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THE RELATIVE VALUATION OF GOLD

DIRK G. BAUR
University of Western Australia

JOSCHA BECKMANN
University of Greifswald

ROBERT L. CZUDAJ
Chemnitz University of Technology

Gold is a globally traded asset and held in large quantities by investors and central banks. Since there is no established model to assess whether the price of gold is overvalued or undervalued, we propose a relative valuation framework based on gold price ratios. This idea is not confined to gold but offers the foundation for relative valuation of a broad range of different assets or asset classes. We analyze gold prices relative to commodity prices, consumer prices, stock prices, dividend, and bond yields and find that the relative value of gold varies significantly over time. An analysis of the factors which drive these variations demonstrates that inflation expectations and uncertainty have a strong influence on gold ratios while macroeconomic fundamentals are less important. More specifically, a boost in confidence decreases the relative price of gold while heightened uncertainty increases the relative price of gold, which confirms the role of gold as a safe haven.

Keywords: Gold, Relative Valuation, Gold–Silver Ratio, Safe Haven

1. INTRODUCTION

Nobody really understands gold prices and I don't pretend to understand them either.
Ben Bernanke, Congressional Testimony, July 18, 2013

Gold was the cornerstone of the international monetary system until 1971 and even today, more than 45 years later, central banks hold gold as currency reserves and store of value.[1] The daily gold market turnover of over 240 billion dollar exceeds the trading volume of all but four currency pairs according to the Bank for International Settlements (BIS) report on global foreign exchange market activity

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in 2010.[2] Despite its importance in the global monetary and financial system, gold prices are not well understood and there is no commonly accepted pricing model.

In this paper, we aim to reduce the lack of understanding regarding gold prices and investigate the usefulness of relative gold valuation. The theoretical foundation for such a ratio analysis and the role of different preferences stems from the Austrian School of Economics. Menger (1871) states that "Value is nothing inherent in goods, no property of them, nor an independent thing existing by itself. It is a judgment economizing men make about the importance of the goods at their disposal for the maintenance of their lives and well-being. Hence, value does not exist out of the consciousness of men." (p. 121). Even if asset prices are random walks and unpredictable, relative asset prices will mean revert in the long run because under- or overvaluations cannot persist. The foundation for this conclusion is rooted in the law of one price which states that two identical items should sell for the same price. The law of one price also implies relative valuations, for example, that the price of an asset is too high relative to another asset. In contrast, the law of one price does not imply absolute valuations, for example, that a price of USD 1000 is the right price.

Accepting that value is relative[3], we propose the use of gold price ratios to assess the relative value of gold to other assets and commodities. Whilst the use of ratios is a rather common approach in finance to value stocks, for example, the price-earnings ratio [see Campbell and Shiller (1998), (2001)] or more generally the rate of return and the Capital Asset Pricing Model[4], there is no commonly accepted framework to value commodities with ratios. To the best of our knowledge, this is the first academic paper that analyzes gold ratios with the objective to assess and understand the relative value of gold and thus to better understand gold price dynamics and the arising implications.[5]

Since this paper analyzes gold price ratios and their macroeconomic drivers, it is also closely connected to the macro-finance literature and provides a further motivation for this study.[6] Campbell and Cochrane (1999) argue, for example, that individual risk aversion and expected returns are negatively related to consumption and the business cycle. Such a different risk-taking behavior of investors in "good" and "bad" times offers an explanation for time variation in gold ratios. Relative gold valuation also offers some insights on linkages between business cycle fluctuations and relative asset prices. In this regard, we also contribute to the literature by paying specific attention to uncertainty, expectations and risk as potential drivers of gold ratios and provide a new – relative – perspective on the hedge and safe haven aspects of gold and linkages to the real economy.

Based on the existing literature of gold summarized in the next section, we study 10 gold price ratios: The gold–silver ratio, the gold–CPI ratio, the gold–commodity price ratio, the gold–oil ratio, the gold–corn ratio, the gold–copper ratio, the gold–Dow (Jones) ratio, the gold–dividend yield ratio, the gold–US Treasury bond yield ratio, and the gold–federal funds rate ratio. The ratios using yields are based on a constructed index of compounded yields. The first six ratios value gold relative to different prices (silver prices, consumer prices, commodity prices) and are thus related to the question if gold is a relative store of value and an inflation hedge, that is a price hedge that insures against rising consumer prices. The gold–Dow ratio tests if gold is also an asset price hedge and the last three ratios study the price of gold relative to compounded yields. The dividend yield, the 10-year US Treasury bond yield, and the federal funds rate can be viewed as a measure of the opportunity cost of holding physical gold. Regardless of the question whether gold is analyzed against asset prices or indices, an increase always reflects a higher relative valuation of gold. Whilst it is obvious that the ratios are not exhaustive and that one could think of a large number of additional ratios, we believe that the chosen ratios can be considered a representative sample of the large set of theoretically possible ratios.[7]

Since value is nothing inherent in goods, it can change which justifies the analysis of ratios through time with a special focus on the variation of the ratios in certain periods, for example, high or low inflation periods. In other words, we study gold price ratios in two dimensions, across different assets and through time.

The variation of the ratios is also potentially useful to make statements about the future (relative) price of gold. Constant ratios would not allow to make statements about a relative over- or undervaluation of gold. Similarly, if the variations of the ratios were not within certain ranges, relative valuation would be impossible as well. This is why Campbell and Shiller (2001) assume stability of the valuation ratio within their historical ranges ("and neither move permanently outside nor get stuck at one extreme of their historical ranges", p. 2). This stability has important implications about mean reversion of the ratios and predictability. Campbell and Shiller (2001) argue "When a valuation ratio is at an extreme level either the numerator or the denominator of the ratio must move in the direction that restores the ratio to a more normal level" (pp. 2–3). We will analyze the dynamics of the gold price ratios both descriptively and econometrically explicitly testing for mean reversion and predictability. To preview our results, we find that gold price ratios are mean-reverting, which demonstrates that they are useful for policymakers and market participants who can expect that long-run deviations representing misalignments are corrected at some future point in time.

We also study the reasons for the variation, that is, which factors drive the fluctuations of ratios and what we can learn from this variation. In doing so, we apply Bayesian model averaging (BMA) in order to allow for both uncertainty about the variables that should be included in the model and the uncertainty about the model structure [Raftery (1995)]. This is particularly important for the gold market that is influenced by both economic and financial variables and global and local factors. This uncertainty about the appropriate econometric model is tackled by BMA using a weighted average of posterior means based on a large number of different models as point estimates.

Relying on this framework, we consider two kinds of regressors. One group consists of macroeconomic variables from the USA, namely industrial production, money supply, consumer prices, and the 3-month Treasury rates. The second set includes measures of expectations and uncertainty. We include macroeconomic uncertainty, economic policy uncertainty, sentiment, inflation expectations, and smoothed US recession probabilities.[8] This overall setting includes standard macroeconomic fundamentals and also accounts for the fact that asset prices are forward looking and therefore incorporate discounted expectations.

The remainder of the paper is structured as follows. Section 2 reviews the underlying idea of ratios, points out linkages to previous studies, and examines the dynamics of the ratios under observation. Moreover, Section 3.1 describes our empirical methodology dealing with determinants of gold ratios and Section 3.2 presents the corresponding results. Section 4 summarizes the findings and provides concluding remarks.

2. RATIO ANALYSIS

2.1. Ratios and Hedges

The ratios can also be used to analyze certain characteristics of gold, namely the store of value and safe haven. More specifically, a stable long-run ratio is consistent with gold's store of value and inflation hedge property, and a stable or rising ratio in periods of uncertainty is consistent with gold's safe haven property. However, all interpretations are only valid in relative terms. For example, gold's store of value property in a relative valuation context could also imply that the price of gold falls together with other assets but not by more than the alternative assets that are considered. Moreover, there is only strong evidence for the store of value property if it holds for a large number of alternative assets. Finally, the safe haven property could entail that the price of gold falls in a crisis period but not by more than the alternative assets. In that case, gold would lose in absolute value terms but not in relative value terms. Hence, the ratio analysis provides a new perspective on these properties compared to other frameworks that are commonly used [e.g. see O'Connor et al. (2015)]. A stable ratio means that there is a perfect correlation between gold and the other asset under consideration. Such a perfect correlation may imply an inflation hedge or an asset price hedge; that is, the price of gold moves with the other asset and thus does not lose its relative value.

A stable ratio does not imply a financial hedge in the sense that gold protects investors against a falling price of an asset or an index. If the correlation is zero or negative on average, for example, if gold returns are uncorrelated with stock returns and gold is therefore a hedge against stock returns, the gold price–stock price ratio would not be stable but vary over time. Accordingly, since gold is a safe haven against other assets (e.g. the stock market) if the correlation is zero or negative in crisis periods only [see Baur and Lucey (2010)], the ratio would not decrease in crisis periods. Hence, we expect a stable ratio if gold is a perfect inflation hedge but a time-varying ratio if gold is an imperfect inflation hedge or a safe haven.

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2.2. Underlying Idea and Literature

Campbell and Shiller (2001) explicitly introduce the idea of relative valuation in the context of stock prices. They use the dividend–price ratio and argue that the ratio should not move out of a specific range and thus should revert to its mean. If we consider the price of gold (g) and another asset (a) as two random walk processes,

$$g_t = g_{t-1} + \varepsilon_t \quad \text{and} \quad a_t = a_{t-1} + \eta_t, \tag{1}$$

both can be expressed as sums of stochastic shocks

$$g_t = g_0 + \sum_{s=1}^{t} \varepsilon_s \quad \text{and} \quad a_t = a_0 + \sum_{s=1}^{t} \eta_s. \tag{2}$$

Therefore, the ratio

$$r_t = g_t/a_t = \frac{g_0 + \sum_{s=1}^{t} \varepsilon_s}{a_0 + \sum_{s=1}^{t} \eta_s} \tag{3}$$

would be a constant if both asset prices are subject to the same stochastic shocks ($\varepsilon_t = \eta_t$). In this spirit, the ratio will not vary substantially over the long run if both assets are co-integrated. This hypothesis can be formally tested by checking for a co-integrating vector of (1,−1) between g_t and a_t or by adopting unit root tests directly to the ratio r_t as will be done in Section 2.4. Co-integration techniques have been adopted by several studies in the context of gold, for example, when analyzing the gold–silver or the gold–CPI relationship [see Escribano and Granger (1998) and Beckmann and Czudaj (2013a) for two examples and O'Connor et al. (2015) for an overview of existing studies]. However, co-integration studies generally focus on the identification of long-run relationships and do not analyze exogenous drivers of misalignments and corrections.

One advantage of the ratio analysis compared to a regression-type framework is that both endogenous and exogenous drivers of the relationships given by the ratios can be easily analyzed. A regression-type model to examine the inflation hedge property of gold can be estimated as follows:

$$\Delta g_t = \alpha + \beta \pi_t + \epsilon_t, \tag{4}$$

where Δg_t is the relative change of the price of gold at t, π_t is the inflation rate at t, and ϵ_t is an error term. Whilst it is not straightforward to analyze the dynamics of this relationship by allowing β to vary and to be a function of exogenous variables, this is a comparably simple exercise using ratios; for example, the gold price–consumer price ratio can be regressed on a large number of regressors and short-run and long-run effects can be established.

Instead of merely analyzing if ratios are mean-reverting, we go one step further and analyze potential drivers of under- and overvaluations of gold reflected by variations of r_t. Campbell and Shiller (2001) argue that ratios which move outside expected boundaries potentially invalidate existing relationships and indicate a new era. This idea is of particular relevance in the context of gold prices which have been characterized by pronounced periods of under- or overvaluation over recent decades. It is also established that short-run variations of gold prices are driven by certain conditions of financial markets which change the relative preference for gold, in particular in times of uncertainty and market stress. Hence, one implicit hypothesis we test is whether such developments introduce relative changes of the gold price due to diverging stochastic shocks in equation (3).

The existing literature generally focuses on specific variables which are potentially linked to the price of gold and uses mainly regression and co-integration frameworks to analyze these relationships. Taking into account the large literature on gold prices, we only elaborate on a few selected studies in the following.[9] One strand of the literature analyzes the inflation hedge property of gold.[10] Recent research of this kind is, for example, provided by Jastram (2009), Beckmann and Czudaj (2013a), as well as Batten et al. (2014). Blose (2010) analyzes whether changes in expected inflation affect gold prices and finds no robust evidence for such a link. A second kind of studies focuses on the role of gold against other assets. For example, Escribano and Granger (1998) study the long-run relationship between gold and silver prices and Capie et al. (2005) examine the hedge property of gold with respect to changes of the US dollar. Baur and Lucey (2010) study the relationship of gold with equity and bond markets and focus on the safe haven property of gold. Finally, some authors have examined gold price determinants from a broader perspective. Baur (2011) studies a large range of variables including different inflation rates, interest rates, and exchange rates, and Bialkowski et al. (2015) estimate the influence of different variables with the aim to determine a fundamental price of gold and to identify bubbles. Faugere and Van Erlach (2005) assess the value of gold using a global required yield theory. None of these papers explicitly consider gold price ratios implicitly by relating gold price changes to changes of other variables. In other words, all studies identify certain drivers of gold, hedge, or safe haven properties based on econometric measures of association.

