



The gold price in times of crisis



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ABSTRACT

Motivated by the recent gold price boom, this paper examines whether an asset bubble exists in the gold market. We approximate gold's fundamental value using several econometric models and apply a Markov regime-switching Augmented Dickey–Fuller (ADF) test which has substantial power for detecting explosive behavior. Although our results are sensitive to the specification of the fundamental value, we show that a model accounting for the current European sovereign debt crisis accurately tracks the gold price observed in the market. We also note that inflation in a general commodity price index and gold ETF demand have a potential to explain the price trajectory.

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1. Introduction and literature review

Since 2001, the price of gold has skyrocketed from a level of US\$ 250 per troy ounce to an all-time high of US\$ 1900 in August 2011, before falling substantially to around US\$ 1200 at the end of June 2013. At first blush, this price trajectory may bear a resemblance to a bubble path. In addition, investment demand for gold has increased substantially over the last decade, which attests to the rising interest in gold as a financial asset (see Fig. 1).¹ It needs to be mentioned, however, that the considered period witnessed some extreme shifts in the underlying economic fundamentals, which are bound to affect the intrinsic value of gold. The recent world financial crisis was characterized by crashing real estate and stock market valuations as well as bank failures, while the current European sovereign debt crisis substantially increased the default risk of several countries. At the same time, interest rates on bank deposits were pushed to very low levels. Related to this, central banks have carried out a very expansive monetary policy addressing the refinancing problems of banks and governments, but simultaneously increasing inflation expectations.

In circumstances like these, investment in gold became a rather appealing option, and financial market participants might have increased its portfolio weight significantly. Gold is seen as a globally accepted currency which never loses its purchasing power, and maintains its value even in the face of erosion of the monetary or banking systems. Not surprisingly, gold has a special position among other precious metals. The study of [Batten, Ciner, and Lucey \(2010\)](#) provides only limited evidence that the volatility of the gold market is affected by the same macroeconomic factors as is the case for other precious metals. The risk-mitigating characteristics of gold have been discussed in prior literature, which evaluated the increasingly important role of gold as a dollar hedge ([Capie, Mills, & Wood, 2005](#); [Sjaastad, 2008](#); [Tully & Lucey, 2007](#); [Zagaglia & Marzo, 2013](#)), an inflation hedge ([Adrangi, Chatrath, & Raffee, 2003](#); [Bloise, 2010](#); [Worthington & Pahlavani, 2007](#)) and a portfolio diversifier ([Hillier, Draper, & Faff, 2006](#); [Jaffe, 1989](#)).² In addition, gold is regarded as a safe haven in times of turmoil ([Baur & Lucey, 2010](#); [Baur & McDermott, 2010](#); [Chan, Trepongkaruna, Brooks, & Gray, 2011](#); [Ciner, Gurdgiev, & Lucey, 2013](#)). On the other hand, the recent gold price boom might indicate a speculative bubble. For example, [Phillips and Yu \(2010\)](#) find evidence for a speculative bubble moving from the equity market (up to 2000) over the US housing market (up to 2007) to the crude oil market (up

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¹ For further information on the global gold market see, for instance, [Shafiee and Topal \(2010\)](#).

² In the same vein, there is also evidence that gold serves as a store of value against other major currencies ([Pukthuanthong & Roll, 2011](#); [Sjaastad & Scacciavillani, 1996](#)).

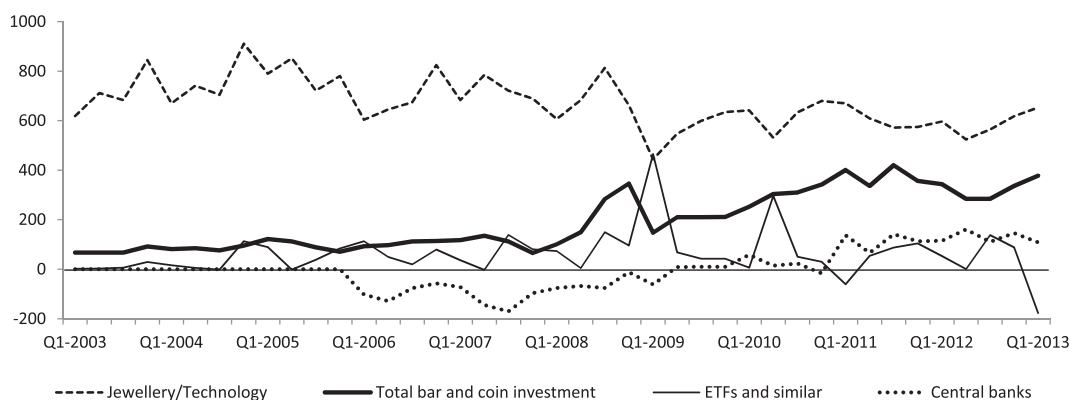


Fig. 1. Gold demand. Notes: The figure shows gold demand by category (in tonnes). Source: World Gold Council (2013).

to mid-2008). Thus, we ask whether the gold market is another victim of such a wandering asset price bubble.

Consideration of price bubbles is important, as they are usually symptomatic of an inefficient resource allocation and can lead to market crashes that reverberate within the wider society. So far, to the best of our knowledge, the possibility that the gold price may currently exhibit a speculative bubble has attracted attention in the academic literature, but no final conclusion has yet been reached. The present paper aims to extend the existing evidence by applying an econometric technique which allows for early detection of explosive behavior in prices. While the future gold returns may be positive as well as negative depending on the factors that underpin the price formation process, any insights into whether a bubble exists can inform judgments about the likelihood of future dramatic market implosions. For this reason, the conclusions offered are relevant not only to academics, but to decision-makers and investors alike. The inferences may be helpful to gold mine managers who need to make long-term operational decisions that take into account future market prices and given extraction costs. They may also be instructive to investors who contemplate their investment and diversification strategies, as well as their hedging needs. Finally, in view of the results, central banks may consider whether to replenish or monetize their gold reserves, determine the extent of their involvement in gold leasing schemes and frame early monetary policy responses.

Until now, econometric testing for speculative bubbles has mainly been focused on (US) stock markets. [Gürkaynak \(2008\)](#) provides a recent in-depth survey of econometric methods used for detecting asset price bubbles. This survey includes the well-known variance bounds tests, West's two-step method, cointegration-based tests as well as the concept of intrinsic bubbles and methods treating bubbles as an unobserved variable. By contrast, little effort has been made to date in identifying speculative bubbles in the gold price. [Blanchard and Watson \(1982\)](#) draw on runs and tail tests, but are unable to conclude whether the gold price was unjustifiably high between 1975 and 1981, given the caveats of their methodology. [Diba and Grossman \(1984\)](#) investigate the stationarity properties of the gold price for the time period from 1975 to 1983, and find that it was entirely based on market fundamentals.

As shown by [Evans \(1991\)](#), however, the ordinary unit-root and cointegration tests do not allow for the detection of the important class of periodically bursting bubbles. Due to the bursting nature of such bubbles, these tests have a tendency to reject the null hypothesis of non-stationarity in favor of the stationary alternative all too often. Being aware of this critique, [Pindyck \(1993\)](#) draws on the convenience yield approach, and calculates gold's fundamental value based on the present value model for commodities. Running tests of forecasting power, Granger causality, and restrictions of appropriately specified vector autoregressive (VAR) models, [Pindyck \(1993\)](#) finds evidence in

favor of gold price bubbles between 1975 and 1990. In addition, based on a dynamic factor model, [Bertus and Stanhouse \(2001\)](#) focus on the gold futures market, and provide weak support for the bubble hypothesis during notable socioeconomic events in the time period from 1975 to 1998. Finally, [Drozd, Grümmer, Ruf, and Speth \(2003\)](#) make use of a log-periodic power law (LPPL), and detect a gold price bubble, analyzing the interval between 1978 and 1982.

With regard to the recent gold price boom, only a few studies provide preliminary empirical evidence. Drawing again on the LPPL approach, [Drozd, Kwapien, Oswiecimka, and Speth \(2008\)](#) support the hypothesis of a gold price bubble from 2003 to 2008. In particular, they are even able to identify a local bubble on top of a long-run bubble, so that the former is called a "super-bubble". In addition, following [Pindyck \(1993\)](#), [Went, Jirasakuldech, and Emekter \(2012\)](#) build on the convenience yield model, and run the duration dependence test which indicates gold price bubbles in the time span from 1976 to 2005. Unfortunately, their approach suffers from the fact that they cannot conclude when speculative bubbles affected the gold price exactly. [Homm and Breitung \(2012\)](#) use the Supremum Augmented Dickey–Fuller (SADF) test, and find evidence for gold price bubbles between 1968 and 1980 (at the 1%-level) and between 1984 and 2010 (at the 10%-level). However, their methodology only tests for explosiveness in the price time series itself, and does not take gold's fundamental factors into consideration. As a consequence, [Homm and Breitung \(2012\)](#) are thus unable to conclude whether their findings might result from major economic events such as the recent world financial crisis and the current European sovereign debt crisis rather than speculative excess. In a similar spirit, [Baur and Glover \(2012\)](#) also draw on the SADF test, and find evidence of explosiveness in the gold price series without allowing for a fundamental value.³ Finally, [Lucey and O'Connor \(2013\)](#) use gold's lease rates in order to approximate the fundamental value of gold. Their application of the Markov regime-switching ADF test gives mixed evidence regarding the existence of gold price bubbles.

