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Oil and gold price dynamics in a multivariate cointegration framework

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Abstract This study delivers further insights into oil and gold price dynamics and their relation to U.S. prices and the dollar exchange rate. Previous studies have frequently analyzed this issue regarding the price either of gold or of oil; however, the role of both quantities has not been analyzed simultaneously in a broader context. To tackle this caveat, we use monthly data for the nominal effective dollar exchange rate, oil, gold and U.S. prices from 1976:01 to 2011:11. We carefully analyze the long-run as well as the short-run dynamics and the long-run impact in terms of shocks, applying a cointegrated VAR model. The main conclusion we reach is that although gold and oil are both important commodities, their economic impact in terms of their shocks differs significantly. In the long-run, both quantities seem to be positively related and shocks to the gold price drive the system. In addition, the gold-oil spread is positively related to U.S. consumer prices, which implies a stronger relationship of consumer prices to the former.

Keywords Multivariate cointegration · Gold price · Oil price

JEL classification · E31 · F31

1 Introduction

Oil and gold are two of the most important quantities in international financial markets. Unsurprisingly, a broad range of empirical research has analyzed their

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relationships to different variables, providing evidence for various causalities. However, the literature is notably silent on the causality between these two variables. In particular, this issue has not been analyzed in a broader context. Figure 1 shows the evolution of prices for gold and oil in nominal terms between 1976 and 2011. Both move together in the long-run with the oil price showing a higher degree of volatility. Recently, both gold and oil seemed to be not completely determined by supply and demand forces. In 2002, both started to experience a sharp upward turn, which lasted until the second half of 2008. However, since 2009, both prices began to rise again (Zhang and Wei 2010).

From a theoretical point of view, the prices of gold and oil should move together, since both are influenced by common macroeconomic factors such as interest rates, exchange rates and prices (Le and Chang 2011). On the other hand, it is frequently argued that both gold and oil may serve as hedge or safe haven assets in different respects, providing some information about future movements of main economic indicators owing to their ability to incorporate expectations about the future path of the economy.

In terms of long-run linkages stemming from both variables, an analysis which includes further macroeconomic quantities is of crucial importance, since focusing on a narrow system may result in neglecting common stochastic trends which drive the long-run causalities between both quantities. In this vein, the aim of this study is to disentangle the underlying causalities between gold prices, oil prices, exchange rates and U.S. consumer prices. The inclusion of the last two quantities is straightforward since oil and gold are both 1) denominated in dollar and 2) closely related to inflation. To the best of our knowledge, this issue has not been analyzed in an unrestrictive multivariate framework before.

The remainder of this paper is organized as follows. The following section provides a brief description of theoretical considerations and summarizes previous empirical findings. Section 3 first describes the data and the empirical methodology. After introducing our framework we then proceed by analyzing our empirical findings with regard to long-run equilibrium, adjustment dynamics and the long-term impact of shocks. Section 4 concludes.

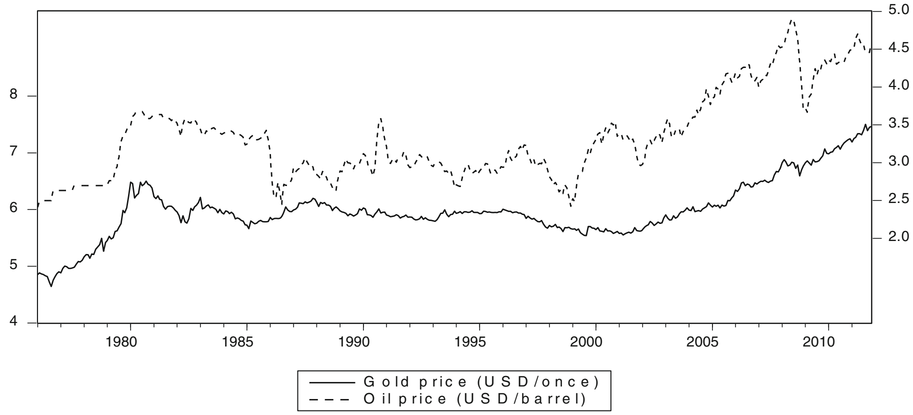

Fig. 1 Natural logarithms of the prices of gold and oil

2 Brief theoretical considerations and a review of the literature

Since a detailed analysis of all linkages related to oil and gold price changes is beyond the scope of this paper, we will in the following briefly describe the strands of literature that have analyzed the dynamics of gold and oil prices in relation to consumer prices and exchange rates.