The macro-finance literature points to a potential transmission of business cycle fluctuations to the relative valuation of gold. The frequently observed link between business cycle fluctuations and risk premia can be explained via different theoretical approaches, such as habits or idiosyncratic risk [Cochrane (2017)]. Higher risk premia on stocks often arise during economic downturns and can drive up the demand for gold and the corresponding price due to safe haven effects. The habit approach introduced by Campbell and Cochrane (1999), for example, argues that individual risk aversion and expected returns are negatively related to consumption and the business cycle. Such a different risk-taking behavior of investors in "good" and "bad" times offers an explanation for time variation in gold ratios. It is also linked to safe haven effects which imply an increasing demand for gold during economic downturns or in times of uncertainty.

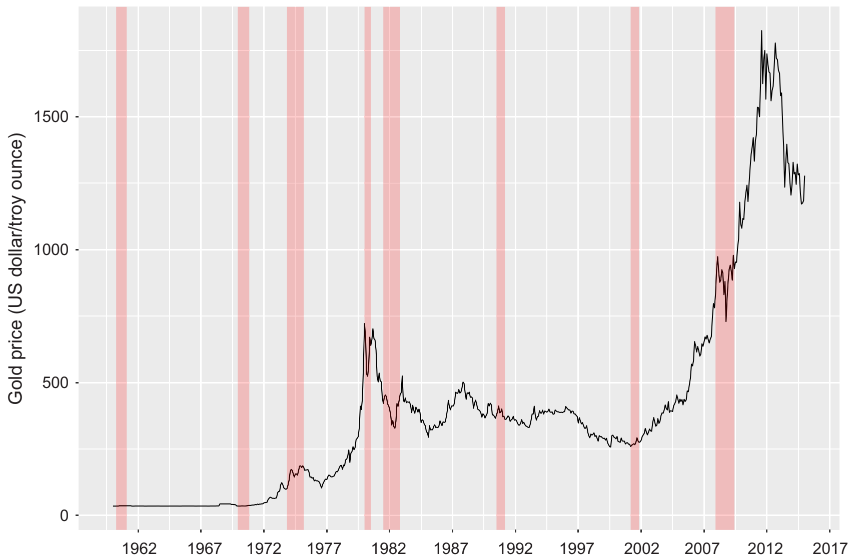

FIGURE 1. The gold price. This figure presents the evolution of monthly gold prices (US dollar per ounce) from 1960:1 to 2015:1. The red-shaded areas represent the US recession periods provided by the National Bureau of Economic Research (NBER).

2.3. Descriptive Analysis

This subsection starts with the presentation of the data and a descriptive statistical analysis as a precursor to the ratio analysis. Figure 1 illustrates the evolution of the price of gold from January 1960 until January 2015 on a monthly basis. The 1960s period is included to contrast two gold price regimes, one in which the price was fixed to the US dollar and one in which the fix to the US dollar was abolished. The different regimes can be clearly identified as the former is characterized by a stable price for most of the 1960s and the latter is characterized by significant fluctuations in the price of gold. All ratios display the significant undervaluation of gold in the final year of the Bretton Woods system with all of them increasing after the abolishment of the gold–dollar peg in 1973 (see Figure 2).

Table 1 presents descriptive statistics of the prices of the assets used for the relative valuation of gold. The table includes gold prices, silver prices,[11] US consumer prices (CPI),[12] a commodity price index (CRB),[13] West Texas Intermediate (WTI) crude oil prices,[14] corn prices, London Metal Exchange (LME) copper prices,[15] the index level of the Dow Jones Industrial Average (DJIA),[16] the cumulative returns of reinvested S&P500 dividends (DIVY), the cumulative returns of the 10-year US Treasury bond yields, and the cumulative returns of the federal funds rate.[17]

We calculate the ratios of gold prices relative to the other asset prices or levels for each month for the January 1960–January 2015 sample period. The

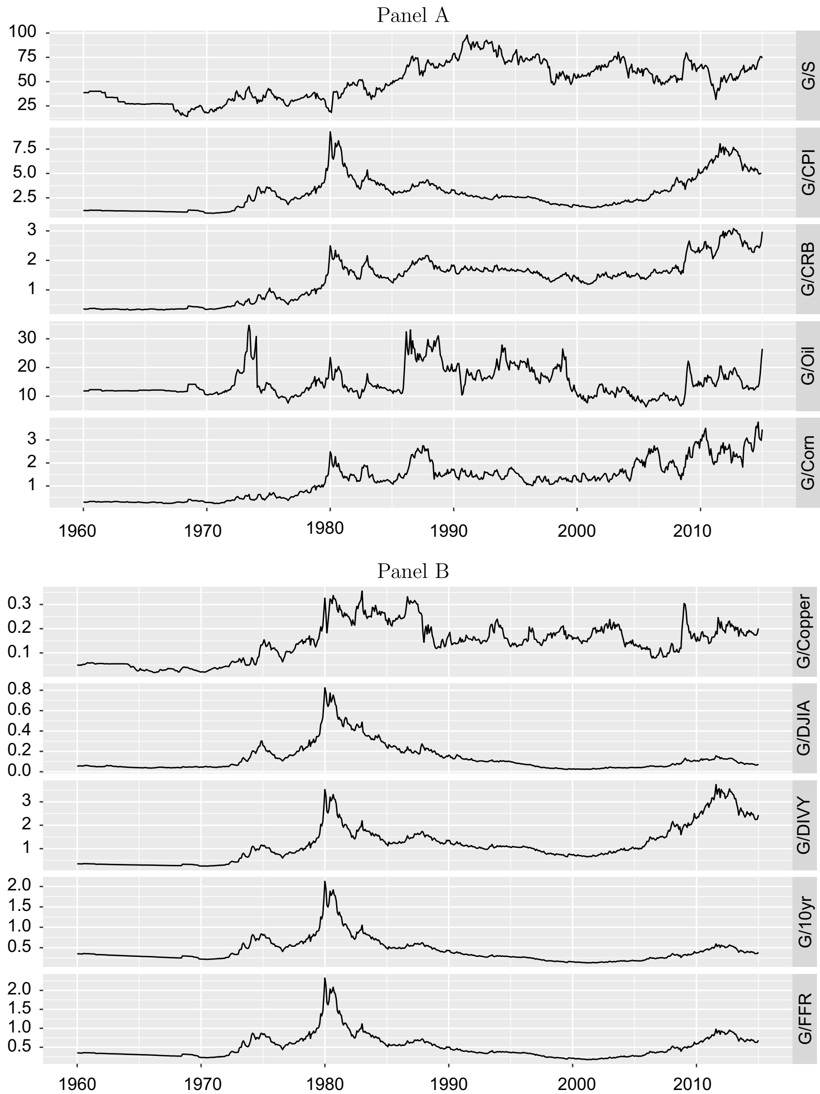

FIGURE 2. Gold ratios. This figure shows the evolution of 10 monthly gold ratios from 1960:1 to 2015:1. Panel A shows the gold price relative to the price of silver, the US CPI, the CRB commodity price index, the price of oil, and the price of corn. Panel B shows the gold price relative to the price of copper, the DJIA, the cumulative returns of reinvested S&P500 dividends (DIVY), the cumulative returns of the 10-year US Treasury bond yields, and the cumulative returns of the federal funds rate.

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TABLE 1. Descriptive statistics

	Gold	Silver	CPI	CRB	Oil	Corn	Copper	DJIA	SPDIVYcum	10-year cum	FFRcum
Median	343.40	5.18	113.65	224.75	19.61	243.00	1721.75	2031.65	285.90	783.31	680.63
Mean	401.19	7.58	117.59	244.79	28.54	262.83	2610.71	4692.76	287.03	1158.54	830.73
Min	35.15	0.91	29.30	95.80	2.92	104.00	612.90	561.28	100.00	100.00	100.00
Max	1824.20	48.48	238.34	679.00	140.00	806.50	9970.00	17, 828.24	524.95	3308.82	1869.91
SE.mean	15.32	0.30	2.64	5.07	1.11	5.20	85.57	185.97	5.10	40.55	25.12
CI.mean	30.07	0.58	5.19	9.95	2.18	10.21	168.02	365.17	10.01	79.62	49.33
std.dev	393.75	7.59	67.94	130.27	28.49	133.66	2199.90	4781.34	131.09	1042.49	645.85

Note: This table reports the median, the mean, the minimum, the maximum, the standard error on the mean (SE.mean), the confidence interval of the mean (CI.mean) at the 0.95 level, and the standard deviation (std.dev) of the price of gold, the price of silver, the US CPI, the CRB commodity price index, the price of oil, the price of corn, the price of copper, the DJIA, the cumulative returns of reinvested S&P500 dividends (DIVY), the cumulative returns of the 10-year US Treasury bond yields, and the cumulative returns of the federal funds rate.

time-varying ratios are presented in Figure 2 and the descriptive statistics of the ratios are reported in Table 2. The graphs and the table show that the ratios are rather volatile and deviate from their long-run (historical) mean for substantial periods of time.

For example, whilst the mean of the gold–silver ratio is 50.33, its standard deviation is 19.56, which implies that the ratio varies substantially through time. Figure 2 shows that the ratio was around 20 in the 1970s and 1980s but increased to levels well above 80 in the 1990s. Similar variations can be observed for the other series. Whilst the gold price appears to have started its bull run peaking in 2011 at values above US$1900 around the year 2004, there is no clear evidence for this being unique to gold. For example, the gold–silver, gold–oil, and the gold–copper ratios do not indicate a structural break around 2004. Gold and oil are the two most liquid commodities. Both can serve as a store of value and are driven by similar factors, for example, inflation, which should dampen the deviations compared to other ratios. The gold–oil ratio indeed appears to be rather stable with less pronounced deviations from its long-run mean but displays a lot of short-run volatility until 2000. Both ratio and underlying variance remain remarkably stable until 2007 with the increase afterwards reflecting the falling price of oil.

Another common feature among 9 of the 10 ratios is the high level around the year 1980 (except for the gold–silver ratio). The fact that the ratios were equally and historically high among a large set of assets in 1980 and decreased significantly afterwards suggests that gold was overvalued relative to other assets at that time. The peak around the year 2010 for most ratios (except the gold–silver ratio) resembles the 1980 commonality and suggests that gold was overvalued relative to the other assets as it is rather unlikely that all other assets were jointly undervalued. In the following, we also analyze if the drivers of the ratios are the same in the 1980s and in the 2010s.

Figure 3 presents the boxplots of the ratios and illustrates that some ratios differ substantially from each other. The gold–silver ratio, for example, is rather symmetric whilst the other ratios are asymmetric and in some cases heavily positively skewed indicating relative overvaluation of gold. The exceptional characteristics of the gold–silver ratio in relation to the other ratios suggest that silver behaves similar to gold despite its higher volatility. This result is not surprising given that both gold and silver are precious metals and share a long monetary history.

In order to assess whether fluctuations of ratios also reflect higher demand for gold, Figure 4 displays ratios plotted against actual global gold-backed exchange-traded fund (ETF) assets under management for the period starting from March 2003. Data for gold ETFs are provided by the World Gold Council and show investment patterns of institutional and individual investors. Both the gold–CPI ratio and the gold–DIVY ratio display a strong co-movement with gold investments. This confirms, for example, the safe haven function of gold in the sense that a higher relative price of gold is due to higher demand. This might also reflect higher risk premia required by investors in times of turbulence. The co-movement of the gold–CPI ratio and gold ETFs also confirms the inflation hedge property of gold in relative terms.

TABLE 2. Descriptive statistics of the gold ratios

	G/S	G/CPI	G/CRB	G/Oil	G/Corn	G/Copper	G/DJIA	G/DIVY	G/10 year	G/FFR
Median	50.97	2.57	1.47	12.97	1.31	1.48	0.08	1.03	0.33	0.38
Mean	50.33	2.90	1.33	14.80	1.29	1.44	0.13	1.17	0.42	0.51
Min	14.06	0.91	0.32	6.31	0.23	1.86	0.02	0.25	0.13	0.17
Max	98.03	9.28	3.08	34.69	3.78	3.56	0.82	3.74	2.13	2.32
SE.mean	0.76	0.07	0.03	0.20	0.03	3.06	0.01	0.03	0.01	0.01
CI.mean.0.95	1.49	0.13	0.05	0.39	0.06	6.01	0.01	0.06	0.02	0.02
std.dev	19.56	1.70	0.71	5.05	0.80	7.87	0.14	0.80	0.29	0.32

Note: This table reports the median, the mean, the minimum, the maximum, the standard error on the mean (SE.mean), the confidence interval of the mean (CI.mean) at the 0.95 level, and the standard deviation (std.dev) of the price of gold relative to the price of silver, the US CPI, the CRB commodity price index, the price of oil, the price of corn, the price of copper, the DJIA, the cumulative returns of reinvested S&P500 dividends (DIVY), the cumulative returns of the 10-year US Treasury bond yields, and the cumulative returns of the federal funds rate.

