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# Gold and Inflation(s) – A Time-Varying Relationship

Brian M. Lucey<sup>a</sup>, Susan Sunila Sharma<sup>b</sup>, Samuel A. Vigne<sup>c</sup>

<sup>a</sup>*Trinity Business School, Trinity College Dublin, Dublin 2, Ireland  
email: blucey@tcd.ie*

<sup>b</sup>*Centre for Economics and Financial Econometrics Research, Faculty of Business and  
Law, Deakin University, 221 Burwood Highway, Burwood, Victoria 3125, Australia  
email:s.sharma@deakin.edu.au*

<sup>c</sup>*Queen's Management School, Queen's University Belfast, BT9 5EE, Northern Ireland,  
United Kingdom and Trinity Business School, Trinity College Dublin, Dublin 2, Ireland  
email: s.vigne@qub.ac.uk (corresponding author)*

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## Abstract

What is the relationship between the price of gold and inflation? How stable is it - over time and across measures of inflation? We examine this for three countries (the USA, the UK and Japan) over forty years and with a variety of measures of inflation and monetary liquidity. We apply a formal test for time variation and proceed to extract time varying cointegration relationships. Both formal and graphical evidence points to a break in the relationship(s) of gold and official inflation in the mid 1990s in the USA but to less clear results for the UK and Japan. However, gold seems to have offered a protection against an increase in money supply throughout nearly the entire past 40 year period in the US and the UK but failed to do so in Japan. Supporting previous findings we find evidence for a time-varying relationship in cointegration between gold and both predicted and realized inflation in nearly all cases. Contrasting multiple inflation indicators, we find evidence for the importance of money supply in the gold/inflation relationship.

*Keywords:* Gold, Inflation, Money Supply, Cointegration, Time-Varying Cointegration

*JEL Code* C22; C50; E31; F30; G1

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## 1. Introduction

The end of the Bretton Woods system in 1971 and the transition of the United States of America from a gold linked currency to a fiat currency led to an increased academic and professional interest in the nature and extent of gold's role in financial markets.

To date however, the ability of gold to act as a financial protector remains in debate. The question of financial protection has been approached from a multitude of angles and some questions are perhaps more comprehensively answered than others. For example, from the work of Baur and Lucey (2010) and Baur and McDermott (2010) the role of gold as a safe haven has been addressed. Work such as Conover et al. (2009) have discussed its role in portfolios. Unfortunately, there is no commonly accepted answer or even model that would best describe the relationship between gold and inflation.

As of now, two distinct different approaches to the relationship between gold and inflation can be observed in academic literature. The first focuses on how inflation affects gold prices: here recent examples are the paper of Batten et al. (2014) who find evidence for time-variation in the gold/inflation relationship and account gold's sensitivity to inflation to interest rate changes, or Bampinas and Panagiotidis (2015) who look at over two hundred years of data and find that gold is an inflation hedge in the long run for both the USA and the UK, Hoang et al. (2016) recently offered evidence in support to the findings of Bampinas and Panagiotidis (2015), and finally, Sharma (2016) who finds evidence for the CPI to be able to predict gold returns in the UK and the USA among other countries. The second approach focuses more on how the price of gold affects inflation, such as Moore (1990) who states that gold prices are affected by the market's view of inflation, or Mahdavi and Zhou (1997) who consider gold to be a leading indicator of the inflation rate. Our paper straddles both strands by looking at cointegration between the two variables in order to understand their basic relationship; we also apply a formal test for time variation and detect breaks

in the relationship among the variables. Our results offer new insights in the relationship between gold and inflation in three major economies and looks into the very roots of inflation: money supply. Recent findings by Hoang et al. (2016) have suggested that gold was not a hedge against inflation for any of the countries considered in the long-run; though it was a hedge in the short-run for both the US and the UK. We complete their results by identifying the breaks in the relationship between the series, visualizing when gold was indeed a hedge against inflation, and by arguing that since gold is a hedge against money supply, its true inflation hedging abilities are not to be found by contrasting the gold price with official CPI rates. Sharma (2016) studies the ability of the CPI of 54 countries to predict the price of gold quoted in US dollars. The author finds that the UK CPI is able to predict the price of gold, observes mixed results for the USA, and finds no such evidence for Japan. We take a more general approach and consider the relationship between gold and inflation rather than looking at the effect that one variable has on the other. Furthermore, the price of gold is considered in the respective national currency to delete the safe haven effect of the US\$ during inflationary periods. Our work therefore offers a valuable contribution to an ongoing investigation of the relationship between gold and inflation.