2.1 Gold, oil and consumer prices

Starting with the relationship to the general price level, both oil and gold prices are considered to offer explanatory power as regards the development of the price level. Over the last decades, the price of oil has been a popular indicator of future consumer price movements (see Czudaj 2011, among others). A direct causality running from oil prices to consumer prices is due to energy-related items which are obtained in the latter, for example fuels, gas and electricity. A second, indirect, transmission through consumer prices stems from the fact that energy prices are also important regarding the production costs of many core items of consumer prices, for instance in transportation costs. Finally, inflationary expectations may also be altered by changes in oil prices, resulting in demands for higher wages and possibly increasing inflation further (Cavallo 2008). However, the question of whether oil shocks have permanent effects on core inflation has still to be clarified. Generally speaking, empirical studies have found that inflationary effects of oil prices have weakened over time (Chen 2009). Such findings have been established mainly by estimating VAR models or by analyzing the importance of oil price shocks in a Phillips Curve framework, where oil price shocks alter inflationary expectations and inflation through supply side shocks.

Blanchard and Gali (2007) and Herrera and Pesavento (2009) use VAR techniques and both find that the importance of oil prices has decreased since the early Eighties.[1] Basing his work on a Phillips Curve framework, Hooker (2002) finds that oil prices had an important impact on U.S. core inflation from 1962 to 1981, while such causality is not observed afterwards. Cavallo (2008) reports similar findings for the period from 1997 to 2008 in the U.S., while a small influence is observed in the U.K. and in Canada. De Gregorio et al. (2007) find that a declining oil price pass-through mechanism is a common feature in 34 developed and developing countries. As an explanation for the weakening link, a less energy-intensive production and a more active monetary policy as well as trade openness are discussed (Chen and Chen 2007). To account for the possibility of transitory shocks, the Federal Reserve Bank also focuses on the core inflation rate, neglecting volatile items such as energy prices.

Turning to the importance of gold price dynamics to inflation, a frequent argument is that the price of gold reflects inflation expectations (Mahdavi and

[1] Blanchard and Gali (2007) analyze the pre- and the post-1983 periods, while Herrera and Pesavento (2009) focus on the periods from 1959 to 1979 and from 1985 to 2006. In both studies, the link is weaker for the second period.

Zhou 1997). According to the expected inflation hypothesis, investors will buy gold if they expect an increase in inflation. The reason is that they either aim at hedging against a decline in the value of money or gamble that gold prices will rise. As a result, gold demand increases. Hence, changes in expected inflation may change the price of gold and investors with knowledge regarding future inflation will have the ability to gain excess revenues. In this vein, gold prices may provide a hedge against future inflation. However, this causality pattern has recently been questioned by Blose (2010). According to his hypothesis of carrying costs, the costs of carrying gold are also affected by expected inflation through changes in interest rates. If those costs offset revenues from speculation, the price of gold is not affected by changing expectations. Empirically, the link between gold and consumer prices has been analyzed in numerous studies. Kolluri (1981), Moore (1990), Laurent (1994), Chappell and Dowd (1997), Mahdavi and Zhou (1997), Harmston (1998), Ghosh et al. (2004), Levin and Wright (2006), Worthington and Pahlavani (2007), Wang et al. (2011), and Beckmann and Czudaj (2013a) have all examined the inflation hedge effectiveness of gold by analyzing the short-run and long-run relationships between the general price level and the price of gold, while the latter three studies allow for different kinds of nonlinearities. Generally speaking, the evidence regarding a long-run relationship between gold and consumer prices strongly depends on the sample period and is not clear-cut although a reasonable conclusion is that gold is at least partially able to provide a hedge against inflation.

2.2 Gold prices, oil prices and exchange rates

Turning to the links related to exchange rates, a direct transmission from U.S. dollar exchange rates to gold or oil prices through changes in supply and demand is a result of the fact that the U.S. dollar serves as the world's numéraire for both prices. If a commodity such as gold or oil is denominated in dollars, a domestic appreciation against the dollar lowers the price of oil or gold in terms of the domestic currency, which increases demand and may result in a general rise in oil or gold prices (Akram 2009; Pukthuanthong and Roll 2011). This mechanism mirrors the law of one price. From a general point of view, a causality running from exchange rates to commodity prices can be derived through an asset-pricing approach of exchange rate determination which links the present exchange rate to the discounted sum of futures fundamentals. However, owing to the fact that fundamentals and exchange rates are jointly determined in equilibrium, convincing empirical support for this theoretically established view has not been delivered (Chen et al. 2008).