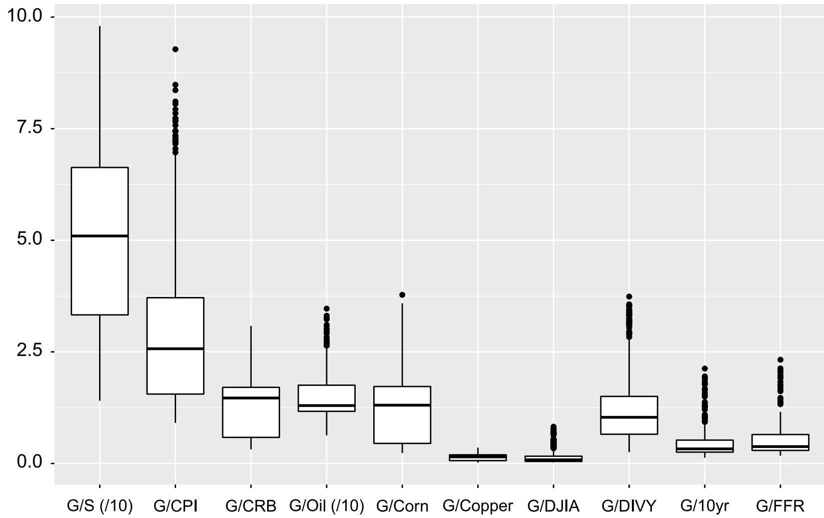

FIGURE 3. Boxplots of the gold ratios. This figure shows boxplot diagrams characterizing the variation of 10 gold ratios during the period running from 1960:1 to 2015:1. The latter displays the gold price relative to the price of silver, the US CPI, the CRB commodity price index, the price of oil, the price of corn, the price of copper, the DJIA, the cumulative returns of reinvested S&P500 dividends (DIVY), the cumulative returns of the 10-year US Treasury bond yields, and the cumulative returns of the federal funds rate. The gold–silver and the gold–oil ratios are divided by 10 to eliminate scale differences.

2.4. Mean Reversion

A crucial question is whether the ratios are mean-reverting—that is, whether the prices for gold and other assets are co-integrated with a long-run coefficient vector of (1,−1). If a ratio is mean-reverting, investors and policymakers can use a high relative valuation as a signal that indicates a nonpersistent overvaluation whilst such a signal would be meaningless if the ratio did not exhibit a tendency to revert to its historical mean. To test for mean reversion, we apply a Perron (2006) type of test and therefore allow for the potential of structural changes in the level of each gold ratio which is reasonable bearing in mind the rather long sample period and several momentous economic events during that period.[18] The corresponding results are reported in Table 3.

We find that all regressions yield a negative coefficient for the lagged ratio and the null of a unit root is rejected for 8 out of 10 gold ratios indicating mean reversion. Solely for the gold–silver and the gold–DIVY ratios, the null can hardly be rejected but the corresponding test statistics are close to the 10% critical value. Bearing in mind the generally low power of unit root tests to reject the null, we do not see this finding as a clear-cut indication against mean reversion of these two ratios. Moreover, a visual inspection of the ratios also illustrates that all ratios exhibit common features and a tendency to revert back to its long-run mean. This

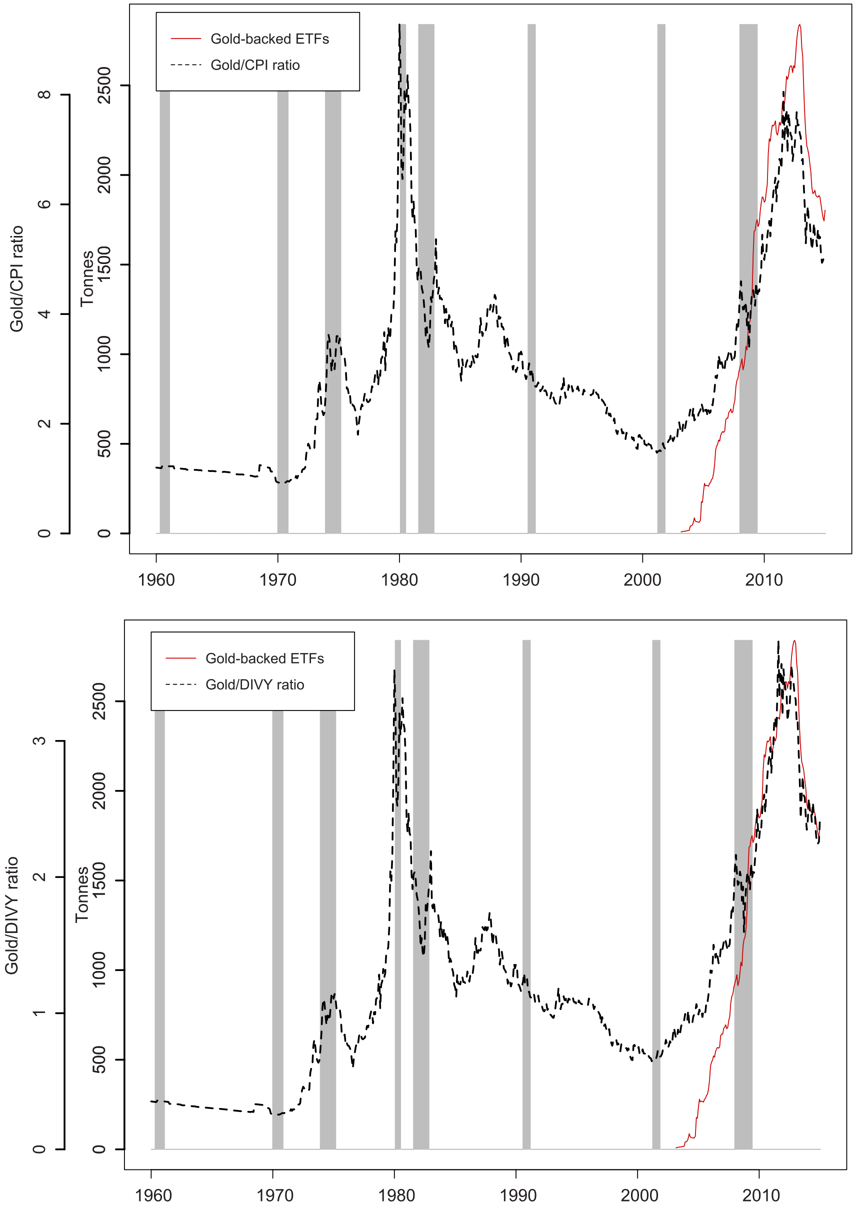

FIGURE 4. Gold ratios and global gold-backed ETF holdings. This figure shows the gold–CPI (top panel) and the gold–DIVY ratio (bottom panel) plotted against actual global gold-backed ETF assets under management measured in Tonnes. Data for gold ETFs are provided by the World Gold Council starting from March 2003 and show investment patterns of institutional and individual investors. The gray-shaded areas represent the US recession periods provided by the NBER.

TABLE 3. Unit root tests

	1960–2015					1971–2015				
Ratio	α	Break 1	Break 2	Lags	t_α-stat.	α	Break 1	Break 2	Lags	t_α-stat.
Gold/silver	−0.060360	1983:11	1997:03	3	−4.856862	−0.087779	1985:07	1996:07	3	−5.138989
Gold/CPI	−0.038551	1979:04	2008:01	8	−5.495496*	−0.047742	1979:04	2008:01	8	−5.732094**
Gold/CRB	−0.084105	1978:05	2008:02	5	−6.355555***	−0.101688	1978:05	2008:02	5	−6.404907***
Gold/oil	−0.104124	1985:09	1998:12	1	−6.158746***	−0.106098	1985:09	1998:09	1	−5.677947**
Gold/corn	−0.090598	1978:03	2007:12	7	−5.274616*	−0.094752	1978:03	2007:12	7	−4.839771
Gold/copper	−0.100001	1978:11	1987:01	5	−6.087645***	−0.128255	1978:11	1987:01	5	−6.361668***
Gold/DJIA	−0.029113	1973:01	1979:04	8	−6.478550***	−0.028009	1979:04	2010:06	8	−5.579445**
Gold/DIVY	−0.038093	1979:04	2006:10	8	−5.227872	−0.045438	1979:04	2006:11	8	−5.284481*
Gold/10 years	−0.039389	1973:01	1979:04	8	−8.202408***	−0.038453	1979:04	2010:06	8	−7.124691***
Gold/FFR	−0.039167	1973:01	1979:04	8	−7.496402***	−0.042629	1979:04	2008:01	8	−7.176031***

Notes: The test proposed by Perron (2006) checks the null of a unit root by allowing for endogenously determined structural changes in the level of each gold ratio. This table reports the mean reversion coefficient (α), the test statistic (t_α), the number of lags selected by the general to specific approach according to the p values, and two endogenously determined structural breaks.

*, **, and *** denote statistical significance at the 10%, 5%, and 1% level, respectively. Critical values for the test statistic t_α are as follows: −5.24 (10%), −5.51 (5%), and −6.06 (1%).

basically indicates that gold prices and the other prices or assets considered cannot deviate from each other over the long run and thus are co-integrated. Therefore, gold ratios can be used to assess in which periods gold was under- or overvalued. The gold–oil ratio appears to be the most stable and also displays the largest negative coefficient estimate. Moreover, to verify the robustness of this result we have also applied this test on a sample period (i.e. 1971–2015) excluding the period prior to the breakdown of Bretton Woods to assure that our findings are not affected by the inclusion of the fixed gold price period prior to 1971. The latter confirms our finding. In addition, Table 3 also provides endogenously determined structural breaks for each gold ratio which roughly serve as a guideline for our (subsample) analysis in Section 3.2. For most of the ratios, we find a structural break around the year 1978 which marks the starting point of our analysis in Section 3.2 and also around the year 2008 in which Lehman Brothers collapsed. Both dates mirror turning points of the gold price.[19]

2.5. Valuations

For valuation purposes, it is important to know whether the current ratios are similar to the historical average or clearly different. A comparison of the ratios in January 2015 with the historical averages shows that the 2015 ratios are larger in most cases with the exception of the gold–DJIA ratio and the gold–10-year bond ratio. All other ratios are clearly larger than their historical average. For the gold–silver ratio, the difference is 50%; that is, the ratio in 2015 stands at 75 compared to a historical average of 50. In contrast, a comparison of the 6-month average of the second half of 2014 with the 5-year average from 2009 to 2014 reveals that the difference is positive for all ratios except the gold–DJIA ratio but relatively small and negligible compared to the comparison with the historical mean spanning the full sample period. For example, the gold–silver ratio is only 1% larger than its 5-year average. A simple regression in which the ratio is regressed on a constant and a trend reveals a positive trend for all ratios except for the DJIA, the 10-year bond, and the FFR ratios. However, despite the statistical significance of the trend coefficients, the results are also influenced by the relatively low ratios in the 1960s. In addition, the trend does not account for the variations throughout the sample. If the trend estimates are ordered, the gold–oil ratio exhibits the weakest positive trend followed by gold–CPI, gold–silver, gold–corn, and gold–CRB. Given the trend coefficients, the gold–oil ratio could be labeled the most stable of all ratios, an interpretation that is also supported by a visual inspection of the ratio.

One can also assess the relative performance of gold over the sample period by comparing the total percentage changes of each variable. The total change of gold over the 55-year period is 3264%, compared to 1614% for silver, 701% for the CPI, 342% for the CRB, 1694% for oil, 237% for corn, 827% for copper, 2763% for the Dow Jones, 424% for the reinvested dividends of the S&P500, 3204% for the reinvested returns on 10-year US Treasury bonds, and 1870% for the reinvested returns on the FFR. This list indicates that gold outperformed all other assets or indices.

2.6. Variations

To investigate whether the variations are statistically significant, we have tested the null hypothesis that the ratio in month t is not different from the historical mean up to that month t and thus have calculated the corresponding t-statistic for each month.[20] The ratios are plotted, and a red-shaded area is added representing t-statistics that are larger than their respective 5% critical values. Figures 5–9 show these areas for the gold ratios. The plots illustrate that the ratios are statistically significantly different from their historical mean especially around the years 1970, 1980, 1990, and 2010. This indicates that gold is not constantly effective as an inflation hedge or an asset price hedge.[21]

Commonalities in lower bound (10%) and upper bound (90%) exceedances of the ratios are plotted in Figure 10. It shows the number of ratios that exceed their respective lower and upper bounds for each month. The time series plot illustrates that there are two exceedance clusters of the lower bounds and two exceedance clusters of the upper bounds. The lower bound clusters are located in the late 1960s and the early 2000s whilst the upper bound clusters are located around the year 1980 and the 2010–2015 period. The exceedance commonalities show the joint under- or overvaluation of gold for each period and thus indicate that gold was rather undervalued in the lower bound exceedance clusters and overvalued in the upper bound exceedance clusters. The reasons for the overvaluation of gold in the 1980s and 2010–2015 period are likely different as the 1980 overvaluation can be attributed to a regime of high inflation, and the 2010–2015 period can be attributed to a regime of low inflation and possibly high uncertainty.