In order to overcome these caveats, we propose to construct gold's fundamental value making use of its role as a dollar hedge, inflation hedge, portfolio diversifier, and safe haven. Drawing on the deviations of the actual gold price from its fitted value, we then apply a Markov regime-switching ADF test to identify periods that are characterized by explosive behavior. Based on estimated probabilities of being in the possible bubble and the non-bubble regime, this approach thus also allows for the detection of speculative bubbles during the recent

³ Admittedly, however, in another study [Baur and Glover \(2014\)](#) provide economic reason for their bubble hypothesis by analyzing the activities of fundamentalists and chartists on the gold market. Their empirical results show that both agent types are important in explaining historical gold prices but that the 10-year bull run of gold in the early 2000s is consistent with the presence of agents extrapolating long-term trends, which might have resulted in a non-fundamental price exaggeration.

world financial crisis and the current European sovereign debt crisis. While our results are to a certain extent dependent on the choice of the gold fundamentals, the most realistic models provide little evidence of speculative bubbles both for the gold price boom from 1979 to 1982 and the more recent period. In particular, we find that the European sovereign debt crisis can be seen as one possible driver for the recent gold price boom.

There are several reasons why the debt crisis is of great importance to the participants of capital markets in general and gold investors in particular. First, the evidence suggests that the crisis has contagious qualities, and may spread cross-border with relative ease (Arghyrou & Kontonikas, 2012). Second, the solvency of governments and the fortunes of the financial sector are very closely intertwined. Caruana and Avdjiev (2012) point out that banks have direct portfolio exposures to sovereign risk, while governments often face the need to recapitalize distressed banks. Lane (2012) refers to this vicious circle as a “diabolic loop”. Third, the fiscal trouble at the periphery endangers the very existence of the euro area. Viewing the situation through the prism of the existing systemic risks, it is easy to understand why investors may have a preference for gold, and why its price has appreciated over time.

This paper proceeds as follows. In Section 2, we discuss the construction of gold's fundamental value. In Section 3, we explain the Markov regime-switching ADF test. In Section 4, we show our baseline empirical results and, by analyzing commodity prices and gold ETF demand, consider explanations alternative to the European sovereign debt crisis story. In Section 5, we briefly conclude.

2. Construction of gold's fundamental value

As outlined above, gold is widely regarded as a dollar hedge, inflation hedge, portfolio diversifier, and safe haven. First, if gold is a hedge against the dollar, its price should be inversely related to the strength of the US currency. Second, if gold is a hedge against inflation, its price should comove with the price index of a basket of goods, so that gold's real value is preserved. Third, if gold is a portfolio diversifier (safe haven) against financial assets such as stocks and bonds, its price should be uncorrelated or negatively correlated with them (in times of market turmoil). These fundamental factors are also considered by Baur (2013a).

Last but not least, we postulate that the gold price is likely to respond to instances of systemic risk, such as the current European sovereign debt crisis. We operationalize the measurement of the severity of the crisis by constructing an empirical gauge based on the difference between the GDP-weighted average 10-year government bond yields of the PIIGS countries (Portugal, Italy, Ireland, Greece, and Spain) and the yield of 10-year German bonds (Bunds). Since the yields are monotonically increasing in the probability of default, this proxy is a barometer of the severity of euro zone tensions. Recent studies on the European sovereign debt crisis have used a spread between yields offered by bonds of the PIIGS countries and Germany as well. Such a spread has thus become a key indicator of the depth of the current European sovereign debt crisis (Calice, Chen, & Williams, 2013; De Santis, 2012; Mody & Sandri, 2011). Kalbaska and Gatkowski (2012) point out that the EU core countries such as France, Germany, and the UK hold a significant proportion of PIIGS debt, and are thus heavily exposed. Market professionals are painfully aware of the gravity of the situation, and assign relatively high probabilities to potential partial or complete euro area disintegration (Brace, 2011).

Based on these possible fundamental factors of the gold price, we explain its rate of return at date t , $r_{Gold,t}$, as follows:

$$r_{Gold,t} = \sum_{i=0}^2 \gamma_{1,i} \cdot r_{FX,t-i} + \sum_{i=0}^2 \gamma_{2,i} \cdot r_{Inflation,t-i} + \sum_{i=0}^2 \gamma_{3,i} \cdot r_{MSCI,t-i} + \sum_{i=0}^2 \gamma_{4,i} \cdot r_{T-Bill,t-i} + \sum_{i=0}^2 \gamma_{5,i} \cdot r_{Spread,t-i} + \nu_t, \quad (1)$$

where $r_{FX,t}$ is the percentage change of the trade-weighted value of the US dollar against other major currencies, $r_{Inflation,t}$ is the percentage change of the US all-urban consumer price index, $r_{MSCI,t}$ is the percentage change of the MSCI World index of major stock markets, $r_{T-Bill,t}$ is the three-month US Treasury bill rate, $r_{Spread,t}$ is the difference between the GDP-weighted average of 10-year government bond yields in PIIGS countries and similar yields in Germany, and ν_t is the error term. $r_{FX,t}$ refers to gold's role as a dollar hedge, $r_{Inflation,t}$ should capture its role as an inflation hedge, and the selection of $r_{MSCI,t}$, $r_{T-Bill,t}$, and $r_{Spread,t}$ is motivated by gold's role as a portfolio diversifier in tranquil periods and as a safe haven in times of market turmoil. In particular, $r_{Spread,t}$ represents the widely used indicator of the current European sovereign debt crisis.

All regressors are allowed to have a contemporaneous and a lagged impact of one and two periods. Our reason for doing so is that predictions are normally based on models including lagged values. In addition, macroeconomic data are published with time delay. Finally, we justify our specification by calculating the adjusted R^2 which is highest for the model with two lags compared with those with only one or even zero lags.

Time series which contain a unit root are adjusted by subtracting the respective variable's mean value of the previous year. All variables are calculated as continuous changes in percentage, and refer to the last day of a month, except for the inflation rate which is only available on a monthly frequency anyway. All (adjusted) time series consist of 462 observations (January 1975–June 2013), except for the spread between the 10-year government bond yields of the PIIGS countries and Germany, which includes 126 observations (January 2003–June 2013). Thus, the latter variable explicitly captures the possible influence of

Table 1
Descriptive statistics.

	Mean	Max	Min	Std	Skew	Kurt	ADF
Gold	0.44	25.22	−23.70	5.57	0.20	2.90	I(0)
Exchange rate	−0.06	6.47	−5.39	1.71	−0.07	0.41	I(0)
Inflation	4.02	13.62	−2.01	2.76	1.45	2.05	I(1)
Adj. inflation	−0.13	3.27	−4.12	1.16	−0.40	0.60	I(0)
MSCI world	0.63	13.57	−20.84	4.47	−0.68	2.18	I(0)
T-Bill	5.14	15.59	0.01	3.40	0.60	0.48	I(1)
Adj. T-Bill	−0.11	4.66	−4.58	1.13	−0.04	2.32	I(0)
PIIGS GDP	1.48	6.49	0.09	1.87	1.29	0.35	I(1)
Adj. PIIGS GDP	0.19	2.51	−1.98	0.71	0.21	1.96	I(0)
PIIGS Pop	1.57	7.10	0.09	2.04	1.33	0.46	I(1)
Adj. PIIGS Pop	0.20	2.59	−2.25	0.79	0.10	1.97	I(0)
PIIGS CDS	1.85	7.68	0.05	2.21	1.02	−0.26	I(1)
Adj. PIIGS CDS	0.17	2.29	−3.07	1.01	−0.70	1.87	I(0)
Gold ETF	24.80	46.73	5.35	13.25	−0.09	−1.50	I(1)
Adj. Gold ETF	2.49	12.09	−14.22	3.79	−1.63	6.94	I(0)
CRB Index	2.41	4.63	1.19	0.77	0.30	−0.95	I(1)
Adj. CRB Index	0.05	1.02	−1.45	0.35	−1.59	5.43	I(0)

Notes: The table reports the arithmetic mean (Mean), the maximum (Max), the minimum (Min), the standard deviation (Std), the skewness (Skew), the excess kurtosis (Kurt), and the degree of integration based on the Augmented Dickey–Fuller test (ADF) for the percentage change of the gold price per troy ounce (Gold), the percentage change of the trade-weighted value of the US dollar against other major currencies (Exchange Rate), the (adjusted) percentage change of the US all-urban consumer price index ((Adj.) Inflation), the percentage change of the MSCI index of major stock markets (MSCI World), the (adjusted) three-month US Treasury bill rate in percent ((Adj.) T-Bill), the (adjusted) spread between the PIIGS countries' and Germany's ten-year government bond yield, where the average PIIGS yield is weighted by GDP ((Adj.) PIIGS GDP) and the size of population ((Adj.) PIIGS Pop), respectively, the scaled (adjusted) spread between the respective CDS premia ((Adj.) PIIGS CDS), the scaled (adjusted) aggregated flows of the two biggest gold ETFs ((Adj.) Gold ETF), and the scaled (adjusted) Commodity Research Bureau index of commodity prices ((Adj.) CRB Index). I(0) indicates stationarity, and I(1) a unit-root. Time series which contain a unit-root are adjusted by subtracting the respective variable's mean of the previous year. All variables refer to the last day of a month, except for the (adjusted) US inflation rate which is only available on a monthly frequency anyway. Gold, exchange rate, inflation, MSCI world, and T-Bill consist of 462 observations (Jan. 1975–Jun. 2013), where the others include only 126 observations (Jan. 2003–Jun. 2013).