Theoretically, if gold is considered an international currency, an increase in expected inflation leads to a reduction of the anticipated purchasing power, which would lead to investors driving down their proportion of cash and investments in gold, hence pushing the price upwards. On the other hand, if gold is considered to be a regular asset, then its price would rise since the definition of inflation is that the dollar price of a typical good rises (Jaffe (1989)). Ghosh et al. (2004) offer a theoretical framework based on the long-run determinants of the gold price: in a competitive market where gold producers are profit maximisers, the price of gold is equal to the marginal extraction cost and to the marginal cost of leasing gold from cen-

tral banks<sup>1</sup>. If the costs associated with extracting gold rise at the general inflation rate, the price of gold will rise at the same rate and hence hedge inflation. Demand for gold can be divided into three different groups: industrial, consumption, and investment. Different inflation indices are relevant to the different types of demand; we therefore work with the CPI to reflect consumer inflation, the PPI to reflect producer inflation, and money supply as an inflation proxy relevant to the investment side. The importance of money supply on the price of gold is discussed since as early as the 19<sup>th</sup> century - Ricardo (1810) indeed argued that the growing amount of Pound Sterling in England was responsible for the increasing gold price. Despite the importance of money supply on the rate of inflation and the price of gold, we argue that an increasing amount of money in an economy leads to an increase in consumption and investment. Money supply therefore positively influences the consumer demand for gold, but also the demand for gold as an investment; exercising a twofold positive pressure on the price of gold.

However, a major issue when looking at gold and inflation arises in the very definition of the term as there is an open debate about how to measure inflation effectively. official inflation rates (as issued by the Bureau of Labor Statistics in the USA, the Office for National Statistics in the UK and the Ministry of Internal Affairs & Communication in Japan) might not truly reflect changes in monetary value<sup>2</sup>. In an extensive literature review, we present different views about the relevance and efficiency of multiple sources of inflation rates and conclude that it might also be meaningful to study the relationship between the gold price and the monetary base of an economy. This paper is an investigation into the ability of the price of gold to protect consumer, producers and investors from inflation in three major economies and major centers of trade. Even though India and China both have a

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<sup>1</sup>see recent work partially confirming this from OConnor et al. (2016)

<sup>2</sup>See for instance the 'Billion prices' project of Cavallo and Rigobon (2016)

considerable demand for gold, the unavailability of consistent data and the relative importance of demand for physical gold rather than gold purchased through a regulated exchange led us to focus on the United Kingdom and Japan, beside of course the United States of America. We also provide a visualisation of the evolution of cointegration between gold and inflation over time. This approach allows both researchers and decision makers to easily understand when gold offered a protection against inflation. A further argument in favour of our choice of country is the economic importance of the countries considered. The results of our analysis impact market actors in three key global economies. While academic literature tends to give an empirical answer as to whether or not gold is cointegrated with inflation, we provide a visualisation of the relationship and discuss the results in the light of the given economic environment.

Building up on previous academic works, namely Batten et al. (2014), Bampinas and Panagiotidis (2015), Hoang et al. (2016) and Sharma (2016) we look at the link between local gold prices and local inflation from a time-varying perspective. A review of relevant academic literature suggests multiple approaches to the issue of the relationship between gold and inflation (Table 1). This paper provides multiple methodological contributions: we apply a lean but thorough methodology to detect time-varying relationships, we also augment these findings with tests revealing the breaks in cointegration and assure robustness of results through re-running the analysis with predicted inflation and inflation surprise derived through an ARIMA model.

Our study sits in the growing field of time-varying issues in the nature of cointegration between gold and inflation and is to our knowledge the first one that provides insights into the time dependency of the cointegration-relationship between gold and money supply.

## 2. Literature Review

The question of gold's ability to offer financial protection in troublesome times has received significant attention. A striking feature is that a variety of different inflation indices have been suggested. This harks to the problem noted in Lucey and O'Connor (2011), namely the difficulty of finding an appropriate inflation rate for gold. Given that it is a quasi-currency, the ideal situation would be to find a measure of its eroding purchasing power over time, but this is fraught with difficulty.

Using the CPI rate to proxy inflation and a Commodity Research Bureau (CRB) commodity futures index to represent commodity prices, Ciner (2011) finds no evidence for a long term, positive relationship between commodity prices and inflation when working with a conventional time series regression. However, a relationship is detected when relying on frequency domain period proving the existence of a nonlinear dynamic between gold and inflation.

Focusing on the price of gold in contrast to a more general commodity price index, Wang et al. (2011) study the long run relationship between gold and inflation and augment the results with a linear cointegration test to examine the hedging ability of gold. Their study is very relevant as the authors work with non-linear tests and focus on threshold cointegration, in contrast to time-varying cointegration. Apart from their methodological contribution, the authors also suggest that changes in the price of gold reflect inflationary pressure. Wang et al. (2011) examine from January 1971 to January 2010 and for the United States of America and Japan. The inflation proxy used is the CPI sourced from the International Financial Statistics of the International Monetary Fund (IMF).

In a very extensive study on the relationship between gold and inflation, Erb and Harvey (2012) focus on 23 different countries to support their finding that gold reports inflation more objectively than State institutions. In their work, the authors define inflation as the country's individual CPI rate

obtained from the IMF.