3. THE DRIVERS OF GOLD PRICE RATIOS

3.1. Empirical Framework and Potential Regressors

As already mentioned in the Introduction, instead of applying simple regression frameworks we make use of BMA in order to account for the uncertainty about the model or more precisely about its structure and its variables. We do this since the evolution of the gold price and thus also of the gold ratios considered in this study is characterized by a high degree of uncertainty about the variables to select and about the structural form.[22]

We include m potential regressors and consider each combination of these as a potential model. This results in $K = 2^m$ different model combinations. Following Raftery (1995), the model-averaged Bayesian point estimator is given by

$$E\left[\beta_j|X\right] = \sum_{k=1}^{K} \tilde{\beta}_j^{(k)} p(M_k|X), \tag{5}$$

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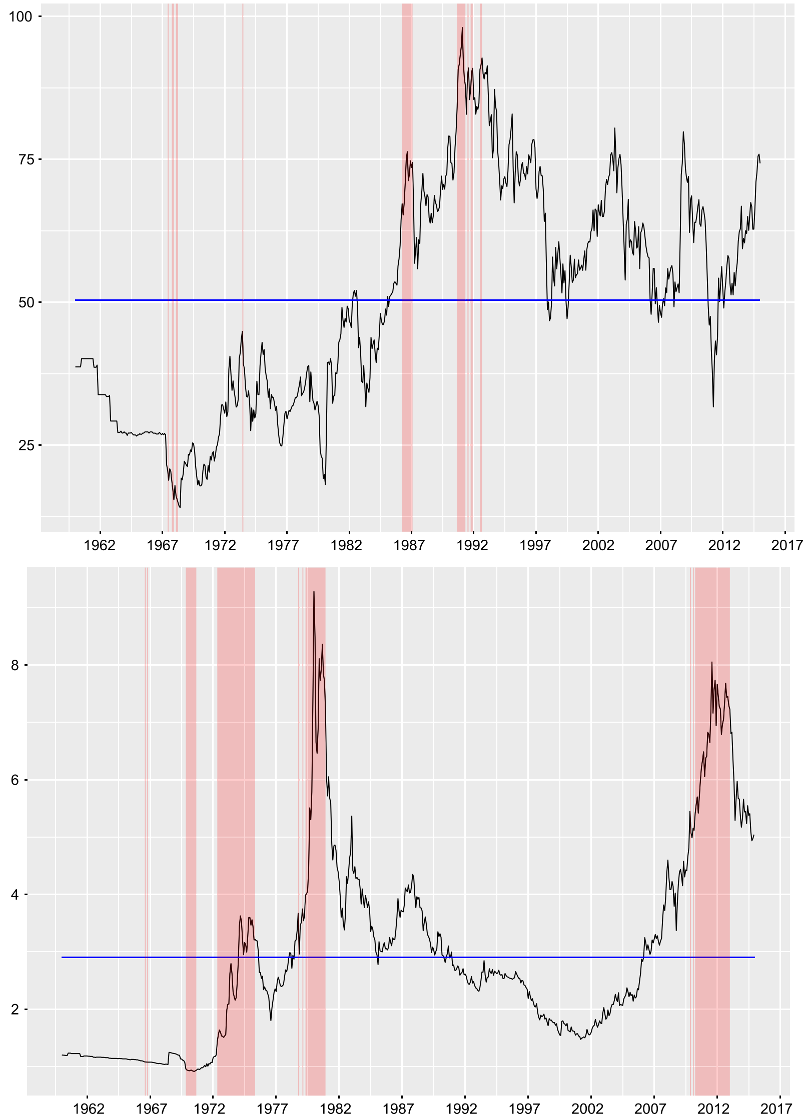

FIGURE 5. Gold–silver and gold–CPI ratios. This figure shows the evolution of the gold–silver (top panel) and gold–CPI ratios (bottom panel) from 1960:1 to 2015:1 together with their historical mean (blue line). The red-shaded area marks the periods in which the ratio is statistically significantly different from its historical mean on a 5% level.

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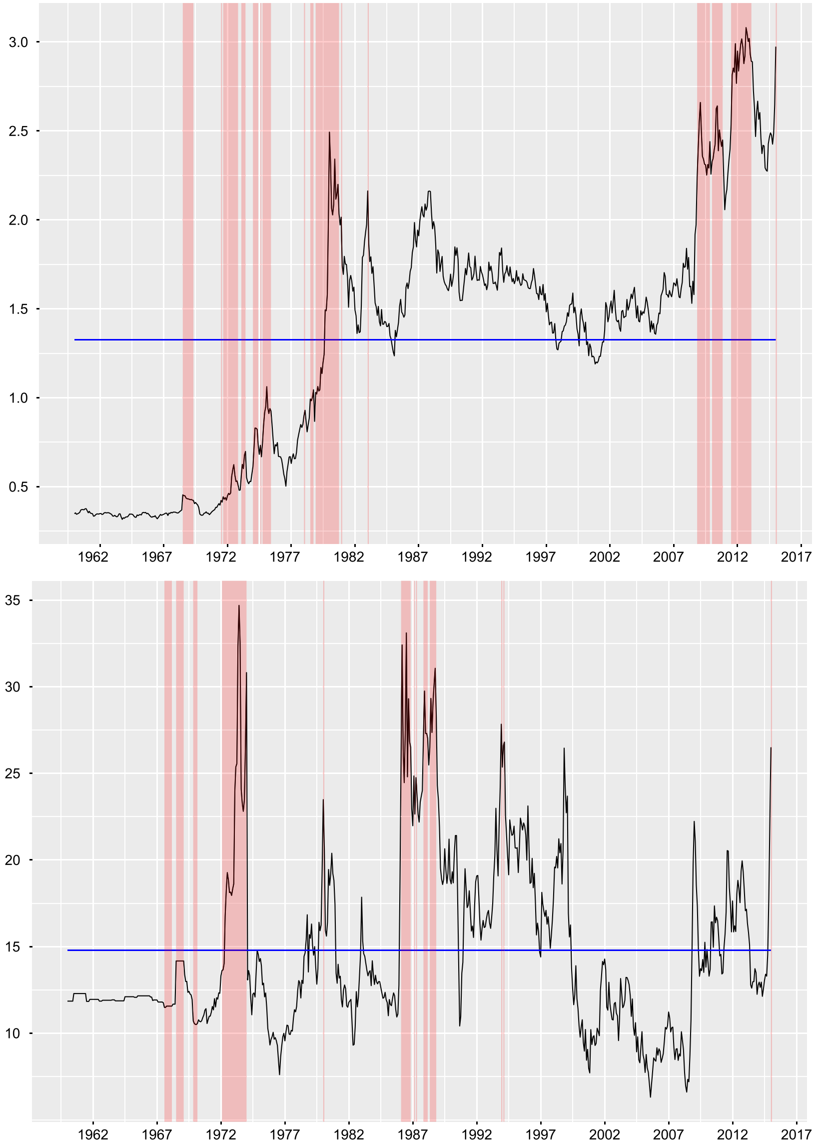

FIGURE 6. Gold–CRB and gold–oil ratios. This figure shows the evolution of the gold–CRB (top panel) and gold–oil ratios (bottom panel) from 1960:1 to 2015:1 together with their historical mean (blue line). The red-shaded area marks the periods in which the ratio is statistically significantly different from its historical mean on a 5% level.

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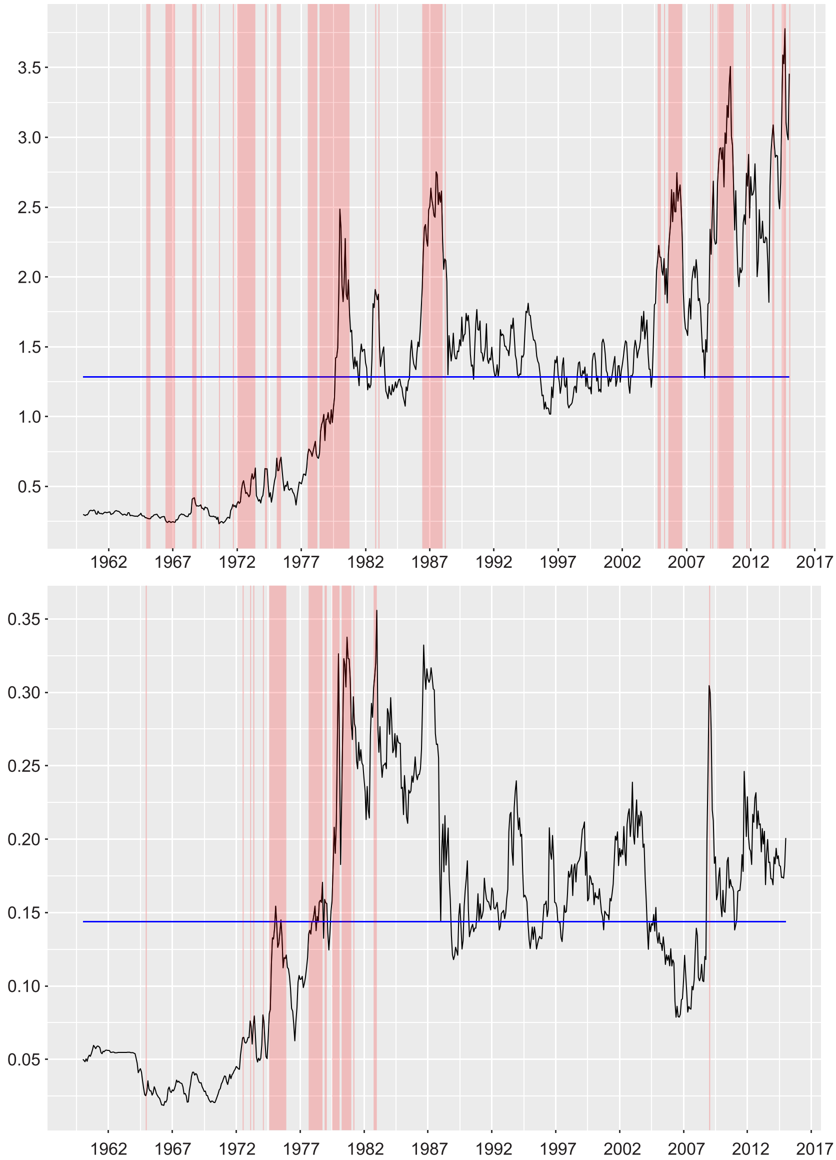

FIGURE 7. Gold–corn and gold–copper ratios. This figure shows the evolution of the gold–corn (top panel) and gold–copper ratios (bottom panel) from 1960:1 to 2015:1 together with their historical mean (blue line). The red-shaded area marks the periods in which the ratio is statistically significantly different from its historical mean on a 5% level.

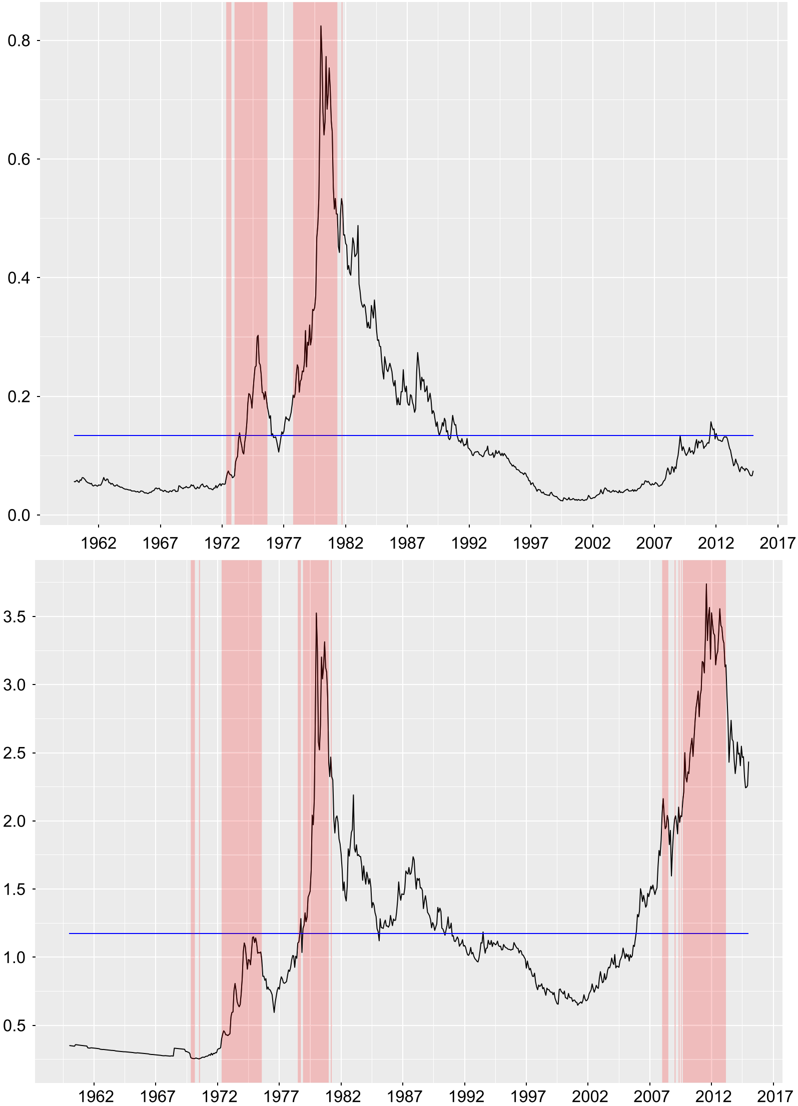

FIGURE 8. Gold–DJIA and gold–DIVY ratios. This figure shows the evolution of the gold–DJIA (top panel) and gold–DIVY ratios (bottom panel) from 1960:1 to 2015:1 together with their historical mean (blue line). The red-shaded area marks the periods in which the ratio is statistically significantly different from its historical mean on a 5% level.