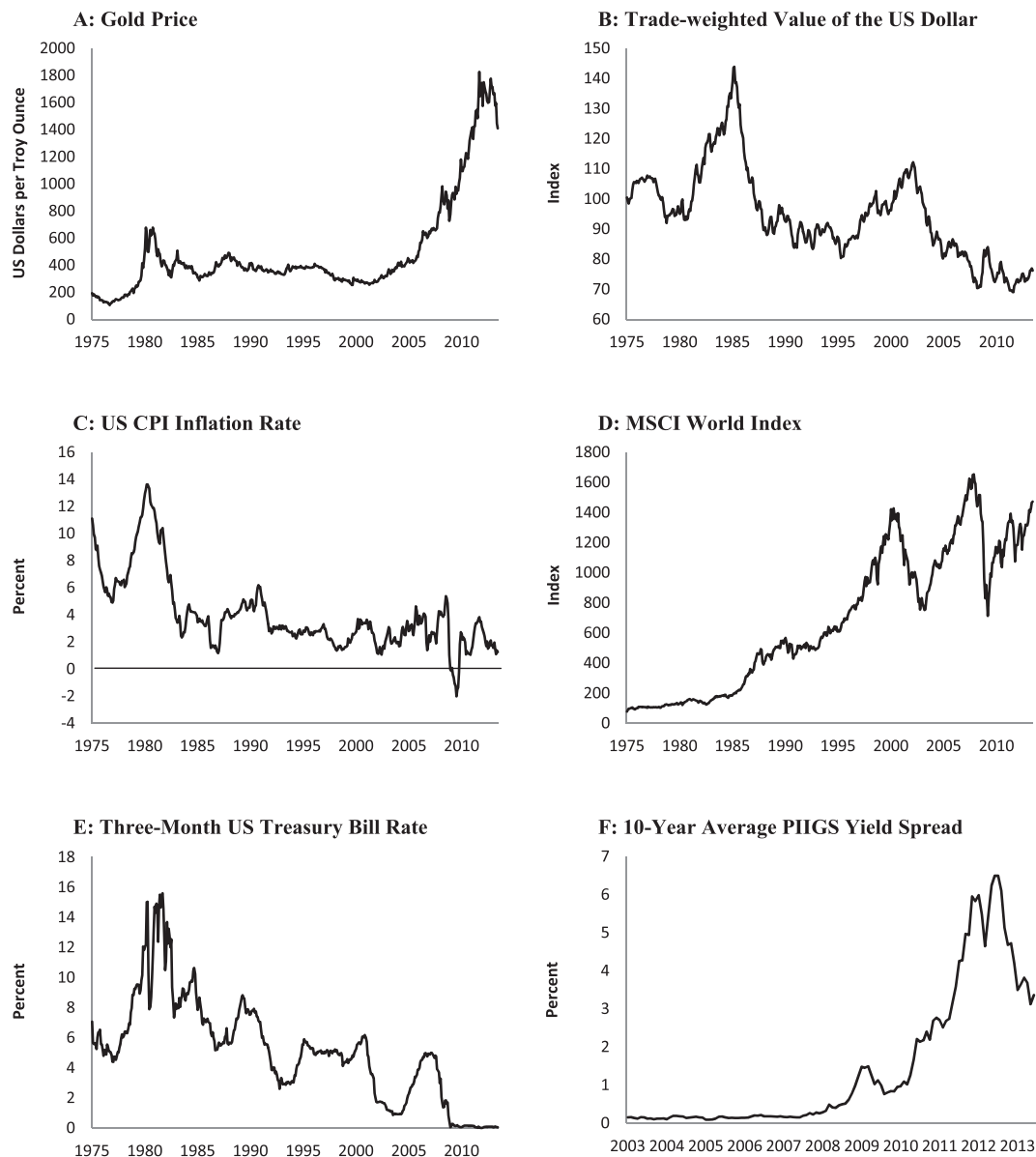


Fig. 2. Gold price and fundamental factors. Notes: Panel A shows the gold price (in US dollars per troy ounce), Panel B the trade-weighted value of the US dollar against other major currencies, Panel C the change of the US all-urban consumer price index (in percent), Panel D the MSCI World Index of major stock markets, Panel E the three-month US Treasury bill rate (in percent), and Panel F the spread of the GDP-weighted average PIIGS countries' and Germany's ten-year government bond yield. All time series are given on a monthly frequency. Panels A to E cover the full sample (Jan. 1975–Jun. 2013). Panel F covers the shortened sample (Jan. 2003–Jun. 2013).

the current European sovereign debt crisis on the gold return. All time series are taken from Thomson Reuters Datastream.

We distinguish between three different models. Model A refers to the shortened sample from January 1975 to December 2007 (396 observations), excluding the spread between the PIIGS countries' and German bond yields in order to calculate gold's fundamental return. It thus covers neither the recent world financial crisis nor the current European sovereign debt crisis.⁴ Model B refers to the full sample (January 1975–June 2013), again excluding the yield spread. As a consequence, a comparison between Models A and B provides evidence about

the impact of the recent world financial crisis on the gold price. Finally, Model C also refers to the full sample, but now includes the yield spread. Therefore, putting Models B and C in relation to each other offers insights into the additional effect of the current European sovereign debt crisis on the gold price.

Since gold's role as a dollar hedge, inflation hedge, portfolio diversifier, and safe haven is not constant over time, we apply a rolling window approach in order to estimate Eq. (1). Our choice of a dynamic specification is based on results from running the Chow test for structural breaks in a model with constant coefficients. Regardless of the breakpoint chosen, this test clearly indicates that the influence of the regressors in Eq. (1) should be modeled as time-varying. Baur (2013a) confirms our findings.

The first window covers the period from March 1975 to February 1980, and is used to calculate fitted gold returns, $\hat{r}_{Gold,t}$, for this time span. The window is then rolled forward by one month, so that new parameter estimates and a fitted return can be obtained for March 1980.

⁴ Since there can be disagreement about the precise date when the world financial crisis began, we also experiment with alternative end points for the shortened sample such as June 2007 when Bear Stearns suspended redemptions from some of its instruments previously labeled of the high grade variety. However, results (not shown, but available upon request) are qualitatively the same as those presented in Section 4.

Table 2
Regression results (1).

	\bar{y}_t	\bar{y}_{t-1}	\bar{y}_{t-2}	Sum	$S(\bar{y}_t)$	$S(\bar{y}_{t-1})$	$S(\bar{y}_{t-2})$
<i>Panel A: PIIGS GDP, rolling</i>							
Exchange rate	−0.4850	−0.3208	0.3198	−0.4859	0.4589	0.2968	0.1047
Adj. inflation	0.0558	2.6695	−2.1429	0.5824	0.1995	0.1995	0.1895
MSCI world	0.2189	0.0772	0.1183	0.4144	0.2668	0.1172	0.3317
Adj. T-Bill	−1.4308	1.5987	−0.5705	−0.4027	0.1870	0.0249	0.0549
Adj. PIIGS GDP	1.9685	−0.7940	−0.3303	0.8442	0.6716	0.2090	0.1194
<i>Panel B: PIIGS GDP, recursive</i>							
Exchange rate	−0.5321	−0.4062	0.4028	−0.5356	0.6209	0.2793	0.0125
Adj. inflation	−0.5341	4.0474	−2.3173	1.1960	0.2219	0.8204	0.8080
MSCI world	0.3052	0.1305	0.0516	0.4873	0.7007	0.4065	0.0973
Adj. T-Bill	−0.5762	0.0575	−0.0120	−0.5308	0.0500	0.0500	0.0250
Adj. PIIGS GDP	1.5314	−0.4682	−0.4413	0.6220	0.5890	0.1918	0.0685
<i>Panel C: PIIGS pop, rolling</i>							
Exchange rate	−0.4844	−0.3231	0.3175	−0.4900	0.4589	0.2993	0.0973
Adj. inflation	0.0520	2.6647	−2.1377	0.5790	0.1995	0.2020	0.1895
MSCI world	0.2181	0.0763	0.1172	0.4116	0.2569	0.1172	0.3292
Adj. T-Bill	−1.4286	1.5990	−0.5755	−0.4051	0.1845	0.0249	0.0549
Adj. PIIGS Pop	1.9590	−0.8344	−0.2958	0.8288	0.6567	0.2239	0.0896
<i>Panel D: PIIGS pop, recursive</i>							
Exchange rate	−0.5320	−0.4074	0.4021	−0.5373	0.6209	0.2793	0.0125
Adj. inflation	−0.5375	4.0429	−2.3125	1.1930	0.2219	0.8204	0.8080
MSCI world	0.3047	0.1300	0.0510	0.4856	0.7007	0.4065	0.0923
Adj. T-Bill	−0.5769	0.0543	−0.0106	−0.5333	0.0500	0.0500	0.0250
Adj. PIIGS Pop	1.5090	−0.5203	−0.3697	0.6189	0.5890	0.1781	0.0548

Notes: Results are shown for the fundamental regression in Eq. (1). \bar{y}_t , \bar{y}_{t-1} , and \bar{y}_{t-2} are the mean values of the contemporaneous (t) and the one- ($t-1$) and two-period lagged ($t-2$) influence, respectively, of the variables in the first column on the gold return. Sum is the mean aggregate impact ($\bar{y}_t + \bar{y}_{t-1} + \bar{y}_{t-2}$). $S(\bar{y}_t)$, $S(\bar{y}_{t-1})$, and $S(\bar{y}_{t-2})$ are the number of significant parameters (at the 10%-level) in relation to the total number of sample windows which include the respective variable. Significance is based on HAC-consistent standard errors (Newey–West).