In the case of oil, two approaches which detect causal effects of oil prices on exchange rates can be distinguished. The first, introduced by Amano and van Norden (1998), argues that a rise in oil prices results in a real depreciation in economies with large oil dependence in the tradable sector (Bénassy-Quéré et al. 2007; Chen and Chen 2007). The second line of reasoning, triggered by Krugman (1983) and Golub (1983), argues that oil price changes imply a reallocation of international portfolios and also a change in trade balances. According to this view, oil-exporting countries experience a wealth transfer if the price of oil rises (Bénassy-Quéré et al. 2007). The ambiguous long-run reaction of the U.S. dollar against other currencies is determined by the weight of oil in total U.S. imports as compared to the U.S. weights in OPEC imports (Bénassy-Quéré et al. 2007; Coudert et al. 2008).

Referring to both kinds of model, the relationship between the price of oil and exchange rates against the dollar has been analyzed for several countries in various studies. We will mention only a few representative studies in the following. Firstly, many authors using cointegration techniques have provided evidence of a real effective appreciation of the U.S. dollar in the case of rising oil prices in the long-run (Amano and van Norden 1998; Clostermann and Schnatz 2000; Bénassy-Quéré, et al. 2007 and Coudert et al. 2008). Focusing on nominal effective dollar exchange rates, Krichene (2005, 2006) concludes that an appreciation of the nominal effective dollar exchange rate may lead to both an increase and a decrease in oil prices.[2] Chen and Chen (2007) apply panel cointegration techniques for the G-7 countries and also find that a rise in oil prices depreciates the domestic currency against the dollar. Beckmann and Czudaj (2013b) also show that this linkage might be characterized by nonlinearity. Overall, the evidence is not clear-cut.

Only a few studies more closely scrutinize the link between exchange rates and the price of gold. Usually, it is argued that the dollar depreciates against other currencies if the gold price denominated in U.S. dollars increases. Sjaastad and Scacciallani (1996) and Sjaastad (2008) analyze the link between the gold price and major exchange rates. The former paper argues that a non-U.S. investor holds more gold because of its implicit foreign exchange hedging properties. In the latter study, a causality stemming from dollar movements to the price of gold denominated in different currencies is detected. However, Pukthuanthong and Roll (2011) show that an increase in the price of gold can be associated with a currency depreciation in every country. Hence, the prices of gold expressed in two currencies will not move in opposite directions. Other studies which focus exclusively on gold and the dollar are provided by Capie et al. (2005) and Lee and Lin (2012). The former finds a negative relationship between the gold price and the yen-dollar and pound-dollar exchange rate while the latter analyzes the gold futures markets as well as the yen-dollar exchange rate and report similar findings. Kim and Dilts (2011) support this finding with regard to gold prices as well as to oil prices and argue that both gold and oil represent safe haven assets from fluctuations in the value of the U.S. dollar. With regard to volatility patterns, Zagaglia and Marzo (2012) find that comovements between the price of gold and the dollar exchange rate have survived the recent phases of market disruptions.

2.3 Oil and gold prices

Finally, studies which analyze the link between gold and oil prices are rare. A causality from oil to gold prices could stem from the idea that oil price shocks have a negative impact on the real economy and share prices, leading investors to look for alternative assets such as gold in terms of a hedge or a safe haven function. The gold price could also change with increasing oil prices if oil-

[2] With respect to the general link between exchange rates and commodity prices, Chen at al. (2008) find robust power of commodity currencies in predicting global commodity prices, while their results provide little evidence of exchange rate predictability based on commodity prices.

exporting countries invest their revenues in gold (Le and Chang 2011). However, to clarify the direction of causality, the question of which of both quantities is more closely related to inflation seems of crucial importance. One view is that an increase in oil prices results in higher inflationary expectations and a higher demand for gold as a hedge against the latter (Pindyck and Rotemberg 1990). However, depending on the structure of investors' portfolios, an increase in gold prices may also lead to a weakening in the demand for oil, for example if speculative behavior increases the gold price over time as a result of changing expectations.[3] On the other hand, Malliaris and Malliaris (2012) state that rising gold prices may signal inflationary expectations and cause oil-exporting countries to seek increases in oil prices. Finally, gold and oil prices may only be correlated, owing to the fact that they are both reflective of changes in the U.S. dollar (Le and Chang 2011). In this case, we would expect a causality running from exchange rates to both oil and gold prices. In our empirical framework, we will introduce the gold-oil spread in order to compare the linkage of both quantities to U.S. inflation.