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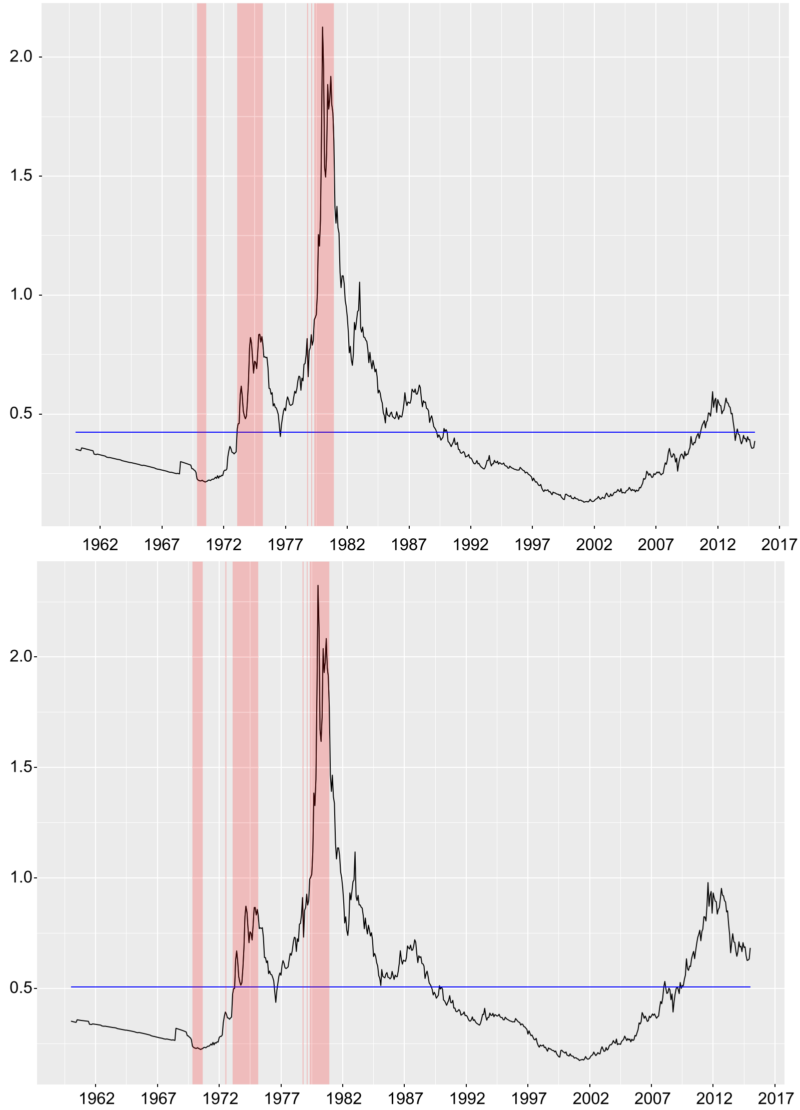

FIGURE 9. Gold–10 years and gold–FFR ratios. This figure shows the evolution of the gold–10 years (top panel) and gold–FFR ratios (bottom panel) from 1960:1 to 2015:1 together with their historical mean (blue line). The red-shaded area marks the periods in which the ratio is statistically significantly different from its historical mean on a 5% level.

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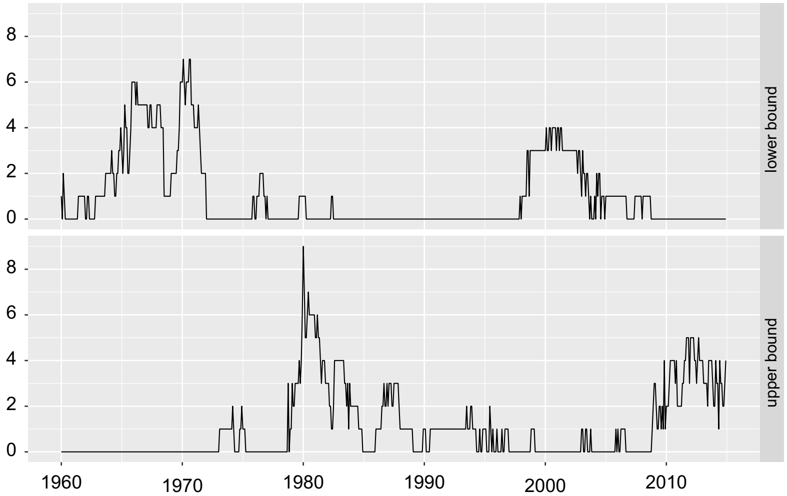

FIGURE 10. Commonality. This figure shows the number of ratios that exceed their respective 10% and 90% quantiles (bounds) in each month. The time-series plot illustrates that there are two exceedance clusters of the lower bounds (undervaluations) and two exceedance clusters of the upper bounds (overvaluations). The lower bound clusters are located in the late 1960s and the early 2000s whilst the upper bound clusters are located around the year 1980 and the 2010–2015 period. The exceedance commonalities show the joint under- or overvaluation of gold for each period and thus indicate that gold was rather undervalued in the lower bound exceedance clusters and overvalued in the upper bound exceedance clusters.

where $\tilde{\beta}_j^{(k)}$ denotes the posterior mean of β_j under model M_k, $p(M_k|X)$ stands for the posterior probability that M_k is the correct model, and X denotes the data. $p(M_k|X)$ is calculated by applying the Bayes' rule

$$p(M_k|X) = \frac{p(X|M_k)p(M_k)}{\sum_{\ell=}^{K} p(X|M_\ell)p(M_\ell)}, \tag{6}$$

where $p(X|M_k)$ is a high-dimensional integral that can be approximated accurately by the simple Bayesian information criterion (BIC). For a linear regression, the BIC can simply be calculated by $BIC_k = n\log(1-R_k^2) + m_k \log n$, where n denotes the number of observations and m_k the number of regressors included in model M_k. We take the prior model probabilities $p(M_k)$ to be equal for each model. Therefore, the point estimates given by $E\left[\beta_j|X\right]$ can be considered as weighted averages of the estimates achieved for all individual models.

As the m potential regressors, we include two different sets of variables. One group consists of macroeconomic variables from the USA, namely industrial production, money supply, consumer prices, and the 3-month Treasury bill rate taken from Thomson Reuters Datastream. In order to account for nonstationarity of these series, we use first differences. The second set includes measures of expectations and uncertainty. We include a measure of macroeconomic uncertainty following Jurado et al. (2015) and Ludvigson et al. (2015), a measure of economic policy uncertainty provided by Baker et al. (2016), consumer sentiments and inflation expectations both based on survey data and provided by the University of Michigan and smoothed US recession probabilities taken from Federal Reserve Economic Data (FRED) and obtained from a dynamic-factor Markov-switching model applied to four-monthly coincident variables (i.e. nonfarm payroll employment, industrial production, real personal income excluding transfer payments, and real manufacturing and trade sales) according to Chauvet (1998). The policy uncertainty index consists of three underlying components: newspaper coverage of policy-related economic uncertainty, the number of federal tax code provisions set to expire in future years, and the disagreement among economic forecasters. The macroeconomic uncertainty measure relies on econometric estimations of common variation in the unforecastable component based on a large number of macroeconomic indicators. In both cases, an increase reflects higher uncertainty.

This overall setting includes standard macroeconomic fundamentals and also accounts for the fact that asset prices are forward looking and therefore incorporate discounted expectations. In the latter regard, analyzing ratios is interesting since we are in a position to assess the impact of expectations and uncertainty on the relative price of gold. This offers a new perspective on the role of gold as a hedge and a safe haven. Including industrial production and recession probabilities also accounts for risk premia fluctuations as a result of actual or expected business cycle dynamics as outlined in the macro-finance literature [Cochrane (2017)]. Due to availability of data, the sample period for our estimations starts in January 1978 on a monthly basis. This excludes the period of stable gold prices in the 1960s. Table 4 reports the correlations between all regressors considered and shows that these are below 0.7 for all regressors and for most of them even below 0.5 in magnitude. Therefore, multicollinearity is not a concern in our estimations.

3.2. Empirical Results

We start the assessment of our results by analyzing our findings over the full sample period. As a benchmark for our interpretation, we rely on posterior inclusion probabilities of each variable over all models as well as on the variables which enter the best models with regard to explanatory power. We also take the magnitude of coefficients and the R^2 for the "best" model into account. Tables 5–14 provide detailed results for all ratios under consideration. We now focus on our main questions step by step.

3.2.1. Which variables are useful for explaining gold ratios?. The unambiguous pattern over the full sample period is that expectations and uncertainty turn out to be far more important for explaining movements of gold ratios than macroeconomic variables. Macroeconomic variables display inclusion probabilities below 0.5 for nearly all ratios. The only exceptions are the impact of changes in industrial production on the gold–Dow ratio, money supply changes on the

TABLE 4. Unconditional correlation between the regressors

	ΔYUS	ΔMUS	ΔPUS	ΔIUS	EPU	MU	sentiments	inflation_exp	recession_prob
ΔYUS	1.000000	−0.104938	0.014049	0.164329	−0.084420	−0.408344	0.274331	−0.109652	−0.581074
ΔMUS	−0.104938	1.000000	−0.248782	−0.061054	0.280017	0.038249	−0.204602	−0.054637	0.058480
ΔPUS	0.014049	−0.248782	1.000000	0.058023	−0.114316	−0.007940	−0.052843	0.255028	−0.017738
ΔIUS	0.164329	−0.061054	0.058023	1.000000	−0.083789	−0.063885	0.099451	0.065604	−0.252443
EPU	−0.084420	0.280017	−0.114316	−0.083789	1.000000	0.067536	−0.400460	−0.162193	0.083451
MU	−0.408344	0.038249	−0.007940	−0.063885	0.067536	1.000000	−0.615534	0.519861	0.685448
sentiments	0.274331	−0.204602	−0.052843	0.099451	−0.400460	−0.615534	1.000000	−0.492122	−0.511211
inflation_exp	−0.109652	−0.054637	0.255028	0.065604	−0.162193	0.519861	−0.492122	1.000000	0.207837
recession_prob	−0.581074	0.058480	−0.017738	−0.252443	0.083451	0.685448	−0.511211	0.207837	1.000000

Notes: This table reports the unconditional correlations between the following regressors: change of US industrial production (ΔYUS), change of US money supply (ΔMUS), change of US consumer prices (ΔPUS), change of US 3-month Treasury bill rate (ΔIUS), economic policy uncertainty index (EPU), macroeconomic uncertainty (MU), consumer sentiment, inflation expectations (inflation_exp), and smoothed US recession probabilities (recession_prob).

TABLE 5. BMA-estimation results: gold/silver

	incl. prob.	$E(\beta_j\|X)$	$SD(\beta_j\|X)$	Model 1	Model 2	Model 3	Model 4	Model 5
Intercept	100.0	1.657e + 02	1.151e + 01	1.645e + 02	1.667e + 02	1.670e + 02	1.692e + 02	1.688e + 02
ΔYUS	30.7	−7.984e − 01	1.385e + 00	.	.	−2.440e + 00	−2.456e + 00	.
ΔMUS	14.2	−7.160e − 12	2.133e − 11	.	.	.	.	−5.658e − 11
ΔPUS	31.8	−1.560e + 00	2.619e + 00	.	−4.644*e* + 00	.	−4.674e + 00	−5.634e + 00
ΔIUS	2.2	−1.167e − 02	1.658e − 01	.	.	.	.	.
EPU	97.8	−6.363e − 02	2.095e − 02	−6.403e − 02	−6.574e − 02	−6.682e − 02	−6.856e − 02	−6.087e − 02
MU	100.0	−6.429e + 01	8.873e + 00	−6.342e + 01	−6.621e + 01	−6.407e + 01	−6.688e + 01	−6.720e + 01
sentiments	100.0	−4.063e − 01	7.310e − 02	−4.019e − 01	−4.032e − 01	−4.121e − 01	−4.135e − 01	−4.222e − 01
inflation_exp	100.0	−5.049e + 00	4.705e − 01	−5.122e + 00	−4.879e + 00	−5.138e + 00	−4.894e + 00	−4.896e + 00
recession_prob	97.7	1.306e − 01	4.056e − 02	1.415e − 01	1.451e − 01	1.100e − 01	1.134e − 01	1.450e − 01
n. var.				5	6	6	7	7
R^2				0.444	0.449	0.449	0.455	0.454
BIC				−2.241e + 02	−2.225e + 02	−2.223e + 02	−2.208e + 02	−2.198e + 02
post. prob.				0.390	0.170	0.159	0.073	0.045

Notes: This table reports for each regressor the posterior probability that the variable should be included in the model (incl. prob.), the Bayesian model averaged (BMA) posterior mean ($E(\beta_j|X)$), and the BMA posterior standard deviation ($SD(\beta_j|X)$). In addition, we also report the posterior means for the five best single models according to their posterior probability (post. prob.) given below. For these five models, we also present the number of variables included (n. var.), the coefficient of determination (R^2), and the BIC. We use the following regressors: change of US industrial production (ΔYUS), change of US money supply (ΔMUS), change of US consumer prices (ΔPUS), change of US 3-month Treasury bill rate (ΔIUS), economic policy uncertainty index (EPU), macroeconomic uncertainty (MU), consumer sentiment, inflation expectations (inflation_exp), and smoothed US recession probabilities (recession_prob).

TABLE 6. BMA-estimation results: gold/CPI

	incl. prob.	$E(\beta_j \mid X)$	$SD(\beta_j \mid X)$	Model 1	Model 2	Model 3	Model 4	Model 5
Intercept	100.0	3.410e + 00	1.041e + 00	3.378e + 00	3.588e + 00	3.118e + 00	3.371e + 00	3.456e + 00
ΔYUS	27.1	6.335e − 02	1.196e − 01	.	.	2.433e − 01	2.162e − 01	.
ΔMUS	55.8	4.071e − 12	4.209e − 12	7.116e − 12	.	7.666e − 12	.	7.209e − 12
ΔIUS	6.4	7.111e − 03	3.617e − 02	.	.	.	.	1.135e − 01
EPU	100.0	1.012e − 02	1.816e − 03	9.764e − 03	1.042e − 02	9.991e − 03	1.067e − 02	9.830*e* − 03
MU	100.0	4.540e + 00	8.104e − 01	4.552e + 00	4.502e + 00	4.620e + 00	4.559e + 00	4.440e + 00
sentiments	100.0	−5.747e − 02	6.761e − 03	−5.672e − 02	−5.907e − 02	−5.552e − 02	−5.817e − 02	−5.687e − 02
inflation_exp	100.0	1.730e − 01	4.213e − 02	1.764e − 01	1.678e − 01	1.788e − 01	1.693e − 01	1.744e − 01
recession_prob	100.0	−2.366e − 02	3.372e − 03	−2.450e − 02	−2.460e − 02	−2.134e − 02	−2.180e − 02	−2.355e − 02
n. var.				6	5	7	6	7
R^2				0.562	0.556	0.567	0.559	0.564
BIC				−3.219e + 02	−3.217e + 02	−3.205e + 02	−3.193e + 02	−3.173e + 02
post. prob.				0.348	0.317	0.175	0.096	0.035

Notes: See Table 5 for details. Compared to all other gold ratios ΔPUS has not been included as a regressor for obvious reason.