For Model(s) A (B and C), the procedure is continued until December 2007 (June 2013), resulting in 335 (401) sets of OLS estimates.⁵

Finally, we calculate gold's fundamental value by multiplying its actual price in February 1975 with the fitted gross return of March 1975, ending up with a fitted gold price for the latter month. Afterwards, we multiply this fitted price with the fitted gross return of April 1975, and repeat this exercise until December 2007 in the case of Model A, and until June 2013 in the case of Models B and C, respectively ($\hat{P}_t = \hat{P}_{t-1} \cdot (1 + \hat{r}_{Gold,t})$). Deviations of the actual gold price from its fitted value ($u_t = P_t - \hat{P}_t$) are interpreted as overvaluation, if positive and as undervaluation if negative, respectively.

3. Markov regime-switching ADF test for bubble detection

Based on the relationship between the actual gold price and its fitted value, we test for speculative bubbles in the former, extending the conventional ADF equation to a standard two-state first-order Markov regime-switching model. In the literature, this approach has mostly been carried out to analyze directly the stationarity properties of the time series under investigation (Funke, Hall, & Sola, 1994; Hall, Psaradakis, & Sola, 1999). By contrast, we use the Markov regime-switching ADF test with respect to the deviations of the actual gold price from its fitted value. The main advantage of this approach is that it does not rely on an informal comparison of the switching patterns of different time series, but allows for solid statistical inference instead. If periodically bursting bubbles exist, we should be able to distinguish between a moderately growing regime on the one hand and an explosive and then collapsing regime on the other hand.⁶ As shown by a

simulation study in Hall et al. (1999), the Markov regime-switching ADF test has substantially more power than the conventional ADF test to detect periodically bursting bubbles.

The Markov regime-switching ADF equation reads:

$$\Delta u_t = \rho_{0,S_t} + \rho_{1,S_t} \cdot u_{t-1} + \sum_{k=1}^K \beta_{k,S_t} \cdot \Delta u_{t-k} + \varepsilon_{S_t}, \quad (2)$$

where Δ stands for the first difference, $S_t = (0, 1)$ is the stochastic regime variable, $\psi = (\rho_{0,S_t}, \rho_{1,S_t}, \beta_{k,S_t})'$, with $k = 1, \dots, K$, are the regime-specific regression coefficients, and $\varepsilon_{S_t} \stackrel{i.i.d.}{\sim} N(0, \sigma_{S_t}^2)$ represents the error term. Judgments on the statistical significance of the regression coefficients are based on critical values obtained by using a parametric bootstrap algorithm (Psaradakis, 1998). If we are able to distinguish between a bubble and a non-bubble regime, we will obtain one $\rho_{1,i}$, $i = (0, 1)$, which is statistically significantly larger than zero (so that regime i is explosive and then collapsing), and another $\rho_{1,j}$, $j = (1 - i)$, which is not (so that regime j is stationary or contains a unit-root). In order to ensure that the error terms are serially uncorrelated, the optimal lag length, K , is determined by starting with $K_{max} = [T^{1/3}]$, where $[\cdot]$ denotes the integer part of its argument, and then reducing the model until the last lagged difference has a statistically significant influence at the 5%-level in at least one regime (general-to-specific approach). Since the probability of S_t being either zero or one depends on the past only through the most recent regime S_{t-1} , the transition probabilities are defined by $p_{00} \equiv \Pr(S_t = 0 | S_{t-1} = 0)$ and $p_{11} \equiv \Pr(S_t = 1 | S_{t-1} = 1)$. Finally, we collect all unknown parameters in the vector $\theta \equiv (\psi, \sigma_{S_t}, p_{00}, p_{11})'$.

In order to estimate θ , we draw on the expectation–maximization (EM) algorithm. The EM algorithm is an iterative procedure that consists of two steps: the expectation step and the maximization step (Hamilton, 1994; Kim & Nelson, 2000). In the expectation step, we estimate the filter probabilities, $\Pr(S_t = i | u_t, \dots, u_1; \theta)$, and the smoothed probabilities, $\Pr(S_t = i | u_T, \dots, u_1; \theta)$, of being in the two regimes, using the estimate of θ from the previous iteration step. In the maximization step, we then draw on these probabilities in order to improve the

⁵ Alternatively, we add a constant to Eq. (1), and repeat the rolling regressions. The fundamentally justified gold return is then defined as the fitted return minus the constant. However, results (not shown, but available upon request) are qualitatively the same as those for the model in Eq. (1).

⁶ Note that Markov regime-switching models may indicate different regimes even though there are no structural breaks in the data. Thus, we first apply a conventional ADF test to the deviations of the actual gold price from its fitted value, and test the stability of the ADF coefficient making use of the Quandt–Andrews unknown breakpoint tests (the supremum, exponential, and average likelihood ratio test).

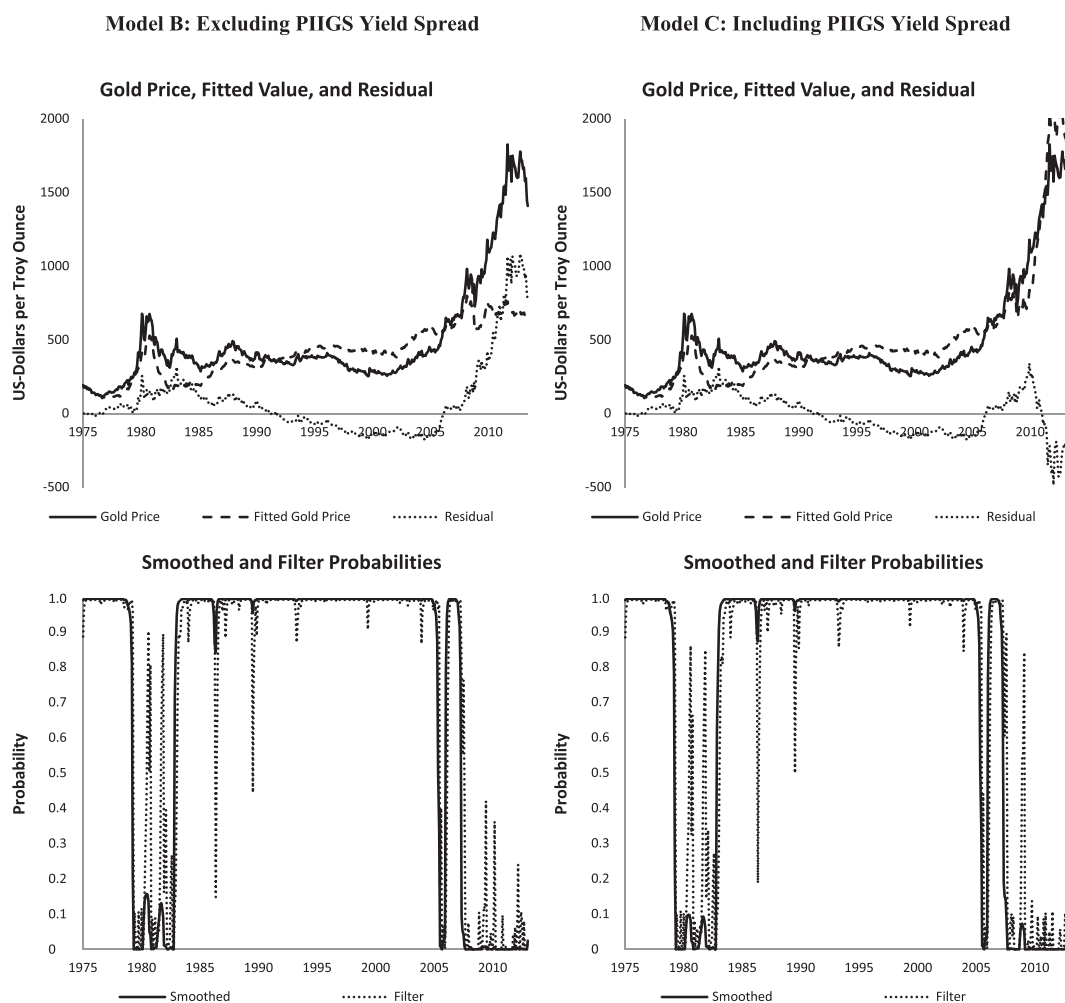


Fig. 3. Gold price, fitted value, and residual-smoothed and filter probabilities. Notes: The left column refers to Model B which excludes the adjusted average PIIGS yield spread in order to calculate gold's fundamental return. The right column refers to Model C which includes the adjusted average PIIGS yield spread. Both models cover the full sample (Jan. 1975–Jun. 2013). In both columns, the upper plot shows the actual gold price (solid line), its fitted value (dashed line), and the difference between both time series (dotted line). The fitted value is calculated as described in Section 2 based on rolling regressions. All time series are denoted in US dollars per troy ounce. The lower plot of each column shows the smoothed (solid line) and the filter probabilities (dotted line) of being in the possible bubble regime (regime 1), using the Markov regime-switching ADF test in Eq. (2), which is based on the difference between the actual gold price and its fitted value.

estimate of θ based on the maximum-likelihood (ML) approach. Given the model in Eq. (2), however, we need not maximize the log-likelihood function numerically, but are able to obtain a closed-form

solution for θ . Furthermore, the EM algorithm is relatively robust with respect to poorly chosen starting values for θ , quickly moving to a reasonable region of the likelihood surface.

Table 3

Stability tests.