Empirically, a minor number of studies have provided evidence that oil price changes also influence the price of gold. Sari et al. (2010) find evidence of a causality running from oil prices to gold prices. Zhang and Wei (2010) identify consistent trends between the prices of crude oil and gold, with a significant positive correlation between 2000 and 2008. Le and Chang (2011) detect causality from oil to gold prices based on Granger (1969) causality tests. They also test for bivariate cointegration and include prices and exchange rates in their framework. Ewing and Malik (2013) provide evidence for a transmission of volatility between gold and oil futures returns while using GARCH models. However, in contrast to this study, these contributions do not analyze the variables simultaneously in a multivariate framework.

Summing up theoretical considerations and the empirical evidence, there is no clear-cut evidence with regard to the direction of causalities owing to the different linkages and transmission channels under consideration. Hence, our unrestricted empirical framework is well suited to disentangle the underlying dynamics.

3 Data, methodology and empirical results

3.1 Data

We use a monthly dataset including the price of gold (g_t) denominated in U.S. dollars provided by the World Gold Council. The consumer price index (CPI) (p_t) for the USA has been taken from the statistics provided by the OECD. Following Lizardo and Mollick (2010), we use the series of the nominal West Texas Intermediate (WTI) crude oil price (o_t) expressed in U.S. dollars per barrel and provided by the Federal Reserve Bank of Saint Louis.[4] The trade-weighted nominal exchange rate of the U.S. dollar is provided by the Board of

[3] Bialkowski et al. (2011) have recently analyzed the possibility of a speculative bubble in the gold price.
[4] The latter shows the same movements such as the Europe Brent and the Dubai crude oil price series, which are also frequently used; however, observations prior to 1986 are not available for both.

Governors of the Federal Reserve System and is given by

$$q_t = q_{t-1} + \prod_{j=1}^{n} \left(\frac{q_{j,t}}{q_{j,t-1}} \right)^{w_{j,t}} \tag{1}$$

where $w_{j,t}$ denotes the weight of country j at time t (Loretan 2005).[5] We use the major index since compared to the broad index, the major index offers the advantage of neglecting the crisis- and inflation-driven exchange rates of emerging countries while focusing on nominal terms.[6] Note that an increase of the exchange rate corresponds to an appreciation of the dollar. All series are taken as natural logarithms. The dataset under investigation starts in January 1976 and ends in November 2011. Hence, we exclude the period immediately after the breakdown of Bretton Woods because of the related turbulences, which influenced both the gold and the oil market and may bias our results. In order to analyze the underlying long-run dynamics, it is important to assure ourselves which order of integration the time series under observation exhibit. The outcomes of the augmented Dickey-Fuller (ADF) test and the Ng-Perron MZa test provide evidence in favor of each series being well approximated by integration order one, e.g. I(1) (Dickey and Fuller 1979; Ng and Perron 2001). This is important, since the U.S. CPI may also be integrated of order two (I(2)), a result which has been previously established in the literature (Juselius 2006).

3.2 The cointegrated VAR approach: econometric methodology and results

Speaking generally, the concept of cointegration refers to linear combinations of non-stationary variables which result in stationary long-run relationships between them. There are different ways to test for cointegration among a couple of variables. In the following, we apply the multivariate test by Johansen (1988), which draws upon the following vector autoregression representation (VAR):

$$\Delta X_t = \Pi X_{t-1} + \Gamma_1 \Delta X_{t-1} + \ldots + \Gamma_{k-1} \Delta X_{t-k-1} + \Phi_1 D_t + \in_t, \quad t = 1, \ldots, T. \tag{2}$$

The non-stationary behavior is accounted for by a reduced rank ($r < p$) restriction of the long-run level matrix Π, which can be fragmented into two $r \times p$ matrices α and β ($\Pi = \alpha\beta'$). β' gives the coefficients of the variables for the r long-run relations, while α contains the adjustment coefficients describing the reaction of each variable to disequilibria from the r long-run relations given by the $r \times 1$ vector $\beta' X_{t-1}$. The terms $\Gamma_1 \Delta X_{t-1} + ... + \Gamma_{k-1} \Delta X_{t-k-1}$ describe the short-run dynamics of the model, using p equations between current variables, lagged variables and equilibrium errors (Juselius 2006). The deterministic components are given by the $p \times 1$ vector ΦD_t, while $\in_t$ describes an independent and identically distributed error term. In the present case,

[5] Geometric rather than arithmetic averaging is applied owing to the fact that the latter may introduce an upward bias due to the measurement of changes in the dollar's average exchange value (Loretan 2005).