TABLE 7. BMA-estimation results: gold/CRB

	incl. prob.	$E(\beta_j \mid X)$	$SD(\beta_j \mid X)$	Model 1	Model 2	Model 3	Model 4	Model 5
Intercept	100.0	2.675e + 00	3.062e − 01	2.702e + 00	2.648e + 00	2.653e + 00	2.589e + 00	2.719e + 00
ΔYUS	12.3	6.310e − 03	2.061e − 02	.	.	4.860e − 02	5.553e − 02	.
ΔMUS	34.6	6.496e − 13	1.024e − 12	.	1.834e − 12	.	1.959e − 12	.
ΔPUS	6.4	4.178e − 03	2.317e − 02	.	.	.	.	.
ΔIUS	3.5	8.354e − 04	6.836e − 03	.	.	.	.	2.360e − 02
EPU	100.0	3.092e − 03	5.340e − 04	3.143e − 03	2.974e − 03	3.199e − 03	3.025e − 03	3.159e − 03
MU	100.0	8.482e − 01	2.402e − 01	8.403e − 01	8.532e − 01	8.532e − 01	8.688e − 01	8.169e − 01
sentiments	100.0	−1.862e − 02	1.983e − 03	−1.887e − 02	−1.826e − 02	−1.866e − 02	−1.799e − 02	−1.890e − 02
inflation_exp	100.0	−9.317e − 02	1.249e − 02	−9.377e − 02	−9.154e − 02	−9.344e − 02	−9.101e − 02	−9.422e − 02
recession_prob	100.0	−5.237e − 03	9.277e − 04	−5.332e − 03	−5.305e − 03	−4.703e − 03	−4.584e − 03	−5.135e − 03
n. var.				5	6	6	7	6
R^2				0.453	0.459	0.455	0.462	0.454
BIC				−2.312*e* + 02	−2.299e + 02	−2.273e + 02	−2.266e + 02	−2.259e + 02
post. prob.				0.514	0.264	0.071	0.051	0.035

Note: See Table 5 for details.

Table 8. BMA-estimation results: gold/DJIA

	incl. prob.	$E(\beta_j\|X)$	$SD(\beta_j\|X)$	Model 1	Model 2	Model 3	Model 4	Model 5
Intercept	100.0	−3.542e − 01	3.959e − 02	−3.509e − 01	−3.832e − 01	−3.742e − 01	−3.433e − 01	−3.328e − 01
ΔYUS	90.3	2.689e − 02	1.223e − 02	3.043e − 02	2.425e − 02	.	3.010e − 02	3.009e − 02
ΔMUS	2.9	3.359e − 16	3.954e − 14	.	.	.	.	.
ΔPUS	6.7	−1.549e − 03	7.428e − 03	.	.	.	−2.328e − 02	.
ΔIUS	2.9	−1.613e − 05	1.321e − 03	.	.	.	.	.
EPU	5.8	−8.603e − 06	4.582e − 05	.	.	.	.	−1.478e − 04
MU	100.0	4.627e − 01	6.111e − 02	4.551e − 01	5.148e − 01	5.100e − 01	4.435e − 01	4.648e − 01
sentiments	3.9	1.329e − 05	1.106e − 04	.	.	.	.	.
inflation_exp	100.0	5.331e − 02	3.075e − 03	5.334*e* − 02	5.243e − 02	5.264e − 02	5.458e − 02	5.252e-02
recession_prob	15.7	−8.434e − 05	2.287e − 04	.	−3.996e − 04	−7.004e − 04	. .	
n. var.				3	4	3	4	4
R^2				0.641	0.643	0.638	0.643	0.642
BIC				−4.267e + 02	−4.228e + 02	−4.225e + 02	−4.223e + 02	−4.220e + 02
post. prob.				0.597	0.085	0.072	0.067	0.058

Note: See Table 5 for details.

TABLE 9. BMA-estimation results: gold/oil

	incl. prob.	$E(\beta_j\|X)$	$SD(\beta_j\|X)$	Model 1	Model 2	Model 3	Model 4	Model 5
Intercept	100.0	1.952e + 01	3.454e + 00	16.62376	16.16210	23.99670	22.98196	22.50085
ΔYUS	2.2	−6.115e − 03	8.837e − 02	.	.	.	.	.
ΔMUS	2.1	9.185e − 14	2.079e − 12	.	.	.	.	.
ΔPUS	67.7	−1.804e + 00	1.493e + 00	−2.50480	.	−3.20142	−2.46153	.
ΔIUS	4.8	2.116e − 02	1.363e − 01	.	.	.	.	.
EPU	2.0	4.291e − 05	1.009e − 03	.	.	.	.	.
MU	50.2	−5.118e + 00	5.757e + 00	.	.	−13.58118	−10.00045	−9.95348
sentiments	1.2	−3.311e − 05	2.410e − 03	.	.	.	.	.
inflation_exp	18.9	7.121e − 02	1.695e − 01	.	.	0.42203	.	.
recession_prob	61.0	−2.455e − 02	2.190e − 02	−0.04335	−0.04291	.	.	.
n. var.				2	1	3	2	1
R^2				0.060	0.044	0.070	0.057	0.042
BIC				−14.58319	−13.62836	−13.29521	−13.24210	−12.54428
post. prob.				0.244	0.151	0.128	0.125	0.088

Note: See Table 5 for details.

TABLE 10. BMA-estimation results: gold/corn

	incl. prob.	$E(\beta_j\|X)$	$SD(\beta_j\|X)$	Model 1	Model 2	Model 3	Model 4	Model 5
Intercept	100.0	2.327e + 00	4.051e − 01	2.349e + 00	2.265e + 00	2.291e + 00	2.332e + 00	2.359e + 00
ΔYUS	18.8	1.575e − 02	3.799e − 02	.	8.383e − 02	.	.	.
ΔMUS	3.5	1.933e − 14	2.343e − 13	.	.	.	5.510e − 13	.
ΔPUS	9.5	1.184e − 02	4.464e − 02	.	.	1.241e − 01	.	.
ΔIUS	3.3	4.647e − 04	7.231e − 03	.	.	.	.	1.392e − 02
EPU	100.0	2.548e − 03	6.994e − 04	2.527e − 03	2.623e − 03	2.573e − 03	2.476e − 03	2.537e − 03
MU	100.0	2.027e + 00	3.192e − 01	2.016e + 00	2.039e + 00	2.091e + 00	2.020e + 00	2.003e + 00
sentiments	100.0	−2.039e − 02	2.595e − 03	−2.046e − 02	−2.011e − 02	−2.043e − 02	−2.028e − 02	−2.049e − 02
inflation_exp	100.0	−1.527e − 01	1.661e − 02	−1.522e − 01	−1.517e − 01	−1.587e − 01	−1.515e − 01	−1.525e − 01
recession_prob	100.0	−8.940e − 03	1.278e − 03	−9.139e − 03	−8.054e − 03	−9.235e − 03	−9.131e − 03	−9.023e − 03
n. var.				5	6	6	6	6
R^2				0.384	0.389	0.387	0.385	0.384
BIC				−1.801e + 02	−1.776e + 02	−1.762e + 02	−1.742e + 02	−1.741e + 02
post. prob.				0.648	0.188	0.095	0.035	0.033

Note: See Table 5 for details.

TABLE 11. BMA-estimation results: gold/DIVY

	incl. prob.	$E(\beta_j\|X)$	$SD(\beta_j\|X)$	Model 1	Model 2	Model 3	Model 4	Model 5
Intercept	100.0	1.790e + 00	4.757e − 01	1.719e + 00	1.600e + 00	2.046e + 00	1.983e + 00	1.867e + 00
ΔYUS	28.9	3.201e − 02	5.749e − 02	.	1.138e − 01	.	.	.
ΔMUS	78.9	3.196e − 12	2.067e − 12	4.168e − 12	4.443e − 12	.	3.212e − 12	.
ΔPUS	67.6	1.839e − 01	1.509e − 01	2.767e − 01	2.838e − 01	.	.	2.022e − 01
ΔIUS	3.3	1.616e − 03	1.171e − 02	.	.	.	.	.
EPU	100.0	4.704e − 03	7.632e − 04	4.678e − 03	4.771e − 03	4.791e − 03	4.422e − 03	5.058e − 03
MU	100.0	2.219e + 00	3.487e − 01	2.248e + 00	2.289e + 00	2.120e + 00	2.171e + 00	2.165e + 00
sentiments	100.0	−2.862e − 02	2.857e − 03	−2.813e − 02	−2.762e − 02	−3.028e − 02	−2.951e − 02	−2.944e − 02
inflation_exp	1.9	1.695e − 04	2.986e − 03	.	.	.	.	.
recession_prob	100.0	−1.063e − 02	1.486e − 03	−1.103e − 02	−9.578e − 03	−1.110e − 02	−1.114e − 02	−1.101e − 02
n. var.				6	7	4	5	5
R^2				0.542	0.547	0.527	0.533	0.532
BIC				−3.028e + 02	−3.016e + 02	−3.005e + 02	−3.005e + 02	−2.991e + 02
post. prob.				0.362	0.204	0.120	0.119	0.058

Note: See Table 5 for details.

TABLE 12. BMA-estimation results: gold/10 years

	incl. prob.	$E(\beta_j \mid X)$	$SD(\beta_j \mid X)$	Model 1	Model 2	Model 3	Model 4	Model 5
Intercept	100.0	−7.382e − 01	1.697e − 01	−5.812e − 01	−8.462e − 01	−8.631e − 01	−6.068e − 01	−8.651e − 01
ΔYUS	48.1	2.173e − 02	2.599e − 02	.	.	4.549e − 02	4.382e − 02	4.825e − 02
ΔMUS	10.1	6.623e − 14	2.485e − 13	.	.	.	.	7.794e − 13
ΔPUS	5.9	−1.962e − 03	1.154e − 02	.	.	.	.	.
ΔIUS	1.1	4.834e − 05	1.666e − 03	.	.	.	.	.
EPU	6.5	2.502e − 05	1.130e − 04	.	.	.	.	.
MU	100.0	1.234e + 00	1.365e − 01	1.189e + 00	1.269e + 00	1.278e + 00	1.201e + 00	1.270e + 00
sentiments	45.7	−9.976*e* − 04	1.245*e* − 03	−2.235e − 03	.	.	−2.156e − 03	.
inflation_exp	100.0	1.221e − 01	6.584e − 03	1.194e − 01	1.241e − 01	1.237e − 01	1.192e − 01	1.245e − 01
recession_prob	100.0	−2.788*ee* − 03	5.994e − 04	−3.213e − 03	−2.933e − 03	−2.369e − 03	−2.660e − 03	−2.355e − 03
n. var.				4	3	4	5	5
R^2				0.722	0.718	0.722	0.726	0.724
BIC				−5.316e + 02	−5.314e + 02	−5.314e + 02	−5.312e + 02	−5.283e + 02
post. prob.				0.212	0.191	0.187	0.174	0.041

Note: See Table 5 for details.

TABLE 13. BMA-estimation results: gold/copper

	incl. prob.	$E(\beta_j \mid X)$	$SD(\beta_j \mid X)$	Model 1	Model 2	Model 3	Model 4	Model 5
Intercept	100.0	2.525e − 02	3.046e − 02	2.529e − 02	4.886e − 02	−2.180e − 02	6.867e − 02	2.771e − 02
ΔYUS	15.1	1.570e − 03	4.339e − 03	.	1.232e − 02	.	.	.
ΔMUS	4.1	5.488e − 15	3.769e − 14	.	.	.	.	.
ΔPUS	6.8	−9.551e − 04	4.360e − 03	.	.	.	.	−1.407e − 02
ΔIUS	2.7	−6.229e − 05	8.390e − 04	.	.	.	.	.
EPU	2.5	4.602e − 07	1.129e − 05	.	.	.	.	.
MU	100.0	2.354e − 01	3.887e − 02	2.427e − 01	1.991e − 01	2.650e − 01	1.725e − 01	2.430e − 01
sentiments	11.6	4.742e − 05	1.572e − 04	.	.	3.707e − 04	.	.
inflation_exp	2.7	−2.464e − 05	3.238e − 04	.	.	.	.	.
recession_prob	80.8	−3.420e − 04	2.083e − 04	−4.294e − 04	.	−3.979e − 04	.	−4.327e − 04
n. var.				2	2	3	1	3
R^2				0.129	0.122	0.133	0.109	0.133
BIC				−4.783e + 01	−4.414e + 01	−4.396e + 01	−4.389e + 01	−4.384e + 01
post. prob.				0.498	0.079	0.072	0.070	0.068

Note: See Table 5 for details.