Examining the macroeconomic drivers of the gold price, Baur (2013) finds that gold is driven by two categories of drivers; the first being traditional drivers such as inflation, the other one being new drivers like central bank demand. Apart from using the American CPI rate, the author also works with a Global CPI index.

More recently, Sharma (2016) studies 54 different countries to understand the ability of the CPI indices there to predict the US Dollar price of gold. Results show that the UK and the US CPI rates have, among others, predictive powers for the London gold price while this evidence is found to be stronger for out-of-sample tests than for in-sample tests.

In contrast to the above works, some papers categorically reject the existence of a positive long-run relationship between gold and inflation.

In one of the few papers to examine physical gold demand, Starr and Tran (2008) work with panel data on physical gold imports of 21 countries and find evidence for a different behaviour of physical in comparison to portfolio demand. A notable finding is that the authors find macroeconomic factors not to be a determinant of physical gold demand; only in one model specification inflation is found to be a driver at the 10% significance level. Working with *Wall Street Journal* survey data, Blose (2010) uses a very different method to calculate inflation and finds evidence that surprises in the CPI do not affect gold spot prices and that investors cannot determine expected inflation solely by observing the price of gold. Erb and Harvey (2013) find that there is little evidence for gold to be an effective hedge against unexpected inflation measured both on the short and on the long term. In a recent paper looking at the relationship between gold and inflation in China, India, Japan, France, the United Kingdom and the United States (between 1978 and 2015 for both the UK and the US), Hoang et al. (2016) works with a nonlinear autoregressive distributed lags (NARDL) model and prove that gold was not a hedge in the long-run for all the observed countries.



It seems however, that gold was a hedge against inflation in the short-run in the UK, the USA and India. The time span for Japan ranges from 1992 to 2015 and a negative relationship between gold and the CPI is observed due to the deflationary episodes Japan went through in the given observation period.

The last pillar of the literature applies a time-variation framework when looking at cointegration between gold and inflation.

Beckmann and Czudaj (2013) study the relationship between inflation and the price of gold to show golds partial ability to hedge against the CPI and the PPI in the USA, the UK, the Euro Area and Japan. They are one of the early contributors to time-variation in cointegration, working with a Markov-switching vector error correction model in a time-window from January 1970 to December 2011. A further paper looking at time-varying cointegration is Batten et al. (2014), who find that excluding data from the early 1980s eliminates the cointegration relationship between gold and the American CPI. They derive time varying cointegration parameters and an inflation sensitivity factor from a Kalman filter, and illustrate how the relationship between gold and inflation changes over time. Also set within a time-varying framework are Bampinas and Panagiotidis (2015) who work with over 200 years of data and focus on the relationship between gold (and silver) and inflation. The time-variation framework follows the approach set out by Bierens and Martins (2010) and is also run with expected inflation measures provided by a Christiano and Fitzgerald (2003) band pass filter and a Hodrick and Prescott (1997) time-series filter. Due to the very long time window under study, the authors work with inflation series obtained from Reinhart and Rogoff (2011).

This paper is therefore a synthesis and development of multiple previous works. Influenced by Beckmann and Czudaj (2013), we take into account CPI rates, PPI rates and money supply. We further take the formal approach

of the two earlier mentioned time-variation papers (Batten et al. (2014) and Bampinas and Panagiotidis (2015)), introducing a formal test for time variation in inflation and find evidence for such variation in our data set.

Table 1 displays the findings of previous papers focused on the relationship between gold and inflation, as well as the inflation rate used.

### **3. Data and Methodology**

Our work is focused on three different countries: the United States, the United Kingdom and Japan. Our choice of countries is motivated in a variety of reasons. First, the UK and the USA are the leading centers for global gold trade. As discussed in Hauptfleisch et al. (2016) these two markets dominate global gold price setting. Japan provides an interesting counterpoint, with the Tokyo exchange also operating as part of the global gold price making system (Xu and Fung (2005), Morales and Andreosso-O’Callaghan (2011)) but in a country with very different inflation experiences to the UK and USA. Recent literature indeed tends to look at a broader set of countries (Hoang et al. (2016) and Sharma (2016) for example). We decided to focus on a smaller set of countries in order to conduct a different type of analysis: we augment the work of Hoang et al. (2016) by identifying breaks, periods and reasons for cointegration, and we take a different approach than Sharma (2016) by converting the Dollar price of gold into local currencies in order to study gold’s potential as a hedge for national investors. We work with the US\$ and Pound Sterling per Troy-ounce official monthly price issued by the London Bullion Market Association. Considering Japan, we convert the US\$ price of gold in Yen at month end exchange rate. Also, we look at official CPI and PPI rates for all the three countries as published by the respective authorities. Concerning money supply, we take into account the most liquid measure available for all countries. We obtained all the time series from Thomson Reuters Datastream except for American Money Zero Maturity downloaded from the St. Louis FRED Database. All time series range from

January 1974 to January 2014 apart from the UK CPI, where data is only available since January 1988. A description of the data is provided in Table 2 and real prices were used for all series.

