for copper futures prices and both USD exchange rates is considerably better. Both WTI and Brent crude oil futures prices are positively related with USD in EUR values. They are inversely related to the USD values on the basis of the trade weighted exchange rate, being presumably strongly affected by fluctuations in other exchange rates.

7. A synthesis

We examine the impact of changes in commodity one-month futures prices on USD exchange rates. Changes in WTI and Brent crude oil futures prices are inversely related with the value of USD in EUR and the USD trade weighted exchange rate. The impact of changes in WTI on USD exchange rates becomes positive under turbulent market conditions that we define as the days of CBOE VIX exceeding the value of 24. However, this positive effect holds only during the most recent sample period of October 5, 2012–August 12, 2016. Changes in copper and gold prices are also inversely related to changes in USD values in EUR and the trade weighted USD exchange rate. We also observe a positive interaction between changes in the two examined metal futures prices and the USD exchange rates during turbulent market conditions, with the exception of the 1999–2002 and 2005–2009 sub-periods.

In essence, market interactions between returns on commodity futures and the exchange rates are not uniform for the examined two crude oils and two metals and exchange rates. There is a correlation between the price of commodity futures and the exchange rates but the relationship is subject to structural breaks over time. The interplay between these returns is very sensitive to the market risk conditions. At normal market periods, i.e. low market risk conditions, there is a significant inverse relationship between commodity futures and exchange rate returns.

These key findings of our study are derived from Bayesian VAR and Bai-Perron multiple breakpoint tests. We further test for dynamic properties of the examined series by employing a stationary Two-State Markov switching process. We find unstable interactions between crude oil as well as gold futures prices and USD exchange rates. Stability of the identified regimes for copper futures prices and both USD exchange rates is considerably better.

In hindsight, we find that USD exchange rates are driven by changes in commodity prices, albeit to varied degrees. Such interaction can be viewed as a special case of the purchasing power parity theory of exchange rate movements where exchange rate changes are affected by the expected price movement in commodity prices.

Although our empirical exercise is focused only on the relationships between four selected commodity futures prices and USD exchange rates, we recognize importance of other factors affecting broader commodity futures prices and exchange rates. Their intricate relationships deserve thorough examination in future research.

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Conflict of interest

The authors declare no conflict of interest in this paper.

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