TABLE 14. BMA-estimation results: gold/FFR

	incl. prob.	$E(\beta_j \mid X)$	$SD(\beta_j \mid X)$	Model 1	Model 2	Model 3	Model 4	Model 5
Intercept	100.0	−1.965e − 01	2.253e − 01	−2.840*e* − 01	−3.329e − 01	1.707e − 02	−9.092e − 03	−3.646e − 01
ΔYUS	45.8	2.219e − 02	2.777e − 02	.	4.880e − 02	.	4.473e − 02	5.219e − 02
ΔMUS	22.5	2.244e − 13	4.834e − 13	.	.	.	.	9.594e − 13
ΔPUS	3.2	−4.302e − 04	7.145e − 03	.	.	.	.	.
ΔIUS	3.8	4.548e − 04	4.001e − 03	.	.	.	.	.
EPU	61.1	5.106e − 04	4.776e − 04	8.219e − 04	8.777e − 04	.	.	7.927e-04
MU	100.0	1.197e + 00	1.445e − 01	1.191e + 00	1.204e + 00	1.190e + 00	1.201e + 00	1.212e + 00
sentiments	100.0	−6.019e − 03	1.391e − 03	−5.523e − 03	−5.319e − 03	−7.245e − 03	−7.165e − 03	−4.988e − 03
inflation_exp	100.0	1.116e − 01	8.243e − 03	1.143e − 01	1.147e − 01	1.060e − 01	1.058e − 01	1.159e − 01
recession_prob	100.0	−4.027e − 03	6.572e − 04	−4.235e − 03	−3.604e − 03	−4.459e − 03	−3.894e − 03	−3.546e − 03
n. var.				5	6	4	5	7
R^2				0.708	0.712	0.704	0.707	0.715
BIC				−5.045e + 02	−5.044e + 02	−5.038e + 02	−5.027e + 02	−5.019e + 02
post. prob.				0.232	0.220	0.162	0.092	0.064

Note: See Table 5 for details.

gold–CPI ratio, and changes of consumer prices on the gold–oil and the gold–DIVY ratio. In all other cases, macroeconomic variables seem to have a negligible impact on the relative price of gold.

In contrast, expectations and uncertainty proxies frequently obtain inclusion probabilities of more than 70%, in many cases even more than 90%. For gold–silver, gold–CPI, gold–corn, and gold–CRB, all five measures display probabilities of more than 95%. For the gold–DIVY (gold–FFR) ratio, only inflation expectations (economic policy uncertainty) out of this group display a probability below 90%. Macroeconomic uncertainty and inflation expectations also provide probabilities above 90% for the gold–Dow and the gold–copper ratios. For the gold–oil ratio, only the recession probability and changes of the CPI provide inclusion probabilities significantly above 50%.

A comparison of the different models confirms the importance of expectations and uncertainty. Except for the gold–oil, the gold–copper, and the gold–Dow ratio, at least four of the forward-looking variables are part of the best model characterized by the highest posterior probability. On the contrary, fundamentals hardly enter the best models. Overall, the lowest R^2 is obtained for the gold–oil ratio which cannot be explained by any of the considered model configurations to a convincing degree. This is not surprising since several possible market specific determinants of oil prices are not included in our setting such as important political events, global economic activity, and global oil production [Kilian (2009)]. As already mentioned in Section 2.3, the gold–oil ratio can be seen as a special case. It is rather stable because both prices for gold and oil may be driven by the same factors, for example, inflation, making the ratio appear relatively stable compared to other ratios.

Our results demonstrate that gold ratios are forward-looking measures which include expectations and the current state of uncertainty. In contrast, current macroeconomic developments are hardly considered to be relevant for future gold ratios. Although the forward-looking behavior of the gold price is not surprising, the importance of expectations and uncertainty is an interesting aspect which will be analyzed in greater detail in the next section.

3.2.2. How are gold ratios affected by uncertainty and expectations?. Both policy uncertainty and macroeconomic uncertainty mostly increase the relative price of gold according to our results. They have a positive impact on the gold–CPI, gold–corn, and the gold–DIVY ratios. In addition, macroeconomic uncertainty has a positive impact on the gold–Dow and the gold–US Treasury rate ratio. In contrast, we find a negative effect for both uncertainty measures on the gold–silver ratio. This outcome suggests that there are periods in which silver is catching up with gold to fulfill its role as an alternative safe haven asset. Silver may be lagging the gold price in normal periods and even substantially deviate from the gold price due to its industrial uses and thus direct link to the business cycle.

A positive impact of uncertainty on the relative price of gold can be considered evidence for the safe haven property of gold. While standard definitions of hedge and safe haven rely on correlation analyses [e.g. Baur and Lucey (2010) and Bialkowski et al. (2015)], our results provide a new perspective on these properties in the sense that gold is the preferred asset in periods of crisis or uncertainty. Our findings also suggest that gold is preferred over other assets in such periods. The discussion of the ratios in Section 2 already illustrated that gold serves as a relative hedge against consumer price and asset price changes since the relative price of gold was not lower at the end of the sample period than at the start of the sample period. The finding that macroeconomic and policy uncertainty lead to an increase in gold ratios and thus the relative price of gold confirms the relative safe haven property of gold. The influence of sentiments further supports this conclusion. An increase in sentiment (economic confidence) decreases the relative price of gold according to most ratios. This finding is intuitively plausible considering the negative correlation between sentiments and our uncertainty measures. The negative relationship of the ratios with recession probabilities further suggests that the safe haven property is a financial property and does not protect investors against real economy phenomena such as an economic downturn. Variations of the gold-oil ratio are also potentially down to hedging effects. If the oil price goes down, oil investors sell gold reserves they kept as a hedge.

3.2.3. Are the results different across samples?. An obvious question is whether our main results hold over different subsample periods. We look at three subperiods: January 1978:01 until December 2000, January 2001 until September 2008, and October 2008 until February 2014. The inclusion probabilities are summarized in Table 15. The end of the first sample is marked by the start of a period of increasing gold prices while the third period starts after the collapse of Lehman Brothers. Although the choice of the subsample is somehow arbitrary, this exercise is sufficient to illustrate that our main findings are robust through time—that is, expectations as well as uncertainty and risk measures are far more important than macroeconomic fundamentals.

Nevertheless a few results are worth mentioning. Most importantly, macroeconomic uncertainty turns out to have a negative impact on most ratios over the final sample after the start of the subprime crisis except for the gold–silver ratio. However, the impact of policy uncertainty remains positive although posterior inclusion probabilities and levels of significance are subject to changes. The different impact of macroeconomic uncertainty might reflect the fact that macroeconomic uncertainty peaked in 2009 and sharply decreased afterwards while the nominal gold price initially continued to increase after 2009 leaving an asymmetric response to increasing and decreasing macroeconomic uncertainty as a possible explanation.[23] Another interesting result for the final sample period is the diminishing effect of the recession probability and the increasing importance of changes in US industrial production. A convincing explanation is that financial markets pay greater attention to the current path of production in the aftermath of a recession while the probability of further recessions is less important.

TABLE 15. Summary of the inclusion probabilities

		Intercept	ΔYUS	ΔMUS	ΔPUS	ΔIUS	EPU	MU	sentiments	infl_exp	recess_prob
	G/S	100.0	30.7	14.2	31.8	2.2	97.8	100.0	100.0	100.0	97.7
	G/CPI	100.0	27.1	55.8	.	6.4	100.0	100.0	100.0	100.0	100.0
	G/CRB	100.0	12.3	34.6	6.4	3.5	100.0	100.0	100.0	100.0	100.0
	G/DJIA	100.0	90.3	2.9	6.7	2.9	5.8	100.0	3.9	100.0	15.7
Full	G/Oil	100.0	2.2	2.1	67.7	4.8	2.0	50.2	1.2	18.9	61.0
sample	G/Corn	100.0	18.8	3.5	9.5	3.3	100.0	100.0	100.0	100.0	100.0
	G/DIVY	100.0	28.9	78.9	67.6	3.3	100.0	100.0	100.0	1.9	100.0
	G/10 years	100.0	48.1	10.1	5.9	1.1	6.5	100.0	45.7	100.0	100.0
	G/Copper	100.0	15.1	4.1	6.8	2.7	2.5	100.0	11.6	2.7	80.8
	G/FFR	100.0	45.8	22.5	3.2	3.8	61.1	100.0	100.0	100.0	100.0
	G/S	100.0	20.4	2.8	82.3	4.4	3.0	100.0	100.0	100.0	11.5
	G/CPI	100.0	6.5	4.6	.	19.4	4.7	100.0	100.0	49.2	100.0
	G/CRB	100.0	4.0	4.1	13.0	5.0	5.9	100.0	100.0	100.0	96.6
	G/DJIA	100.0	13.2	4.7	17.7	10.5	5.3	100.0	100.0	89.6	95.1
sub	G/Oil	100.0	3.4	3.3	28.9	3.2	79.8	32.9	7.1	14.0	96.5
sample I	G/Corn	100.0	4.0	10.9	5.0	4.4	100.0	100.0	6.1	100.0	6.5
	G/DIVY	100.0	7.7	4.4	3.6	16.2	4.3	100.0	100.0	3.7	100.0
	G/10 years	100.0	15.2	4.7	17.0	19.6	6.3	100.0	100.0	100.0	100.0
	G/Copper	100.0	7.2	22.8	55.9	2.2	2.1	100.0	7.2	100.0	100.0
	G/FFR	100.0	13.1	4.4	11.9	22.4	5.6	100.0	100.0	100.0	100.0
	G/S	100.0	13.6	7.0	9.2	23.3	100.0	8.1	4.2	100.0	4.4
	G/CPI	100.0	18.2	6.9	.	48.3	73.6	100.0	75.8	100.0	100.0
	G/CRB	100.0	8.3	4.7	17.5	49.9	6.8	100.0	18.8	7.9	100.0
	G/DJIA	100.0	11.5	6.2	16.2	9.4	31.9	100.0	100.0	100.0	100.0

sub	G/Oil	100.0	7.3	14.1	5.1	37.2	9.5	7.7	16.6	100.0	11.2
sample II	G/Corn	100.0	7.1	8.3	9.0	5.1	29.2	100.0	8.5	100.0	100.0
	G/DIVY	100.0	12.6	6.3	20.3	51.0	81.9	100.0	84.8	96.2	100.0
	G/10 years	100.0	16.2	5.3	24.8	48.8	76.5	100.0	81.8	95.0	100.0
	G/Copper	100.0	6.8	10.7	6.6	36.4	96.2	100.0	37.9	100.0	100.0
	G/FFR	100.0	18.4	5.1	23.7	41.6	77.7	100.0	73.9	98.8	100.0
	G/S	100.0	22.6	7.8	56.5	39.9	6.1	100.0	100.0	100.0	5.7
	G/CPI	100.0	59.4	3.4	.	3.8	73.6	100.0	96.0	74.9	31.6
	G/CRB	100.0	11.4	5.8	8.2	6.1	84.9	100.0	9.4	38.6	90.9
	G/DJIA	100.0	10.6	7.2	56.0	25.1	39.6	95.4	100.0	7.2	11.7
sub	G/Oil	100.0	99.6	12.3	22.8	35.9	100.0	16.0	28.7	56.6	8.5
sample III	G/Corn	100.0	85.0	6.8	7.9	5.4	6.4	24.3	6.1	100.0	52.6
	G/DIVY	100.0	58.8	3.3	3.5	3.8	71.0	100.0	96.3	85.9	30.0
	G/10 years	100.0	55.3	3.0	4.4	3.4	69.3	100.0	95.1	80.9	27.8
	G/Copper	100.0	28.0	8.9	10.3	22.3	13.9	100.0	49.4	99.0	100.0
	G/FFR	100.0	58.0	6.7	6.7	6.5	80.9	100.0	74.5	92.1	46.9

Notes: This table provides a summary of the posterior inclusion probabilities for the full sample period (1978:01–2014:02) and three subsample periods: 1978:01–2000:12 (I), 2001:01–2008:09 (II), and 2008:10–2014:02 (III). The full sample period results are also included in Tables 5–14.

3.2.4. Robustness test: exchange rate effects and macro factors. It is well-established that the gold price denominated in US dollars is inversely related to the value of the US dollar. The same relationship holds for other US dollar-denominated assets such as oil and corn. However, this raises the question whether fluctuations of gold against indices, mirrored by the gold ratio relative to CRB or the Dow Jones, are driven by changes of the effective dollar exchange rate. An inspection of the graphs provided in Section 2 suggests that this is not the case. While the dollar experienced a large appreciation between 1980 and 1985 and sharply depreciated afterwards, the corresponding ratios display different swings across this period. Correlation analysis and the inclusion of the nominal effective dollar exchange rate as an additional regressor in alternative specifications confirm this result. In the latter case, both the posterior inclusion probabilities and the coefficients remain nearly unchanged and for the change of the effective dollar exchange rate, the probabilities of inclusion are far below 0.5 for each gold ratio.

As a second robustness check, we have also extended our set of regressors by including macro factors introduced by Ludvigson and Ng (2009). We identify some explanatory power of some of the macro factors for gold ratios but the vast majority of results remains unchanged. This confirms our previous findings and shows that fluctuations of gold ratios are not solely driven by common macro factors. In addition, to check for the robustness of the uncertainty effects, we have also included the financial uncertainty measure provided by Jurado et al. (2015) and have also re-run all BMA estimations while including all three uncertainty measures (i.e. economic policy uncertainty, macroeconomic uncertainty, and financial uncertainty) separately. The corresponding results confirm the robustness of our findings. All additional findings have been omitted to save space but are available upon request.