	SupLR	Prob.	ExpLR	Prob.	AveLR	Prob.
<i>Panel A: PIIGS GDP, rolling</i>						
Model A	8.7632	0.0466	0.6745	0.3266	0.8642	0.4046
Model B	19.4473	0.0003	8.1028	0.0000	13.0593	0.0000
Model C	3.2157	0.5105	0.3520	0.5804	0.6499	0.5317
<i>Panel B: PIIGS GDP, recursive</i>						
Model B	9.8708	0.0280	3.2438	0.0110	4.5945	0.0112
Model C	2.8966	0.5757	0.3014	0.6415	0.5328	0.6189

Notes: Results are shown for Quandt–Andrews unknown breakpoint tests measuring the stability of the ADF coefficient in the conventional ADF equation. The time series used represents the deviations of the actual gold price from its fitted value. The fitted value is calculated as described in Section 2. Model A refers to the shortened sample (Jan. 1975–Dec. 2007), excluding the respective proxy for the current European sovereign debt crisis in order to calculate gold's fundamental return. Model B refers to the full sample (Jan. 1975–Jun. 2013), again excluding the respective proxy, while Model C also refers to the full sample, but includes the proxy. SupLR, ExpLR, and AveLR are the values of the supremum, the exponential, and the average likelihood ratio test, respectively, and Prob. is the corresponding p -value. The optimal lag length of the conventional ADF equation is determined by using the Schwartz information criterion.

4. Empirical results

4.1. Empirical results

We start the empirical analysis by calculating the descriptive statistics of the univariate time series necessary to estimate Eq. (1), based on the samples as described in Section 2. As shown by Table 1, the largest positive gold return is more than 25%, and occurred during the last gold price boom in February 1980, followed closely by the largest negative return of more than 23% in April 1980. In addition, the largest value of the US inflation rate is more than 13%, and was measured during the second oil crisis in March 1980 which coincides with the last gold price boom. Apart from this, world stock markets faced their largest decrease of more than 20% in November 2008, reflecting the recent world financial crisis. Finally, the spread between the GDP-weighted average of 10-year government bond yields in the PIIGS countries and the 10-year German bonds yield, which had always been positive but skyrocketed over the last couple of years, reached its peak of almost 6.5 percentage points in June 2012, highlighting the current European

Table 4
Markov regime-switching ADF test (1).

PIIGS GDP, rolling				
	Coef.	t-Value	Coef.	t-Value
Model A	$S_t = 0$		$S_t = 1$	
ρ_{0,S_t}	0.2339	3.6081***	−0.0186	−2.9499***
ρ_{1,S_t}	−0.1234	−2.8328	−0.0175	−2.8594
β_{1,S_t}	0.0140	0.1171	−0.1958	−3.8432***
β_{2,S_t}	−0.2380	−1.9490*	−0.1891	−3.8080***
σ_{S_t}	0.3033		0.1111	
p_{00}, p_{11}	0.9318		0.9863	
Model B	$S_t = 0$		$S_t = 1$	
ρ_{0,S_t}	0.1789	2.5656**	−0.0161	−2.5382**
ρ_{1,S_t}	0.0049	0.3266**	−0.0158	−2.6737
β_{1,S_t}	−0.3348	−3.5880***	−0.1803	−3.6167***
β_{2,S_t}	−0.2532	−2.6960***	−0.1686	−3.5195***
σ_{S_t}	0.5036		0.1143	
p_{00}, p_{11}	0.9729		0.9899	
Model C	$S_t = 0$		$S_t = 1$	
ρ_{0,S_t}	0.0183	0.3722	−0.0156	−2.4355**
ρ_{1,S_t}	−0.0246	−0.9283	−0.0161	−2.6101
β_{1,S_t}	−0.0355	−0.3782	−0.1759	−3.4905***
β_{2,S_t}	−0.0501	−0.5229	−0.1707	−3.4842***
σ_{S_t}	0.5252		0.1147	
p_{00}, p_{11}	0.9758		0.9903	

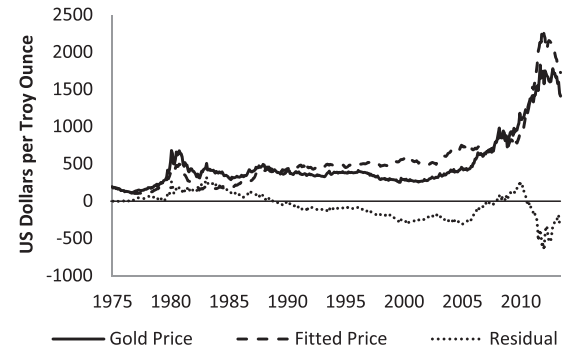
Notes: Results are shown for the Markov regime-switching ADF test in Eq. (2). The time series used represent the deviations of the actual gold price from its fitted value. The fitted value is calculated as described in Section 2. Model A refers to the shortened sample (Jan. 1975–Dec. 2007), excluding the adjusted average PIIGS yield spread in order to calculate gold's fundamental return. Model B refers to the full sample (Jan. 1975–Jun. 2013), again excluding the adjusted average PIIGS yield spread. Model C refers to the full sample, including the adjusted GDP-weighted average PIIGS yield spread. $S_t = (0, 1)$ is the stochastic regime variable. ρ_{0,S_t} , ρ_{1,S_t} , and β_{k,S_t} , with $k = 1, \dots, K$, are the regression coefficients. The optimal lag length, K , is determined by starting with $K_{max} = [T^{1/3}]$, where $[\cdot]$ denotes the integer part of its argument, and then reducing the model until the last lagged residual difference has a statistically significant influence at the 5%-level in at least one regime. ***, **, and * denote statistical significance at the 1%, 5%, and 10%-level, respectively. All tests are two-sided except for ρ_{1,S_t} , which is left-tailed (right-tailed) for the smaller (bigger) coefficient. Critical values are obtained by using a parametric bootstrap algorithm (Psaradakis, 1998). σ_{S_t} denotes the variance of the error term. p_{00} and p_{11} denote the transition probabilities.

sovereign debt crisis. The value of the spread started to diminish in the second half of 2012, after the partial write-down of the Greek debt in March 2012, and the announcement of the Outright Monetary Transactions (OMT) program by the European Central Bank in August 2012. The OMT authorizes stabilizing interventions in the European sovereign bond markets with the aim of bringing the long end of the yield curve downwards. It appears that this particular policy objective has to a large extent been reached. Fig. 2 gives a visual impression of the (original) time series used for our empirical analysis.

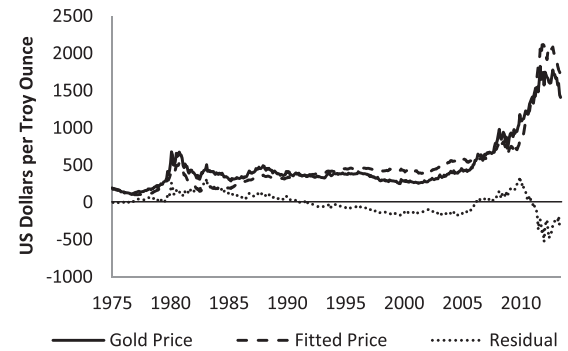
More importantly, as indicated by the conventional ADF test, the gold return, the change of the effective US exchange rate, and the world stock market return are stationary, while the US inflation rate, the three-month US Treasury bill rate, and the spread between the PIIGS countries' and Germany's bond yields are characterized by a unit-root. Thus, we adjust the latter three time series by subtracting the respective variable's mean value of the previous year in order to make them suitable for use in the regression in Eq. (1).

Finally, we also apply variance-inflation tests to examine whether the correlations between our independent variables have consequences for the precision of our estimates. Chatterjee and Price (1991) suggest that values for Variance Inflation Factors (VIFs) in the region of 10 indicate a problem. According to the variance-inflation tests for our model with and without the yield spread, none of the regressions suffers from the multicollinearity problem.

A) PIIGS GDP, Recursive



B) PIIGS Pop, Rolling



C) PIIGS Pop, Recursive

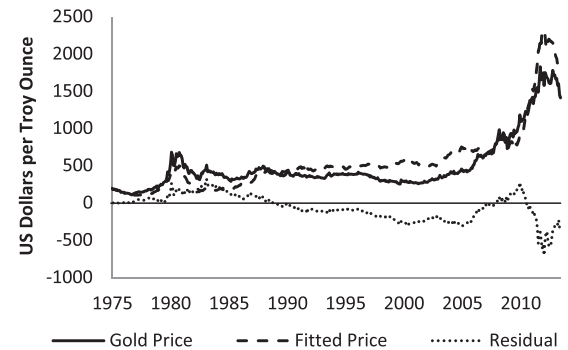


Fig. 4. Alternative specifications of PIIGS yield spread. Notes: All panels show the actual gold price (solid line), its fitted value (dashed line), and the difference between both time series (dotted line). The fitted value is calculated as described in Section 2. In Eq. (1) we use the adjusted average PIIGS bond yield spread weighted by GDP for the recursive regressions (Panel A), and the adjusted average PIIGS bond yield spread weighted by population for the rolling (Panel B) and the recursive regressions (Panel C), respectively.

4.2. Regression results

In Panel A of Table 2, we show the results of the rolling window approach used to estimate the time-varying impact of the five fundamental factors on the gold return. Instead of reporting the parameter estimates for each window, we focus on the mean values of the contemporaneous and the one- and two-period lagged influence. In addition, we calculate the mean aggregate impact of the contemporaneous and the lagged regressors. As expected, the gold return is negatively affected by the change of the effective US exchange rate and the adjusted three-month US Treasury bill rate, but has a positive relationship with the adjusted US inflation rate and, in particular, with the adjusted spread between the ten-year government bond yields of the PIIGS countries and Germany. Only the consistently positive influence of the world

Table 5
Markov regime-switching ADF test (2).