Running a common test for integration (Dickey et al. (1979)) (Table 3) and working with a lag length defined by the Schwarz Bayesian Information Criterion (SBIC), we check for cointegration between gold and inflation/money supply across the whole sample by running a Johansen test and focusing on the trace statistic. The reason we define the lag length through the SBIC, is to assure conformity with the Bierens and Martins (2010) test, which also uses this.

As can be observed in Figures 1 to 3, all time series considered in this analysis are trending - questioning the efficiency of the Dickey-Fuller procedure. Narayan et al. (2010) propose a unit root test that accounts for structural breaks occurring at an unknown time and specifies two different models: the first with two breaks in the level of a trending data series and the second with two breaks in the level and slope of the series. The Narayan et al. (2010) procedure is advantageous in long trending series and provides more robust results than the traditional Augmented Dickey-Fuller procedure. Results of the Narayan et al. (2010) procedure can be found in Table 4. It should be noted that the results for Japan are in conflict with the Dickey Fuller test results in Table 3, pointing towards the deflationary episodes the Japanese economy was going through. Indeed, the Narayan et al. (2010) procedure points towards breaks in the early 2000's, when the CPI rate of Japan is stagnating (Figure 3).

Building upon Johansen's approach, Bierens and Martins (2010) introduce a time varying VECM in which the cointegrating vectors are smooth functions of time. The main convenience of their approach for our work is that it is rooted within Johansen's approach and therefore allows us to expand the previously used econometric test.

Acknowledge a time-varying VECM of order  $p$  written in the following

form

$$\Delta X_t = \sum_{j=1}^{p-1} \Phi_j \Delta X_{t-j} + \alpha \beta'_t X_{t-1} + \gamma_0 + \varepsilon_t, \quad t = 1, \dots, T \quad (1)$$

where  $\varepsilon_t \sim N_k(0, \Omega)$ ,  $\alpha$ , is a fixed  $k * r$  matrix (with  $r$  representing the cointegrating rank of the system), and  $\beta_t$  is a time-varying  $k * r$  matrix with rank  $r$ . We test the null hypothesis of time-invariant cointegration (where  $\Pi'_t = \Pi' = \alpha \beta'_t$ ), against the alternative hypothesis of time-varying cointegration of the type  $\Pi'_t = \alpha \beta'_t$ .  $\Omega$  and  $\Phi_j$  are  $k * k$  matrices and  $T$  is the number of observations.

Assuming standard smoothness and orthonormality conditions, Bierens and Martins (2010) Lemma 1 proves that the parameters of the time-varying cointegrating vector  $\beta_t$  can be approximated by a finite sum of Chebyshev time polynomials  $P_{i,T}(t)$  of decreasing smoothness for some fixed  $m$

$$\beta_t = \beta_m(t/T) = \sum_{i=0}^m \xi_{i,T} P_{i,T}(t), \quad t = 1, \dots, T \quad (2)$$

where  $1 \leq m < T - 1$ .  $\xi_{i,T} = \frac{1}{T} \sum_{t=1}^T \beta_T P_{i,T}(t)$  for  $i = 0, \dots, T - 1$  are unknown  $k * r$  matrices.

Chebyshev time polynomials are defined by:

$$P_{0,T}(t) = 1, P_{i,T}(t) = \sqrt{2} \cos\left(\frac{i\pi(t - 0.5)}{T}\right) \quad (3)$$

where  $t = 1, 2, \dots, T$  and  $i = 1, 2, 3, \dots$

Also, Chebyshev time polynomials are orthonormal, so for all couples of integers  $i, j$ , the following property holds:  $\frac{1}{T} \sum_{t=1}^T P_{i,T}(t) P_{j,T}(t) = 1(i = j)$ .

When testing for time-varying cointegration, following hypotheses are set up:

Time-invariant cointegration:  $H_0 : \xi_{i,T} = O_{k*r}$  for  $i = 1, \dots, m$ , and  $\xi_i = O_{k*r}$  for  $i > m$ .

Time-varying cointegration:  $H_1 : \lim_{T \rightarrow \infty} \neq O_{k*r}$  for some  $i = 1, \dots, m$ , and  $\xi_i = O_{k*r}$  for  $i > m$ .