[6] The broad index provided by the Federal Reserve constitutes twenty-six currencies. Seven of them - the euro, the Canadian dollar, the Japanese yen, the British pound, the Swiss franc, the Australian dollar and the Swedish krona - are summarized under the major index. The nominal broad index increased by nearly 40 per cent between 1980 and 2004 owing to the higher inflation rate of several economies obtained in the broad index (Loretan 2005).

the expression ΦD_t includes the constant term μ and dummies to account for outliers in the residuals.

For each model, the choice of the lag length is based on the Schwarz criterion and tests for autocorrelation. According to Rahbek et al. (2002), the rank test results we gain in the following are still robust under ARCH-effects. Owing to the fact that our sample period includes several extraordinary events, such as the recent crisis, dummy variables have been introduced to account for resulting outliers, following the methodology described by Juselius (2006). The rejection of the assumption of normality is only due to excess kurtosis, so that our results are still reliable.[7] The corresponding statistics are available upon request.

Regarding the deterministic components, Johansen (1994) distinguishes between five different configurations of a cointegrated VAR model. In this vein, an important question is whether deterministic trends obtained in the data cancel out in the long-run relationships. Since the CPI as well as prices for oil and gold may exhibit deterministic trends, we test for the significance of a trend in the long-run relationships, as described in the following.

We now proceed with the determination of the rank, that is, the number of stationary long-run relationships. This analysis is crucial, as the results of restriction and validity tests as well as the reliability of the estimation depend on the right choice of the rank (r). To identify the number of cointegrating relations r the trace test developed by Johansen (1988) is applied. In a nutshell, the idea is to separate the eigenvalues λ_i, i=1,…,r that correspond to stationary relations from those eigenvalues λ_i, i=r+1,...,p which belong to non-stationary eigenvectors. The test statistic of the corresponding likelihood test, the so-called trace test, is given by

$$trace(r) = -T\sum\nolimits_{i=r+1}^{p}\log\left(1-\widehat{\lambda}_i\right). \tag{3}$$

As a check of robustness we have also simulated the asymptotic critical values for the rank test based on random walks with lengths of 400 and 2,500 replications. A summarization of the results for the trace test is provided in Table 1.

The null of no cointegration is rejected highly significant and the hypothesis of a rank of one is rejected at the 5 % level but not at the 1 % level, according to both the standard and the simulated critical values. However, the null of at most two cointegration relations between the variables cannot be rejected. In addition, a closer look at the recursively estimated trace test statistic and an inspection of the adjustment coefficients for the unrestricted model (which are both available upon request) suggests that two cointegration relationships persist. Hence, we continue our analysis based on two long-run relations. Before the underlying dynamics are analyzed, an important question is whether some variables do not enter any of the long-run relationships or do not adjust to deviations from the long-run equilibrium. To tackle these issues, we run likelihood ratio tests of exclusion and of weak exogeneity. The first test investigates whether a variable can be omitted from the cointegration space by implying zero restrictions on the long-run coefficients, while the latter tests the hypothesis that no adjustment towards the long-run equilibrium occurs by assessing

[7] Since excess kurtosis does not introduce a significant bias to the estimated cointegration vectors, the findings are more sensitive to excess skewness (Juselius and MacDonald 2004; Juselius 2006).

Table 1 Trace test

p-r	r	Eig. Value	Trace	Frac95	Frac95*	p-Value	p-Value*
4	0	0.140	106.963	63.659	61.907	0.000	0.000
3	1	0.060	42.729	42.770	41.158	0.050	0.037
2	2	0.034	16.246	25.731	24.513	0.481	0.432
1	3	0.004	1.718	12.448	11.876	0.971	0.966

Note: The table shows Johansen's (1988, 1991) cointegration test. r denotes the cointegration rank. Critical values are taken from MacKinnon et al. (1999). The asterisk refers to a simulation with T=400 and 2,500 replications

whether the adjustment coefficients are zero (Juselius and MacDonald 2004). We present the results in Tables 2 and 3.