	Coef.	t-Value	Coef.	t-Value
Panel A: PIIGS GDP, recursive				
Model B $S_t = 0$			$S_t = 1$	
ρ_{0,S_t}	0.208	2.6407***	−0.0222	−2.8647***
ρ_{1,S_t}	−0.0008	−0.0379***	−0.0101	−2.3170
β_{1,S_t}	−0.2889	−2.8945***	−0.1249	−2.6386***
β_{2,S_t}	−0.2475	−2.4001**	−0.1358	−3.2153***
σ_{S_t}	0.5710		0.1360	
p_{00}, p_{11}	0.9537		0.9858	
Model C $S_t = 0$			$S_t = 1$	
ρ_{0,S_t}	0.0016	0.0300	−0.0203	−2.4657**
ρ_{1,S_t}	−0.0204	−0.8993	−0.0096	−1.8272
β_{1,S_t}	0.0741	0.7833	−0.0801	−1.5774
β_{2,S_t}	−0.0749	−0.7752	−0.1584	−3.2108***
σ_{S_t}	0.5582		0.1348	
p_{00}, p_{11}	0.9745		0.9903	
Panel B: PIIGS pop, rolling				
Model C $S_t = 0$			$S_t = 1$	
ρ_{0,S_t}	0.0106	0.2151	−0.0155	−2.4238**
ρ_{1,S_t}	−0.0177	−0.7097	−0.0161	−2.6068
β_{1,S_t}	−0.0704	−0.7484	−0.1752	−3.4762***
β_{2,S_t}	−0.0473	−0.4936	−0.1702	−3.4746***
σ_{S_t}	0.5288		0.1147	
p_{00}, p_{11}	0.9758		0.9903	
Panel C: PIIGS pop, recursive				
Model C $S_t = 0$			$S_t = 1$	
ρ_{0,S_t}	−0.0018	−0.0340	−0.0202	−2.4518**
ρ_{1,S_t}	−0.0164	−0.7482	−0.0096	−1.8232
β_{1,S_t}	0.0321	0.3377	−0.0801	−1.5769
β_{2,S_t}	−0.0624	−0.6441	−0.1579	−3.2030***
σ_{S_t}	0.5631		0.1348	
p_{00}, p_{11}	0.9743		0.9902	

Notes: See Table 4. The fitted value is calculated as described in Section 2, based on gold's fundamental returns from the recursive window regression with the GDP- and the population-weighted average PIIGS yield spread (Panels A and C), and from the rolling window regressions with the population-weighted average PIIGS yield spread (Panel B), respectively.

stock market return does not perfectly coincide with gold's role as portfolio diversifier.⁷ Finally, we show the number of significant parameters in relation to the total number of windows, which include the respective variable, for the contemporaneous and the lagged influence on the gold return. Overall, the ratios indicate that the regressors selected serve as reasonable proxies in order to reflect gold's role as a dollar hedge, inflation hedge, portfolio diversifier, and safe haven.

Based on the fitted gold returns, we then calculate gold's fundamental value as outlined in Section 2, and put it in relation to the actual gold price. Both time series and the deviations of the actual gold price from its fitted value are shown in the upper part of Fig. 3. The plot in the left column refers to Model B which excludes the adjusted spread between the PIIGS countries' and Germany's bond yields in order to calculate gold's fundamental return, while the plot in the right column refers to Model C which includes the yield spread.⁸ Interestingly, both plots indicate a persistent overvaluation of the gold price in the first half of the 1980s, but differ sharply with respect to the most recent times. While Model B suggests a substantial overvaluation over the last few years, Model C leads to a close co-movement of the actual gold price and its fitted value. As a consequence, we argue that the current European

⁷ Note that Baur (2013b) also finds that the price of gold is positively related to stock market movements in emerging markets and on a global level but slightly negatively correlated with the S&P500 supporting the property of gold as a hedge at least for mature stock markets.

⁸ Since Model A is nested in Model B, we do not show graphical illustrations for the former separately.

sovereign debt crisis might be seen as one possible driver of the recent gold price boom.

In order to validate this visual evidence empirically, we turn to the econometric analysis of the deviations of the actual gold price from its fitted value. Using these deviations, we first estimate the conventional ADF equation, and test the stability of the ADF coefficient by making use of the Quandt–Andrews unknown breakpoint tests. Results for Models A to C are reported in Panel A of Table 3. Interestingly, they indicate that only in the case of Model B do the deviations of the actual gold price from its fitted value appear to show different adjustment dynamics over time. By contrast, no such instability of the ADF coefficient can be detected for Models A and C. Since the conventional ADF test does not display explosive behavior for the full sample of any model, we conclude that only Model B may lead to (relatively short) periods of emerging and then collapsing speculative bubbles.

As a consequence of the stability tests, we further conclude that analyzing the deviations of the actual gold price from its fitted value in the case of Model B requires the Markov regime-switching ADF test from Eq. (2). For reasons of comparison, we also run this bubble test for Models A and C. Results for all three models are reported in Table 4. Interestingly, they have some characteristics in common. First, the constant is positive in regime 0, negative in regime 1, and nearly always statistically significant. Second, starting with $p_{max} = [T^{1/3}] = 7$, we end up with two lagged differences for each model in order to ensure that the error terms are serially uncorrelated. Third, regime 0 is always more volatile, but less persistent than regime 1 ($\sigma_0 > \sigma_1$, $p_{00} < p_{11}$), so that we expect the former to indicate periods that are possibly affected by speculative bubbles.

More importantly, in all three models, the ADF coefficient ρ_{1,S_t} is not statistically significantly smaller or bigger than zero in both regimes.⁹ The only exception is regime 0 of Model B, which shows explosive behavior. Thus, once we focus on the shortened sample from January 1975 to December 2007 (Model A), we do not find evidence of speculative bubbles in the gold price. Instead, we interpret the gold price boom from 1979 to 1982 as a response to skyrocketing inflation. Our results thus challenge the findings of Diba and Grossman (1984), Pindyck (1993), Bertus and Stanhouse (2001), and Drozd et al. (2003). By contrast, extending the sample up to June 2013 but excluding the adjusted spread between the PIIGS countries' and Germany's bond yields in order to calculate gold's fundamental return (Model B) leads to explosive deviations of the actual gold price from its fitted value. The corresponding smoothed and filter probabilities are shown in the lower part of the left column in Fig. 3, and indicate a speculative bubble in the gold price since the beginning of 2008. As a consequence, the recent world financial crisis does not seem to suffice as an explanation for the recent gold price boom. However, once we use the full sample, and include the yield spread, as shown in Eq. (1), in order to calculate gold's fundamental return (Model C), we again do not find evidence of speculative bubbles in the gold price. The corresponding smoothed and filter probabilities are shown in the lower part of the right column in Fig. 3. Thus, the outcome of the Markov regime-switching ADF tests corresponds to the results of the stability tests, using the conventional ADF equation.

Next, we repeat the econometric analysis as outlined in Section 2, but now use a recursive window approach in order to calculate gold's fundamental returns. This approach works as follows: The first window again covers a period of five years. In contrast to the rolling window approach, however, we then continuously extend the subsample by one month, so that the last window is equal to the full sample. Put differently, while the rolling approach is characterized by a constant window length, the recursive approach does not neglect the data from the beginning of the sample.

In Panel B of Table 2, we show the results of the recursive window approach used to estimate the time-varying impact of the five fundamental

⁹ Note that, as in the case of the conventional ADF equation, ρ_{1,S_t} follows a different distribution than the other coefficients so that critical values are not the same.

Table 6
Regression results (2).

	\bar{Y}_t	\bar{Y}_{t-1}	\bar{Y}_{t-2}	Sum	$S(\bar{Y}_t)$	$S(\bar{Y}_{t-1})$	$S(\bar{Y}_{t-2})$
<i>Panel A: PIIGS CDS</i>							
Exchange rate	−0.5101	−0.4285	0.4168	−0.5218	0.5761	0.2868	0.0474
Adj. inflation	−0.5451	3.9821	−2.2598	1.1771	0.2145	0.8429	0.8080
MSCI world	0.3162	0.1214	0.0465	0.4841	0.7382	0.4065	0.1072
Adj. T-Bill	−0.4665	−0.1899	0.1149	−0.5416	0.0750	0.0175	0.0100
Adj. CDS PIIGS	0.2119	−0.1594	0.0267	0.0793	0.8219	0.4247	0.5068
<i>Panel B: gold ETF</i>							
Exchange rate	−0.5136	−0.4205	0.4074	−0.5268	0.6110	0.2793	0.0524
Adj. inflation	−0.4810	3.7831	−2.0350	1.2671	0.2120	0.9352	0.8279
MSCI world	0.3063	0.1297	0.0456	0.4816	0.7406	0.3965	0.0773
Adj. T-Bill	−0.6029	−0.2157	0.2325	−0.5861	0.0250	0.0250	0.0000
Adj. Gold ETF	0.5822	2.1066	−2.3291	0.3596	0.1233	0.5205	1.0000
<i>Panel C: CRB Index</i>							
Exchange rate	−0.5257	−0.3545	0.3075	−0.5727	0.5411	0.0723	0.0125
Adj. inflation	−1.1180	4.3986	−2.4090	0.8716	0.0424	0.6035	0.6135
MSCI world	0.2465	0.0965	0.0101	0.3532	0.5761	0.2419	0.0000
Adj. T-Bill	−1.3972	0.9258	−0.1370	−0.6085	0.1646	0.0750	0.0000
Adj. CRB Index	0.1149	−0.1068	−0.0007	0.0075	0.9198	0.6728	0.0062

Notes: See Table 2. Results are shown for the recursive regression in Eq. (1).

factors on the gold return. As in the case of the rolling window approach, the gold return is negatively affected by the change of the effective US exchange rate and the adjusted three-month US Treasury bill rate, but has a positive relationship with the adjusted US inflation rate, the world stock market return, and, in particular, the adjusted spread between the 10-year government bond yields of the PIIGS countries and Germany. In addition, the regressors selected again serve as reasonable proxies in order to reflect gold's role as a dollar hedge, inflation hedge, portfolio diversifier, and safe haven.