If we substitute (2) in (1), we get:  $\Delta X_t = \sum_{j=1}^{p-1} \Phi_j \Delta X_{t-j} + \alpha (\sum_{i=0}^m \xi_i P_{i,T}(t))' X_{t-1} + \gamma_0 + \varepsilon_t$ , which we can rewrite as

$$\Delta X_t = \sum_{j=1}^{p-1} \Phi_j \Delta X_{t-j} + \alpha \xi' X_{t-1}^m + \gamma_0 + \varepsilon_t, \quad (4)$$

where  $\xi' = (\xi'_0, \xi'_1, \dots, \xi'_m)$  is an  $r * (m+1)k$  matrix of rank  $r$ . Further,  $X_{t-1}^m$  is defined by

$$X_{t-1}^m = (X'_{t-1}, P_{1,T}(t)X'_{t-1}, P_{2,T}(t)X'_{t-1}, \dots, P_{m,T}(t)X'_{t-1})' \quad (5)$$

The null hypothesis of time-invariant cointegration corresponds to  $\xi' = (\beta', O_{r,k,m})$ , so that  $\xi' X_{t-1}^m = \beta' X_{t-1}^m$ , with  $X_{t-1}^0 = X_{t-1}$ . We can test the null hypothesis with a likelihood ratio test:

$$LR_T^{tvc} = -2[\hat{l}_T(r, 0) - \hat{l}_T(r, m)] \quad (6)$$

The above equation differentiates between two cases: in the time-invariant case we have  $m = 0$ , whereas in the time-varying case we have  $m > 0$ . In the former case,  $\hat{l}_T(r, 0)$  is the log-likelihood of the VECM(p) (3), so that  $X_{t-1}^{(m)} = X_{t-1}$ . In the later case,  $\hat{l}_T(r, m)$  is also the log-likelihood of the VECM(p) (3), but for the case where  $X_{t-1}^{(m)}$  is given by (4). In both cases,  $r$  is the cointegration rank, and the  $LR_T^{tvc}$  statistic is asymptotically distributed as a chi-squared distribution with  $r * m * k$  degrees of freedom (Bampinas and Panagiotidis (2015)). We ran the Bierens and Martins (2010) testing procedure using the EasyReg software developed by the Department of Economics of the Pennsylvania State University.

We also run recursive regressions of the series in order to plot the Johansens test Trace Statistic and hence visualise when the series start/stop to be cointegrated using the graph function from RATS. The initial time window chosen when running these regressions is always equal to three times the lag of the series as inputted in the Johansen regression, allowing us to run the recursive regression in a less restrictive framework.

Building upon time-variance in the nature of cointegration between gold and inflation, we have chosen to work with a Gregory and Hansen (1996) and a Bai and Perron (2003) multiple break test in order to derive the major structural break in cointegration for all our time series.

Result robustness is assured by running the Johansen test of cointegration on subperiods pointed out by our formal testing procedures<sup>3</sup>. In other words, when the initial results suggest that there isn't a cointegration relationship between gold and inflation during a specific time period, we run a Johansen test for that specific subperiod to double check that the observation is accurate.

An ARIMA model is used to derive predicted inflation and it's relationship with the price of gold is also tested. Finally, we look at inflation surprise: the difference between actual inflation and predicted inflation.<sup>4</sup>

#### 4. Results

Considering the time window between 1974 and 2014 in the United States, gold is cointegrated with all inflation measures considered while this relationship varied through time (Table 5 and Table 6). The result from Figures 4 to 6 are very revealing; we see evidence that since around the mid 1990s, gold stops to be cointegrated with inflation, results reflecting the decrease of the gold price during this period against an increase of the rate of inflation and the amount of money in circulation. The results of the Gregory and Hansen (1996) test (Table 7) report a major break in cointegration in the late 1990s, pointing towards the period in which the dollar price of gold was at its lowest during the past 30 years. With the price of gold increasing after, these results nicely point towards the point in time during which the price of gold trends upwards, alongside inflation and money supply. The Bai and Perron (2003) multiple breaks testing procedure points toward two

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<sup>3</sup>Our subperiod robustness tests hold for every period and are available on demand.

<sup>4</sup>The numerical results of our ARIMA modelling procedure are available on demand.

main findings (Table 8). First, they consistently point towards the Global Financial Crisis and the accompanying sovereign debt crisis, but they also point towards the breaking period and the shift in cointegration between gold and American money supply in the early 1990s.

In the United States of America, gold was cointegrated with official inflation only in the first half of the sample, results in line with Batten et al. (2014). The regime shifts pointed out by the formal testing procedure are coherent with those derived from Beckmann and Czudaj (2013) using a Markov-switching approach. Furthermore, since 2012, gold and official inflation are once again cointegrated, results in line with Baur and Lucey (2010) and Baur and McDermott (2010) who find evidence for gold's capacity to act as a hedge during market turmoil. Looking at inflation from a more classical point of view and arguing that true inflation pressure is linked to liquid money in circulation, we can see that except for a few years, gold is cointegrated with US liquid money throughout the whole sample (Figure 6). Examining the evidence in Figures 4 and 5, it is noticeable that gold failed to be a hedge against CPI and PPI in the late 1990's: a period marked by economic difficulties such as the Asian Financial Crisis, the Russian Financial Crisis, the Dot-com Bubble and the early days of the 2000s recession. The return to a cointegration relationship between the series around 2008 is to be explained by the short period of deflation that affected America during that time. Hoang et al. (2016) points towards the structural importance of deflation for the long-run relationship between gold and the CPI. We augment this argument and suggest that global financial turmoils do not always come hand in hand with gold's inflation hedging capacity. Furthermore, money supply returns back to a cointegration relationship in the late 1990's. In light of our argumentation, that the very root of inflation lies in an increase in money supply rather than in a rise of official inflation rates, a pattern is observed between financial shocks and the long-run relationship between gold and money in the USA. Especially the beneficial effects of the financial

turmoils of the late 1990's, or the oil price shock of 1979 can be observed in Figure 6. These findings shed more light on gold's safe haven potential during economic troubles: the explanation is perhaps to be found in the relationship with money supply rather than with official inflation rates.