According to our results, all restrictions on either the long-run coefficients or the adjustment coefficients are clearly rejected even at the 5 % level conditional on the choice of r=2. Hence, none of the variables should be excluded from the cointegration space. The deterministic trend should also not be excluded; this implies that the underlying trends do not cancel out in the long-run relationships. When we have determined the rank, the Johansen approach provides the maximum likelihood estimates of the cointegrating relations $\beta' X_{t-1}$. In cases of a rank larger than one, it is necessary to impose merely identifying restrictions on β to achieve interpretable economic relationships for the long-run structure; otherwise the cointegration vector is not unique. Based on economic considerations, further restrictions can also be implemented to realize a model which is over-identified. Hypothesis testing of cointegration vectors is done by specifying the s_i free varying parameters in each β vector according to the term

$$\beta = (H_1 k_1, \ldots\ldots, H_t k_t) \tag{4}$$

with β as $(p_1 \times r)$ and k_i as $(s_i \times 1)$ coefficient matrices, and H_i as a $(p_1 \times s_i)$

Table 2 Tests of exclusion

r	DGF	5 % C.V.	p	g	q	o	t
1	1	3.841	0.359	3.039	14.908	10.702	2.705
			[0.549]	[0.081]	[0.000]	[0.001]	[0.100]
2	2	5.991	12.133	8.820	18.739	18.500	14.346
			[0.002]	[0.012]	[0.000]	[0.000]	[0.001]
3	3	7.815	23.834	17.258	21.353	30.171	25.902
			[0.000]	[0.001]	[0.000]	[0.000]	[0.000]

Note: The table shows likelihood ratio (LR) tests on variable exclusion which are distributed as χ^2 with p degrees of freedom. P-values are reported in brackets. *, ** and *** denote significance at the 10 %, 5 % and 1 % levels. The gold price is denominated by g, o refers to the oil price, q to the effective exchange rate, p to consumer prices and t to the time trend

Table 3 Tests of weak exogeneity

r	DGF	5 % C.V.	p	g	q	o
1	1	3.841	26.210	1.434	1.921	2.046
			[0.000]	[0.231]	[0.166]	[0.153]
2	2	5.991	36.178	6.023	9.497	13.389
			[0.000]	[0.049]	[0.009]	[0.001]
3	3	7.815	46.615	17.616	13.809	16.789
			[0.000]	[0.001]	[0.003]	[0.001]

Note: The table shows LR tests on weak exogeneity which are distributed as χ^2 with p degrees of freedom. P-values are in brackets. *, ** and *** denote significance at the 10 %, 5 % and 1 % levels. The gold price is denominated by g, o refers to the oil price, q to the effective exchange rate and p to consumer prices

design matrix. In the following, we base the tests of our hypotheses on a likelihood ratio procedure, as described by Juselius (2006). Since one main aim of this study is to analyze the causality between gold and oil prices, we imply zero restrictions on consumer prices in the first equation while the exchange rate is restricted to zero in the second equation. To determine whether gold or oil are more strongly related to inflation, we use the gold-oil spread in the second relations by implying a proportional relationship between both. The resulting configurations are presented in Table 4.

The implied restrictions are accepted with a very high p-value of 0.453 and each coefficient of the cointegration vectors is highly significant. Autocorrelation is only rejected for the first lag at the 5 % level. According to the first relation, the prices of gold and oil are positively related. In addition, a nominal effective appreciation of the dollar coincides with a decreasing gold price and an increasing oil price. Turning to the second relation, U.S. consumer prices are positively linked to the gold-oil spread. This finding may be interpreted in the sense that U.S. consumer prices are more strongly related to gold compared to oil: If the price of gold is higher compared to oil, consumer prices increase. Note that this finding does not necessarily imply that the price of oil and U.S. consumer prices are negatively related in a bivariate system. A first result is that gold and oil move together in the long-run, according to both relations.

As a next step, we analyze the adjustment pattern in our next phase. Note that this gives an idea of causality with regard to long-run disequilibria while an interpretation in terms of long-run shocks will be provided below. As already mentioned, none of the variables is weakly exogenous so we expect all variables to contribute to the adjustment to long-run deviations. However, the results suggest that the exchange rate and the price of oil adjust to deviations from the first cointegration relation. As for the second relation, both consumer prices and the oil price adjust with the correct sign while the adjustment coefficient for gold enters with the wrong sign.