Based on the fitted gold returns from the recursive regression, we then calculate gold's fundamental value as outlined in Section 2, and put it in relation to the actual gold price. Results are shown in Panel A of Fig. 4. Afterwards, we again measure the stability of the ADF coefficient in the conventional ADF equation, using the deviations of the actual gold price from its fitted value. Results for Models B and C are reported in Panel B of Table 3. As in the case of the rolling window approach, we find that different adjustment dynamics are present over the full sample only if gold's fundamental return is calculated without considering the adjusted yield spread.

Finally, we re-run the Markov regime-switching ADF test, still using the deviations of the actual gold price from its fitted value. Results for Models B and C are reported in Panel A of Table 5. In line with the above results, only Model B leads to explosive deviations of the actual gold price from its fitted value, while Model C does not indicate speculative bubbles.

Apart from this check of the methodological robustness, we are also interested in whether our results depend on the construction of the proxy for the current European sovereign debt crisis. Thus, we repeat the rolling and the recursive window regression, but now use an alternative variable in order to calculate gold's fundamental returns: the (adjusted) spread between the population-weighted average of 10-year government bond yields in the PIIGS countries and the 10-year German sovereign bond yields. Descriptive statistics for this proxy are reported in Table 1. As in the case of the GDP-weighted spread, the population-weighted yield spread had always been positive but increased sharply over the last couple of years.

In Panels C and D of Table 2, we show the results of the rolling and the recursive window approach employed to calculate fitted gold returns. While the effects of the other fundamental factors are similar to the results reported in Panels A and B of Table 2, the adjusted population-weighted spread has the expected positive influence on the gold return. Based on the fitted gold returns, we again calculate gold's fundamental value as outlined in Section 2, and put it in relation

to the actual gold price. Results are shown in Panels B and C of Fig. 4. Based on the deviations between both time series, we re-run the Markov regime-switching ADF test. Results are reported in Panels C and D of Table 5. As in the case of the GDP-weighted yield spread, using the new proxy in Model C does not allow for rejecting the null hypothesis of no speculative bubbles in the gold price.

Our results are thus in contrast to those of Drozd et al. (2008), Went et al. (2012), Homm and Breitung (2012), and Baur and Glover (2012) who find evidence in favor of the bubble hypothesis. In addition, we conclude that the current European sovereign debt crisis, reflected by the skyrocketing spread between the PIIGS countries' and Germany's bond yields, can be seen as one possible driver of the recent gold price boom.

4.3. Alternative proxies

Finally, we leave the comparison of the PIIGS countries with Germany completely aside, and turn to three alternative variables which might have contributed to the recent gold price trajectory: the (adjusted) average of the five-year senior credit default swap (CDS) premia of the PIIGS countries, the gold demand by ETFs (already shown in Fig. 1) and the Commodity Research Bureau (CRB) index of commodity prices.¹⁰ Thus, even though we still stick to Eq. (1) in order to calculate fundamental values, we emphasize that our fifth regressor does not necessarily represent a proxy for the current European sovereign debt crisis anymore, but instead offers alternative interpretations of the recent gold price boom.

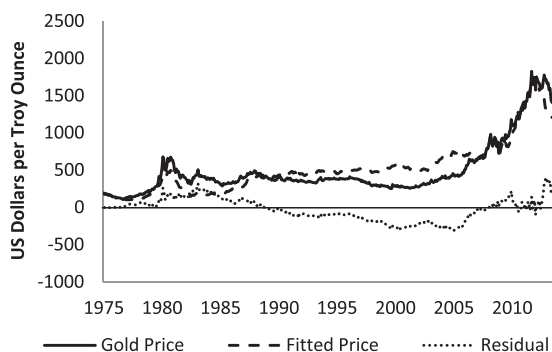
In a CDS on bonds, the protection buyer (e.g. a bank) purchases insurance against the event of default of the security that the protection buyer holds. The buyer agrees with the protection seller (e.g. an investor) to pay a premium. In the event of default, the protection seller has to compensate the protection buyer for the loss incurred. Our variable is an arithmetic average of CDS spread indices for PIIGS countries and one would expect that it will increase monotonically in the probability of default. ETF demand is proxied by aggregating the flows into the ETF SPDR Gold Shares and the ETF iShares Gold Trust, two funds which invest the entirety of their portfolios in gold. These ETFs are the two largest funds operating in the gold market, which had a market share of 97% at the point when data became available. In June 2013, it

¹⁰ Data for all three variables are taken from Bloomberg.

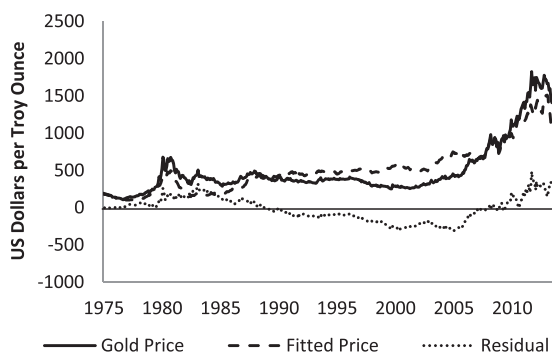
was still 69%. By contrast, the CRB index does not rely on the gold market alone, but is a weighted average of futures prices for 19 commodities. Gold has a weight of only 6% in this index, so that endogeneity poses no problem. Similar to the gold price, the CRB index skyrocketed up to mid-2008, then crashed down during the recent world financial crisis, but later recovered substantially.

Results of the fundamental regressions are shown in Panels A to C of Table 6, and confirm our prior findings for the conventional gold price factors. More importantly, we see that the average PIIGS CDS premia, the gold demand by ETFs, and the CRB index have significant power to explain recent gold price movements as well. Fig. 5 visualizes this outcome by comparing actual to fitted gold prices. Accordingly, running the Markov regime-switching ADF test leads to similar results as before (see Panels A to C of Table 7): the three alternative variables all help explain away any speculative bubble in recent gold price dynamics.

A) PIIGS CDS



B) Gold ETFs



C) CRB

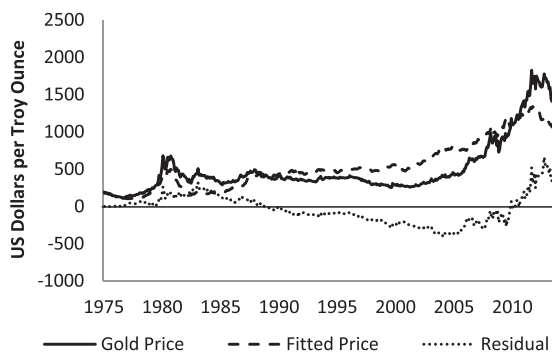


Fig. 5. Alternative proxies. Notes: All panels show the actual gold price (solid line), its fitted value (dashed line), and the difference between both time series (dotted line). The fitted value is calculated as described in Section 2. In Eq. (1) we use the adjusted average PIIGS CDS spread (Panel A), the adjusted demand by the two biggest gold ETFs (Panel B), and the adjusted CRB index (Panel C), respectively, for the recursive regressions.

Table 7
Markov regime-switching ADF test (3).

	Coef.	t-Value	Coef.	t-Value
<i>Panel A: PIIGS CDS</i>				
Model C	$S_t = 0$		$S_t = 1$	
ρ_{0,S_t}	0.1703	2.6537***	-0.0195	-2.3969**
ρ_{1,S_t}	-0.1048	-2.4983	-0.0094	-1.7914
β_{1,S_t}	-0.1536	-1.6029	-0.0811	-1.6087
β_{2,S_t}	-0.0687	-0.6957	-0.1576	-3.2142
σ_{S_t}	0.5213		0.1344	
ρ_{00}, ρ_{11}	0.9735		0.9904	
<i>Panel B: Gold ETF</i>				
Model C	$S_t = 0$		$S_t = 1$	
ρ_{0,S_t}	0.1775	2.9520***	-0.0223	-2.7256***
ρ_{1,S_t}	-0.0699	-2.1444	-0.0098	-1.8951
β_{1,S_t}	-0.1607	-1.7656*	-0.0929	-1.8127*
β_{2,S_t}	-0.1407	-1.5445	-0.1717	-3.4592***
σ_{S_t}	0.4695		0.1323	
ρ_{00}, ρ_{11}	0.9776		0.9909	
<i>Panel C: CRB Index</i>				
Model C	$S_t = 0$		$S_t = 1$	
ρ_{0,S_t}	0.1160	2.2435**	-0.0261	-3.0473***
ρ_{1,S_t}	-0.0238	-1.1416	-0.0061	-1.2841
β_{1,S_t}	-0.3073	-3.5673***	-0.0776	-1.4823
β_{2,S_t}	-0.1532	-1.7376*	-0.1632	-3.1794***
σ_{S_t}	0.5721		0.1342	
ρ_{00}, ρ_{11}	0.9877		0.9939	

Notes: See Table 4. The fitted value is calculated as described in Section 2, based on gold's fundamental returns from the recursive window regression with the PIIGS CDS spread (Panel A), the aggregate flows to gold ETFs (Panel B), and the CRB index (Panel C), respectively.

5. Conclusion

Motivated by the recent gold price boom, this paper investigates whether rapidly growing investment activities have caused a new asset price bubble. Drawing on gold's role as a dollar hedge, inflation hedge, portfolio diversifier, and safe haven, we calculate fundamentally justified returns, and approximate gold's fundamental value. Based on the deviations of the actual gold price from its fitted value, we then apply a Markov regime-switching ADF test which has substantial power to detect explosive behavior. Even though the particular results from our empirical testing are dependent on the definition of gold fundamentals, we find that models which consider the impact of the current European sovereign debt crisis are able to capture the actual behavior of the gold price quite closely. Consequently, we conclude that one does not need to resort to the irrational bubble explanation in order to account for the considerable swings observed in the gold market. To a large extent, these results are in contrast to much of the existing literature.