The United Kingdom shows results similar to the United States of America. Gold was cointegrated with all three inflation measures and this relationship is varying through time (Table 5 and 6). Again, gold is also cointegrated with expected inflation and inflation surprise on the long run. The shift in cointegration for the UK CPI occurs in the late 2000s, results backed by both the Gregory and Hansen (1996) and the Bai and Perron (2003) multiple break test. Concerning both the UK PPI and British liquid money, the shift in cointegration between gold and the mentioned time series happened in the late 1990s. The Bai and Perron (2003) test points towards the late financial crisis for both time series and also towards the late 1980s for the PPI, where gold was on the verge of cointegration with the PPI for nearly a year (Table 8 and Figure 8). Concerning the British monetary base, the Gregory and Hansen (1996) test points towards a major break in the late 1990s, in contrast to the Bai and Perron (2003) results indicating a break in the mid 1990s, in line with Figure 9.

Though gold was cointegrated with British inflation over the past 40 years, it seems that this relationship does not hold any longer. Looking at gold and British liquid money leads us to question the ability of the precious metal to offer protection against inflation in the United Kingdom. Regarding liquid money in the UK, it seems that as Bank of England rates trended steadily downwards we find a weakening ability of gold to hedge changes in monetary supply; this opens a discussion for investors, especially whether or not they should reconsider their hedging positions in a low interest environment. In regard to the United Kingdom, Hoang et al. (2016) argue that gold is not a hedge against inflation in the long-run but is indeed one in the short run. Our findings support their conclusion and show that the explanation



can be found in the time period between 1988 and 2009. Furthermore, considering Figures 6 to 8, a negative effect of international financial turmoils can be observed: global financial distress weakens the cointegration between gold and inflation measures. In contrary to the United States, gold is not an effective refuge of inflation during global market turmoils in the United Kingdom.

In Japan, the results are not uniform. Gold is cointegrated with the CPI, but not with either the PPI nor Money supply over the past 40 years (Table 5). When the Johansen test fails to show evidence for cointegration, it is impossible to run a Bierens and Martins (2010) test; however, the relationship between gold and Japanese CPI seems to be varying through time (Table 6). Considering Figures 10 to 12, we find evidence for a multitude of observations: it seems that the late 1970's and early 1980's are driving the empirical cointegration relationship between gold and the Japanese CPI, but also, that since 1985, gold and the Japanese CPI are not cointegrated any longer. Concerning the Japanese PPI, we observe a break in cointegration since the late 1990's, up until the recent financial crisis that seems to have pushed back gold and the PPI to a cointegration relationship (Figure 11). The last observation to make about gold's relationship with inflationary pressures in Japan is about money supply, here it is very clear that gold was never cointegrated with the Japanese monetary base throughout the past 40 years (Figure 12).

So in conclusion, we observe mixed results for Japanese inflation. Gold seems to have offered protection against the Japanese CPI, especially in the early period of our sample, but is not cointegrated with neither the Japanese PPI nor the Japanese monetary base. In more recent periods, we can assert that gold is not cointegrated with the Japanese CPI but offers protection against an increase in Japanese producer price inflation. It is remarkable, that the gold price in Yen was never cointegrated with the Japanese monetary base throughout the sample of the past 40 years. Looking at monthly

data between 1992 and 2015, Hoang et al. (2016) conclude that the relationship between gold and the Japanese CPI was negative: our results support this conclusion. Considering a longer time frame however yields to a different conclusion: only since the mid 1980's, the relationship between gold and the CPI is negative. An explanation is to be found in the deflationary period Japan has been going through henceforth. Interpreting the results for the long-run relationship between gold and the PPI should be done carefully: the evidence for cointegration during the 1980's and 1990's can be explained by the fact that both time series were trending downwards during that time. In other words, producer price deflation was linked to a decreasing gold price, hence not exactly making gold an attractive investment. The relationship between gold and Japanese money supply (Figure 12) is an illustration of the opposite direction of the two series over time: an increasing amount of money against a decreasing gold price. Considering the evidence on hand, it can be concluded that gold is not an attractive investment against inflation in Japan.

## 5. Conclusion

Our work contributes to a growing field of academic research about time-variation in the cointegration relationship between the price of gold and different American, British and Japanese inflation indices.