Overall, one long-run causality seems to run from gold prices to the other quantities with a positive relationship arising between oil and gold. As far as the first relation is concerned, the pattern that an increase in oil prices coincides

Table 4 Specification of the vector error correction model

Panel (a): Cointegration vectors

	p	g	q	o	t
β_1		0.225***	1	−0.355***	0.003***
		(3.397)		(−5.649)	(9.995)
β_2	1	−0.117***		0.117***	−0.003***
		(−2.699)		(2.699)	(−18.366)

Panel (b): Test of restricted model: $\chi^2(1)$=0.564 [0.453]

Panel (c):

Test for autocorrelation				Test for ARCH			
LM(1):	$\chi^2(16)$	=39.786	[0.001]	LM(1):	$\chi^2(100)$	=117.931	[0.106]
LM(2):	$\chi^2(16)$	=19.594	[0.239]	LM(2):	$\chi^2(200)$	=275.336	[0.000]
LM(3):	$\chi^2(16)$	=24.812	[0.073]	LM(3):	$\chi^2(300)$	=402.979	[0.000]
LM(4):	$\chi^2(16)$	=21.803	[0.150]	LM(4):	$\chi^2(400)$	=556.102	[0.000]

Panel (d): Adjustment coefficients

	Δp	Δg	Δq	Δo
α_1	−0.004***	0.000	−0.014***	0.072***
	(−4.987)	(0.013)	(−2.751)	(3.164)
α_2	−0.005***	−0.116***	0.030***	−0.171***
	(−3.052)	(−3.341)	(2.880)	(−3.677)

Note: Panel (a) shows the estimates of the cointegration vector with t-statistics in parenthesis. Panel (b) shows the test for over-identifying restrictions, which is an LR-test [p-value]. Panel (c) shows LR tests on autocorrelation and ARCH which are distributed as χ^2 with degrees of freedom in parentheses [p-value]. Panel (d) gives the adjustment coefficients towards the long-run equilibrium. The gold price is denominated by g, o refers to the oil price, q to the effective exchange rate and p to consumer prices

with an appreciation of the dollar may be explained by the portfolio structure of oil investors as outlined in Section 2.2. The result that the dollar depreciates in case of a rising gold price is also in line with the analysis of Chapter 2: A rise in the price of gold denominated in dollar is usually associated with a depreciation of the dollar according to the law of one price (Pukthuanthong and Roll 2011). With regard to the second relation, the positive relationship between the gold-oil spread and consumer prices possibly mirrors the ability of gold to provide a partially hedge against inflation as outlined in Section 2.1. Altogether, the fact that oil prices, consumer prices and the exchange rate do all adjust to disequilibria from at least one long-run relation complicates the interpretation of our findings. However, a preliminary result is that gold prices do not seem to play an important role in the overall adjustment mechanism but drive the long-run system.

We now turn to an interpretation in terms of long-run shocks to gain further insights. Strictly speaking, the estimation of the Π matrix does provide equilibrium and adjustment patterns in long-run relationships rather than direct long-run causalities. However, the moving average (MA) representation of the model enables us to study the long-run impact of shocks or to conduct an analysis of the pushing forces of the system (Tuxen 2009). Considering the several possible causalities that were described in Section 2, such an analysis is well suited to delivering further insights. As a starting point, consider the following reformulation of the Π matrix in Eq. (2)

$$x_t = C\sum\nolimits_{i=1}^{t}(\varepsilon_i + \Phi_1 D_i) + C^*(L)(\varepsilon_t + \Phi D_t) + P_0 + u_t. \tag{5}$$

Similarly to Π, the matrix C can be expressed as a product of two matrices (Juselius 2006). $C = \beta_\perp\left(\alpha'_\perp(I - \Gamma_1)\beta_\perp\right)^{-1}\alpha'_\perp$ is a matrix of rank $p{-}r$, $\beta_\perp$ and $\alpha_\perp$ are the $p \times p - r$ orthogonal complements of β and α, respectively, $C^*(L)$ is a stationary matrix-lag polynomial. P_0 depends on the initial values, and $u_t = \alpha'_\perp \boldsymbol{\varepsilon}_t$ describes $p - r$ common shocks that have a permanent effect on the variable system (Johansen 1996; Juselius 2006). While $\alpha_\perp$ gives the coefficients for the common stochastic trends that drive the system, $\beta_\perp$ shows the reaction of each variable to those trends (Juselius et al. 2011). Hence, the long-run impact matrix C shows how each variable is affected by accumulated shocks to other variables and can be written as follows for our setting

$$\begin{bmatrix} p_t \\ g_t \\ o_t \\ q_t \end{bmatrix} = \begin{bmatrix} c_{11} & c_{12} & c_{13} & c_{14} \\ c_{21} & c_{22} & c_{23} & c_{24} \\ c_{31} & c_{32} & c_{33} & c_{34} \\ c_{41} & c_{42} & c_{43} & c_{44} \end{bmatrix} \tag{6}$$

As an example, the first row ($c_{12}{-}c_{14}$) displays how the price level is affected by shocks to the different quantities. The estimation of the C matrix for our reduced model is presented in Table 5.