The most likely explanation for the gold price boom from 1979 to 1982 is skyrocketing inflation caused by the second oil crisis and amplified by a very expansive monetary and fiscal policy, which led financial market participants to look for stable investments in unstable times. Similarly, many investors might have returned to gold as a safe haven in times of the recent world financial and, in particular, the current European sovereign debt crisis, thereby creating excess demand and the corresponding price surge. In the presence of serious questions regarding the viability of the banking sector and the international monetary system, the acquisition of gold represents a perfectly rational reaction of this part of investors. It is therefore unsurprising that our proxy for the severity of the debt crisis, which is derived from the sovereign bond yields of the PIIGS countries, is able to explain the recent evolution of gold prices. We also remark that the inflation in commodity prices and flow of funds into gold-focused ETFs likely contributed to the price dynamics. Further studies should explore these two factors in greater detail.

A key question that arises as a by-product of our research is how to define the relevant fundamental drivers of commodity prices. A large number of standardized valuation models are available for securities that provide periodic cash flows, such as bonds and stocks. Most of these valuation techniques, however, are not directly applicable in the context of commodities. While some approaches, such as the convenience yield model (Pindyck, 1993), may provide guidance to investors, we feel that our knowledge in this field is still inchoate. Future research should focus on how to provide a robust pricing framework for commodities in general and gold in particular. Our contribution to the pricing debate is related to the observation that episodes of severe crisis have non-negligible ramifications for market valuations.

References

- Adrangi, B., Chatrath, A., & Raffee, K. (2003). Economic activity, inflation, and hedging: The case of gold and silver investments. *Journal of Wealth Management*, 6(2), 60–77.
- Arghyrou, M. G., & Kontonikas, A. (2012). The EMU sovereign-debt crisis: Fundamentals, expectations and contagion. *Journal of International Financial Markets Institutions and Money*, 22(4), 658–677.
- Batten, J. A., Ciner, C., & Lucey, B.M. (2010). The macroeconomic determinants of volatility in precious metals markets. *Resources Policy*, 35, 65–71.
- Baur, D.G. (2013a). The autumn effect of gold. *Research in International Business and Finance*, 27, 1–11.
- Baur, D.G. (2013b). *Gold – Fundamental drivers and asset allocation*. Working Paper. University of Technology Sydney.
- Baur, D.G., & Glover, K. J. (2012). A gold bubble? Finance discipline group working paper 175. University of Technology Sydney.
- Baur, D.G., & Glover, K. J. (2014). Heterogeneous expectations in the gold market: Specification and estimation. *Journal of Economic Dynamics and Control*, 40, 116–133.
- Baur, D.G., & Lucey, B.M. (2010). Is gold a hedge or a safe haven? An analysis of stocks, bonds and gold. *Financial Review*, 45(2), 217–229.
- Baur, D.G., & McDermott, T. K. (2010). Is gold a safe haven? International evidence. *Journal of Banking and Finance*, 34(8), 1886–1898.
- Bertus, M., & Stanhouse, B. (2001). Rational speculative bubbles in the gold futures market: Application of dynamic factor analysis. *Journal of Futures Markets*, 21(1), 79–108.
- Blanchard, O. J., & Watson, M. W. (1982). *Bubbles, rational expectations and financial markets*. NBER Working Paper No. 945.
- Blose, L. E. (2010). Gold prices, cost of carry, and expected inflation. *Journal of Economics and Business*, 62(1), 35–47.
- Brace, R. (2011, October). *Breaking up the Euro*. Treasury and Risk, 16.
- Calice, G., Chen, J., & Williams, J. (2013). Liquidity spillovers in sovereign bond and CDS markets: An analysis of the Eurozone sovereign debt crisis. *Journal of Economic Behavior and Organization*, 85, 122–143.
- Capie, F., Mills, T. C., & Wood, G. (2005). Gold as a hedge against the dollar. *Journal of International Financial Markets Institutions and Money*, 15(4), 343–352.
- Carauana, J., & Avdjiev, S. (2012). Sovereign creditworthiness and financial stability: An international perspective. *Banque de France, Financial Stability Review*, 16, 71–85.
- Chan, K. F., Treepongkaruna, S., Brooks, R., & Gray, S. (2011). Asset market linkages: Evidence from financial, commodity and real estate assets. *Journal of Banking and Finance*, 35(6), 1415–1426.
- Chatterjee, S., & Price, B. (1991). *Regression diagnostics*. New York: Wiley.
- Ciner, C., Gurdgiev, C., & Lucey, B.M. (2013). Hedges and safe havens: An examination of stocks, bonds, gold, oil and exchange rates. *International Review of Financial Analysis*, 29, 202–211.
- De Santis, R. (2012). *The Euro area: Sovereign debt crisis safe haven, credit rating agencies and the spread of the fever from Greece, Ireland and Portugal*. ECB Working Paper No. 1419.
- Diba, B. T., & Grossman, H. I. (1984). *Rational bubbles in the price of gold*. NBER Working Paper No. 1300.
- Drozd, S., Grümmer, F., Ruf, F., & Speth, J. (2003). Log-periodic self-similarity: An emerging financial law? *Physica A: Statistical Mechanics and its Applications*, 324(1–2), 174–182.
- Drozd, S., Kwapien, J., Oswiecimka, P., & Speth, J. (2008). Current log-periodic view on future world market development. *Acta Physica Polonia A*, 114(3), 539–546.
- Evans, G. W. (1991). Pitfalls in testing for explosive bubbles in asset prices. *American Economic Review*, 81(4), 922–930.
- Funke, M., Hall, S. G., & Sola, M. (1994). Rational Bubbles during Poland's hyperinflation – Implications and empirical evidence. *European Economic Review*, 38(6), 1257–1276.
- Gürkaynak, R. S. (2008). Econometric tests of asset price bubbles: Taking stock. *Journal of Economic Surveys*, 22(1), 166–186.
- Hall, S. G., Psaradakis, Z., & Sola, M. (1999). Detecting periodically collapsing bubbles: A Markov-switching unit root test. *Journal of Applied Econometrics*, 14(2), 143–154.
- Hamilton, J.D. (1994). *Time series analysis*. Princeton, NJ: Princeton University Press.
- Hillier, D., Draper, P., & Faff, R. (2006). Do precious metals shine? An investment perspective. *Financial Analysts Journal*, 62(2), 98–106.
- Homm, U., & Breitung, J. (2012). Testing for speculative bubbles in stock markets: A comparison of alternative methods. *Journal of Financial Econometrics*, 10(1), 198–231.
- Jaffe, J. F. (1989). Gold and gold stocks as investments for institutional portfolios. *Financial Analysts Journal*, 45(2), 53–59.
- Kalbaska, A., & Gatkowski, M. (2012). Eurozone sovereign contagion: Evidence from the CDS market (2005–2010). *Journal of Economic Behavior and Organization*, 83(3), 657–673.
- Kim, C. J., & Nelson, C. R. (2000). *State space models with regime switching*. Cambridge, MA: MIT Press.
- Lane, P. R. (2012). The European sovereign debt crisis. *Journal of Economic Perspectives*, 26(3), 49–67.
- Lucey, B.M., & O'Connor, F. (2013). *Do bubbles occur in the gold price? An investigation of gold lease rates and Markov switching models*. Borsa Istanbul review.
- Mody, A., & Sandri, R. (2011). *The Eurozone crisis: How banks and sovereigns came to be joined at the hip*. IMF Working Paper WP/11/269.
- Phillips, P. C. B., & Yu, J. (2010). *Dating the timeline of financial bubbles during the sub-prime crisis*. Cowles foundation discussion paper No. 1770.
- Pindyck, R. S. (1993). The present value model of rational commodity pricing. *Economic Journal*, 103(418), 511–530.
- Psaradakis, Z. (1998). Bootstrap-based evaluation of Markov-switching time series models. *Econometric Reviews*, 17(3), 275–288.
- Pukthuanthong, K., & Roll, R. (2011). Gold and the dollar (and the Euro, Pound, and Yen). *Journal of Banking and Finance*, 35(8), 2070–2083.
- Shafiee, S., & Topal, E. (2010). An overview of global gold market and gold price forecasting. *Resources Policy*, 35(3), 178–189.
- Sjaastad, L. A. (2008). The price of gold and the exchange rates: Once again. *Resource Policy*, 33(2), 118–124.
- Sjaastad, L. A., & Scacciavillani, F. (1996). The price of gold and the exchange rate. *Journal of International Money and Finance*, 15(6), 879–897.
- Tully, E., & Lucey, B.M. (2007). A power GARCH examination of the gold market. *Research in International Business and Finance*, 21(2), 316–325.
- Went, P., Jirasakuldech, B., & Emekter, R. (2012). Rational speculative bubbles and commodities markets: Application of duration dependence test. *Applied Financial Economics*, 22(7), 581–596.
- World Gold Council (2013). World gold council publications archive. <http://www.gold.org>
- Worthington, A.C., & Pahlavani, M. (2007). Gold investment as an inflationary hedge: Cointegration evidence with allowance for endogenous structural breaks. *Applied Financial Economics Letters*, 3(4), 259–262.
- Zagaglia, P., & Marzo, M. (2013). Gold and the U.S. Dollar: Tales from the turmoil. *Quantitative Finance*, 13(4), 571–582.