Having first proven the existence of a shift in cointegration between gold and official inflation in the United States since the mid 1990's, we also examined at gold and money supply to understand the true relationship between the price of gold and the amount of cash in circulation. Being one of very few papers to look at inflation from this point of view, we showed that gold did indeed offer protection against growing money stocks in the American economy. However, considering the time-varying nature of our observations, one cannot empirically assert that gold is cointegrated with inflation.

The results are similar for the United Kingdom, where we can say that gold did offer protection against a rise in both the level of inflation and money supply, though it might fail to do so in the near future. If inflation is defined as an increase in the monetary base, we can assert that gold is no hedge against a falling value of the British Pound.

Japan on the other hand seems to be a very different case. Here, it seems that gold is not cointegrated with the PPI and money supply, but was indeed with the CPI. The non-cointegration relationship between gold and Japanese monetary base allow us to conclude that gold is not an optimal hedge against inflation in Japan.

We also look at a longer time span for Japan and show that during periods of inflation, a cointegration with the CPI is observed. Concluding that "gold and Japanese inflation have a negative relationship" is therefore not entirely correct as they only do so during deflationary periods. We augment and expand on the works the results of Hoang et al. (2016)) and Sharma (2016) in multiple ways: first of all, we illustrate when gold and inflation are cointegrated and provide the dates during which a break in the cointegration amongst the series occur. This allows us to reconsider previous conclusion that gold and inflation did not have a long-run cointegration and explains any finding for a short-run relationship. The breaks identified amongst the series point towards the importance of financial turmoils and deflationary periods in the relationship beteen gold and inflation. The reliable long-run relationship between gold and US money supply is strong evidence in favour of reconsidering former results, namely that "gold is not a hedge against inflation in the long-run". As gold is cointegrated with money supply, the relationship with inflation is to be found in the very root of the measure rather than in the relationship with a subjectively published CPI index.

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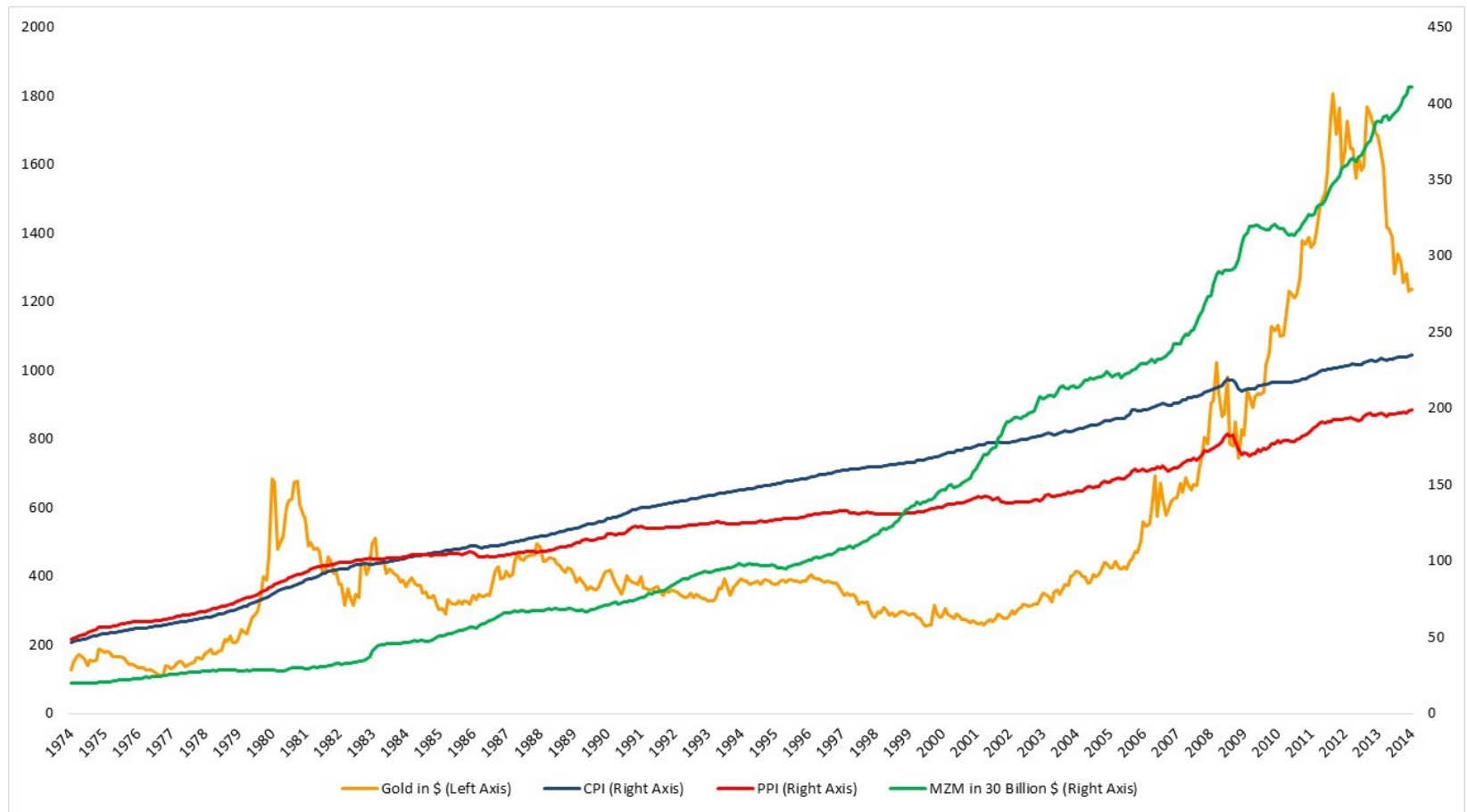
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Figure 1: Gold and US Indices