We now analyze step by step the reaction of each variable to the different accumulated long-run shocks. U.S. consumer prices do react positively to gold price shocks, mirroring the ability of gold to incorporate inflation expectations and to serve as a hedge against inflation as argued above according to the second long-run relation. Note that the negative effect of oil price shocks on consumer prices is due to the proportionality restriction of the second relation: An increase in oil prices reduces the gold-oil spread which is positively related to U.S. prices. The finding that a nominal effective depreciation of the dollar causes U.S. prices to raise is in line with the theoretical concept of purchasing power parity (PPP).[8]

Shocks to U.S. prices and the oil price both affect the price of gold negatively. The negative oil-gold relationship is somehow puzzling considering the arguments raised in Section 2 but may again be due to the proportionality restriction of Section 2. Turning to the exchange rate, the findings suggest that an increase in the price of oil appreciates the dollar and mirrors the first long-run relationship. The same wisdom holds with regard to the finding that shocks to gold prices force the dollar to depreciate according to the law of one price. Finally, oil prices react positively to gold and exchange rate shocks, but negatively to price shocks. The negative impact of price shocks may again mirror the restriction between gold and oil of Section 2.

[8] Previous research has illustrated that the relationship between consumer prices and the nominal exchange rate is nonlinear and mainly driven by nominal exchange rate adjustment. Since this pattern is not the main point of our study, we do not explain this finding in detail. A discussion is provided by Beckmann (2013).

Table 5 Moving average representation

	p	g	q	o
p	−0.679	0.083***	−0.205***	−0.074***
	(−1.195)	(3.793)	(−2.776)	(−2.763)
g	−11.213**	1.271***	0.292	−0.512**
	(−1.987)	(5.828)	(0.398)	(−1.926)
q	0.606	−0.088**	0.660***	0.158***
	(0.526)	(−1.973)	(4.406)	(2.911)
o	−5.407*	0.559***	2.043***	0.120
	(−1.901)	(5.083)	(5.534)	(0.899)

Note: The table gives the results of the long-run impact matrix obtained from a moving average representation for the identified model, as described in Section 3.2. The gold price is denominated by g, o refers to the oil price, q to the effective exchange rate and p to consumer prices

Generally speaking, the positive impact of shocks to the gold price on oil is in line with the identified long-run relationships.

Finally, it should be mentioned that the dynamics described correspond to a long-run impact but not to short-run effects and are conditional on our identified long-run structure. Considering our previous findings regarding long-run relations and adjustment coefficients, a reasonable conclusion might be that gold prices are mainly responsible for one common stochastic trend, since both oil and gold are positively related and the oil price does adjust. Hence, the causality seems to run mainly from gold prices to oil prices.

4 Conclusion

The aim of this study was to disentangle the underlying causalities between gold and oil prices, exchange rates and U.S. consumer prices. The results deliver evidence of different causalities and are not straightforward to interpret. Firstly, an increase in the price of gold depreciates the dollar, as suggested by the law of one price. On the other hand, the price of oil and the effective dollar exchange rate are positively related. Since both gold and oil are denominated in dollar, an analysis in terms of bilateral dollar exchange rates instead of effective exchange rate is necessary to explain this pattern from an investor's point of view.

Another interesting finding is that consumer prices are positively related to the gold-oil spread which implies a stronger relationship of consumer prices to the former. Besides the ability of gold to incorporate future inflation, this finding may be explained by the fact that the relationship between inflation and oil has weakened over time. Finally, the causality seems mainly to run from gold prices to oil prices for the sample under investigation, since both variables are positively related and oil prices adjust, according to the results of the long-run relationship and the adjustment patterns. Gold prices translate positively into oil prices. Our main conclusion is that, although gold and oil are both important commodities, their economic impact differs significantly.

Changes in oil prices may be stronger related to expectations about the real economy, while gold prices are perhaps driven mainly by portfolio choices and investors' sentiments and perform an indicator function.

From our point of view, an explanation for the various causalities is an important issue for further research. An obvious extension would be the inclusion of instabilities, for instance in terms of structural breaks or time-varying short-run dynamics in the spirit of Beckmann and Czudaj (2013a) who analyze gold and consumer prices for different currencies in a bivariate regime-switching framework.[9] Another interesting topic is using futures instead of spot prices for gold and oil.

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