3.2.5. Are gold ratios useful for predicting gold prices?. Our in-sample results considered so far raise the question whether the relative price of gold can be useful for predicting future nominal gold prices. This idea is in line with Campbell and Shiller (2001), who adopt ratios to forecast stock prices. We analyze this question by considering lagged ratios as explanatory variables for future gold price changes in an out-of-sample exercise.[24] Our findings reported in Tables 16–18 suggest low prediction power of ratios for future gold price changes for lags 3 and 12. The results for lag 6 are different as two ratios, namely the gold–CPI ratio and the gold–DIVY ratio, display high inclusion probabilities and significant coefficient estimates. The ratios and the sign of the estimated coefficients are plausible as they suggest that an increasing gold–CPI ratio leads to a lower gold price in 6 months and that a decreasing gold–CPI ratio leads to a higher gold price in 6 months. Hence, the gold price appears to follow consumer price inflation. The results for the gold–dividend ratio are equally plausible economically.

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TABLE 16. Predictive power of the gold ratios: 3-month ahead

	incl. prob.	$E(\beta_j\|X)$	$SD(\beta_j\|X)$	Model 1	Model 2	Model 3	Model 4	Model 5
Intercept	100.0	1.860247	1.26769	1.892	1.682	1.668	1.712	1.867
ΔG/S$_{t-3}$	2.4	0.002734	0.06827	.	.	.	.	.
ΔG/CPI$_{t-3}$	10.3	−2.161063	25.16574	.	.	.	−116.493	.
ΔG/CRB$_{t-3}$	2.3	0.008296	2.60311	.	.	.	.	.
ΔG/Oil$_{t-3}$	2.4	0.005150	0.12466	.	.	.	.	.
ΔG/Corn$_{t-3}$	2.8	−0.168440	1.85625	.	.	.	.	.
ΔG/DJIA$_{t-3}$	2.3	0.295658	11.29194	.	.	.	.	.
ΔG/DIVY$_{t-3}$	14.2	17.569647	61.99291	.	100.467	78.353	292.698	8.651
ΔG/10 years$_{t-3}$	8.4	−10.451685	44.30188	.	.	−166.009	.	.
ΔG/Copper$_{t-3}$	2.3	0.318915	12.64718	.	.	.	.	.
ΔG/FFR$_{t-3}$	9.0	−13.443665	54.13202	.	−187.518	.	.	.
n. var.				0	2	2	2	1
R^2				0.000	0.012	0.011	0.011	0.001
BIC				0.000	5.243	5.622	5.662	6.067
post. prob.				0.592	0.043	0.036	0.035	0.028

Notes: This table reports the BMA-estimation results of the change of the gold price regressed on lagged changes of the ratios. See Table 5 for further details.

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TABLE 17. Predictive power of the gold ratios: 6-month ahead

	incl. prob.	$E(\beta_j \vert X)$	$SD(\beta_j \vert X)$	Model 1	Model 2	Model 3	Model 4	Model 5
Intercept	100.0	1.559e + 00	1.2568	1.550	1.607	1.602	1.545	1.589
ΔG/S$_{t-6}$	6.9	−4.402e − 02	0.1982	.	.	−0.638	.	.
ΔG/CPI$_{t-6}$	95.1	−1.791e + 02	61.4475	−188.897	−184.665	−178.298	−179.625	−184.025
ΔG/CRB$_{t-6}$	3.6	−8.594e − 01	6.5941	.	.	.	.	−23.682
ΔG/Oil$_{t-6}$	2.4	−3.147e − 03	0.1292	.	.	.	.	.
ΔG/Corn$_{t-6}$	8.5	−1.418e + 00	5.5808	.	−16.773	.	.	.
ΔG/DJIA$_{t-6}$	2.5	1.213e + 00	21.8334	.	.	.	.	.
ΔG/DIVY$_{t-6}$	97.3	4.597e + 02	144.0782	481.284	481.363	451.468	473.277	483.207
ΔG/10 years$_{t-6}$	7.3	−3.312e + 01	182.7609	.	.	.	.	.
ΔG/Copper$_{t-6}$	5.8	−8.102e + 00	41.4068	.	.	.	−140.503	.
ΔG/FFR$_{t-6}$	5.3	2.733e + 01	162.0581	.	.	.	.	.
n. var.				2	3	3	3	3
R^2				0.031	0.035	0.034	0.033	0.032
BIC				−7.467	−3.532	−3.126	−2.767	−1.841
post. prob.				0.604	0.085	0.069	0.058	0.036

Notes: This table reports the BMA-estimation results of the change of the gold price regressed on lagged changes of the ratios. See Table 5 for further details.

Table 18. Predictive power of the gold ratios: 12-month ahead

	incl. prob.	$E(\beta_j \mid X)$	$SD(\beta_j \mid X)$	Model 1	Model 2	Model 3	Model 4	Model 5
Intercept	100.0	1.921834	1.28341	1.917	1.938	1.918	1.929	1.960
ΔG/S$_{t-12}$	3.2	0.010130	0.09539	.	.	.	.	.
ΔG/CPI$_{t-12}$	3.8	−0.189838	1.43540	.	.	.	.	.
ΔG/CRB$_{t-12}$	2.5	0.092895	2.81965	.	.	.	.	.
ΔG/Oil$_{t-12}$	2.6	0.007033	0.13369	.	.	.	.	.
ΔG/Corn$_{t-12}$	3.2	−0.216737	2.12240	.	.	.	.	.
ΔG/DJIA$_{t-12}$	2.5	−0.333065	11.78456	.	.	.	.	.
ΔG/DIVY$_{t-12}$	4.1	−0.557450	3.84439	.	.	.	.	−13.590
ΔG/10 years$_{t-12}$	4.2	−1.255965	8.38525	.	.	−29.641	.	.
ΔG/Copper$_{t-12}$	6.8	−7.874954	36.21825	.	−116.427	.	.	.
ΔG/FFR$_{t-12}$	4.1	−1.059871	7.28829	.	.	.	−25.754	.
n. var.				0	1	1	1	1
R^2				0.000	0.003	0.002	0.002	0.002
BIC				0.000	4.462	5.397	5.456	5.462
post. prob.				0.630	0.068	0.042	0.041	0.041

Notes: This table reports the BMA-estimation results of the change of the gold price regressed on lagged changes of the ratios. See Table 5 for further details.

If the gold–DIVY ratio increases, the price of gold increases in 6 months due to lower opportunity costs of holding gold. Similarly, if the gold–dividend ratio decreases, the price of gold decreases in 6 months due to higher opportunity costs of holding gold. These results are consistent with the overall evidence for mean reversion as reported above. However, it must be noted that the evidence for predictability is rather weak, a finding consistent with the structural breaks in the ratios that adversely affect predictability.

The finding of weak predictability is in line with several results in the financial economics literature. For example, exchange rates are hard to predict out-of-sample frequently leaving the random walk as the most convincing predictor in terms of points forecast adequacy. This is also due to the fact that the in-sample fit does not necessarily translate into out-of-sample predictability [Rossi (2013)].

4. SUMMARY AND CONCLUDING REMARKS

This paper is the first study on gold ratios and thus on the relative valuation of gold. We have analyzed the prices of gold relative to the prices of other assets such as silver, oil, corn, copper, a commodity price index, consumer prices, stock prices, a portfolio based on reinvested dividends, bond yields, and interest rates. The results show that the ratios share common variations and are significantly different from their historical mean for several periods especially around the years 1970, 1980, 1990, and 2010. The gold price ratios in 2015 do not indicate any over- or undervaluation of gold relative to the 5-year period from 2009 to 2014 but a clear overvaluation relative to the historical averages over the period from 1960 to 2015. We also find that the ratios are mean-reverting, which renders them meaningful for investors and policymakers since misalignments are corrected in the long run. Moreover, all gold ratios are higher in 2015 than in 1960, which demonstrates that gold did not lose its relative value and thus purchasing power against other variables or assets.

When analyzing the factors which drive variations, we find an important impact of expectations and uncertainty on gold ratios while macroeconomic fundamentals turn out to be less important. Although the weak importance of macroeconomic fundamentals looks surprising at first sight, it mirrors the forward-looking nature of asset prices. The finding that a boost in confidence measured by sentiment decreases the relative price of gold whilst an increase in economic policy or macroeconomic uncertainty increases the relative price of gold confirms the role of gold as a safe haven. This pattern is also in line with the macro-finance literature which postulates that the risk premia required by consumers vary over the business cycles, resulting in a lower demand for risky assets. Overall, the methodology to study the hedge and safe haven characteristics of gold based on ratios and thus the relative valuation of gold offers a novel perspective to the commonly employed correlation analysis. Future research could apply relative valuation to stock prices using commodity prices, consumer prices, and bond prices, among others.

NOTES

1. The combined gold reserves of all economies in the world totaled 32,056.5 tonnes in November 2014.

2. See http://www.bis.org/publ/rpfxf10t.pdf.

3. All values are relative. A fruit, say an orange, is generally expressed in terms of a currency, for example, 1 US dollar. The same is true for a car (e.g. 30,000 US dollar) or an ounce of gold (e.g. 1200 US dollar). Relative values are more informative since they reflect the direct value by eliminating currency as the common numerator, for example, 25 ounces of gold per car.

4. The rate of return is a ratio of prices at t over prices at $t-1$, and the Capital Asset Pricing Model relates stock returns of companies to excess stock returns of the market.

5. The financial adviser Incrementum AG has analyzed gold ratios in their annual report "In Gold We Trust" (2014). Escribano and Granger (1998) motivate their analysis of the gold–silver relationship with the gold–silver ratio but without analyzing potential drivers of deviations from a long-run relationship.

6. See Morley (2016) and Cochrane (2017) for two recent surveys.

7. One of the ratios that are not explicitly examined in this paper is the gold–monetary base ratio. The US monetary base increased from 50,000 million US dollars to 4,000,000 million US dollars from 1960 to 2015. This is a total change of 7900% compared to a change in the price of gold of about 3264%. Hence, this ratio can be characterized by a continuously decreasing line and could not be used to predict future gold price changes (see below).

8. The role of gold has hardly been explicitly analyzed in the context of policy uncertainty. One study is provided by Jones and Sackley (2016), who find that increases in economic uncertainty contribute to increases in the price of gold. However, the authors do not take the relative price of gold and macroeconomic uncertainty into account and do not address the role of gold as a safe haven in this context.

9. See O'Connor et al. (2015) for a detailed overview of the literature on gold.

10. The inflation hedge property of gold reflects the idea that gold increases with inflation and thus acts as a store of value against a portfolio of goods and services. The inflation hedge property implies a positive correlation of gold price changes with inflation and is therefore different to a typical financial hedge which implies a zero or negative correlation.

11. The gold–silver ratio represents the co-integration relationship between gold and silver prices shown by Escribano and Granger (1998) with monthly data from 1971 to 1990.

12. The gold–CPI ratio addresses the question if gold acts as an inflation hedge as analyzed within co-integration frameworks by Wang et al. (2011) and Beckmann and Czudaj (2013a).

13. A reasonable alternative would be to use the IMF commodity price index as a proxy for overall commodity price behavior. However, the sample period for this series provided by the IMF starts in 1992 and would therefore strongly restrict our sample size.

14. The gold–oil spread has already been analyzed in the literature in a different context. See Beckmann and Czudaj (2013b).

15. The gold–copper ratio can be seen as a determinant of market sentiment on economic growth since the price of an industrial metal like copper is typically associated with economic growth due to the important role of copper in construction and infrastructure projects. An increase in the gold–copper ratio can therefore be viewed as a sign that expectations for future economic growth are rising.

16. An alternative would be to use the MSCI world index instead of the DJIA. However, the correlation between both indices is nearly one and therefore this choice has no impact on our results.

17. All time series used in our ratio analysis are taken from Sharelynx and Thomson Reuters Datastream.

18. The application of the classical Augmented Dickey-Fuller (ADF) test points in favor of nonstationarity for the majority of gold ratios. Solely for the gold–oil, the gold–10-year bond, and the gold–FFR ratio, the unit root null can be rejected at a 5% level. However, it is well known that the ADF test has very low power in the presence of structural breaks. Therefore, we do not rely on the corresponding results.

19. The number of break points that need to be accounted for is to some extent arbitrary. However, including more than two break points confirms the result that most of the gold ratios are mean-reverting.

20. Since the variance of a ratio of two random variables is not well defined, for the construction of the t-statistics we have used the following approximation of the variance of the ratio A/B applying a Taylor expansion according to Stuart et al. (1998, p. 351):

$$Var(A/B) \approx \frac{\overline{A}^2}{\overline{B}^2}\left[\frac{\hat{\sigma}_A^2}{\overline{A}^2} - 2\frac{s_{A,B}}{\overline{AB}} + \frac{\hat{\sigma}_B^2}{\overline{B}^2}\right],$$

where $\overline{A}$ and $\overline{B}$, respectively, represent the sample averages of random variables A and B, $\hat{\sigma}_A^2$ and $\hat{\sigma}_B^2$ are their sample variances, and $s_{A,B}$ is the sample covariance between A and B.

21. This confirms the finding of a time-varying inflation hedge function of gold (Beckmann and Czudaj, 2013a).

22. The importance to account for model uncertainty when analyzing gold has already been stressed by Baur et al. (2016), among others, in studies focusing on an appropriate gold return forecast. It appeared to be beneficial to use a dynamic version of the model averaging approach to reduce the forecast error. However, we rather focus on the identification of the main determinants of the gold ratios than on a forecast in this section. Time-variation in the coefficients is considered by the subsample analysis in Section 3.2.

23. Based on the measure suggested by Jurado et al. (2015), large macroeconomic uncertainty occurs on three occasions in the post-war period: 1973–74, 1981–82, and 2007–09.

24. Strictly out-of-sample means that no information ahead of period t is adopted for predictions for period $t+1$.

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