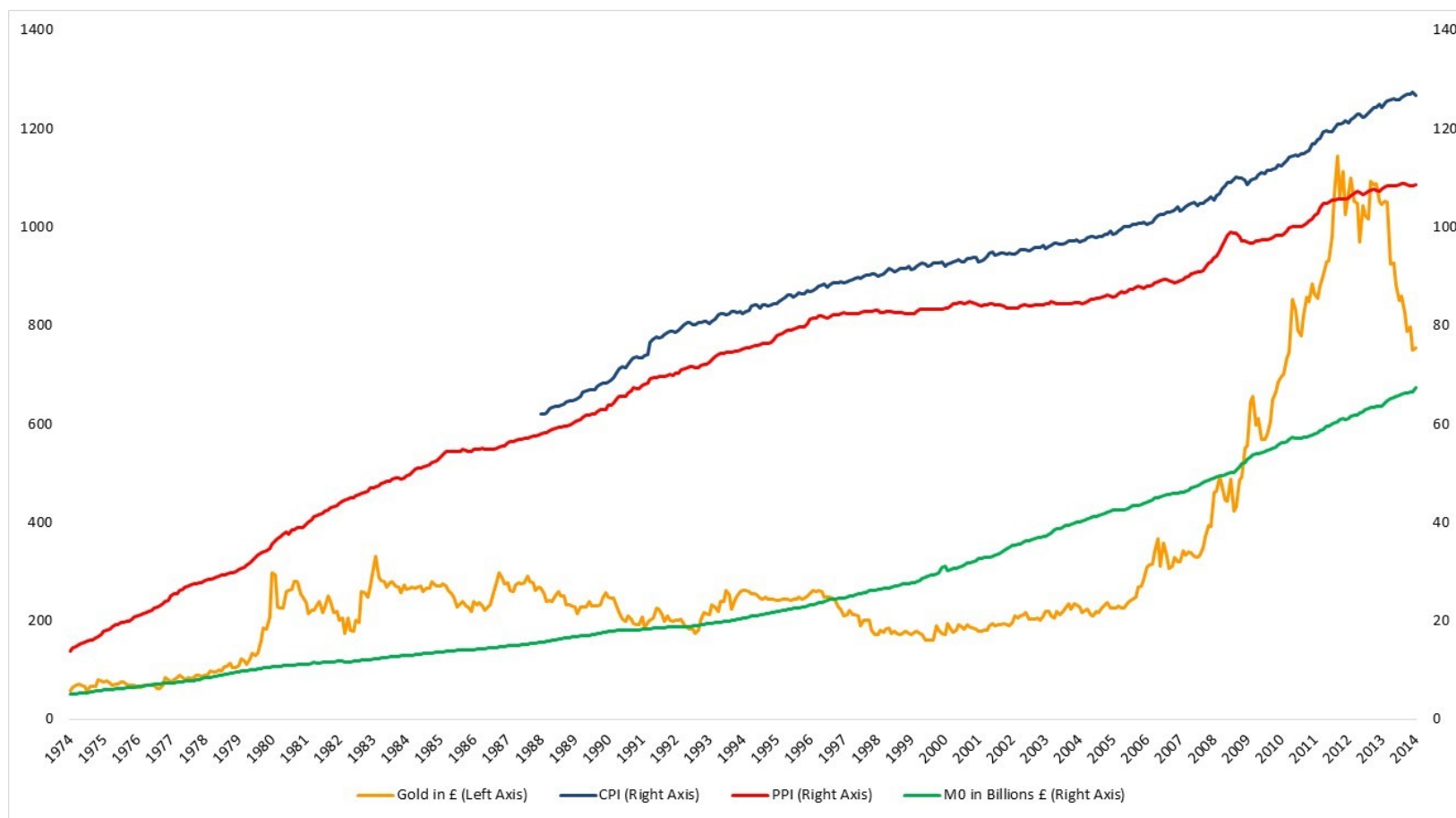
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Note: The above figure displays the price of gold in US Dollars against the nominal US CPI, the US PPI and US Money Zero Maturity.

Figure 2: Gold and UK Indices

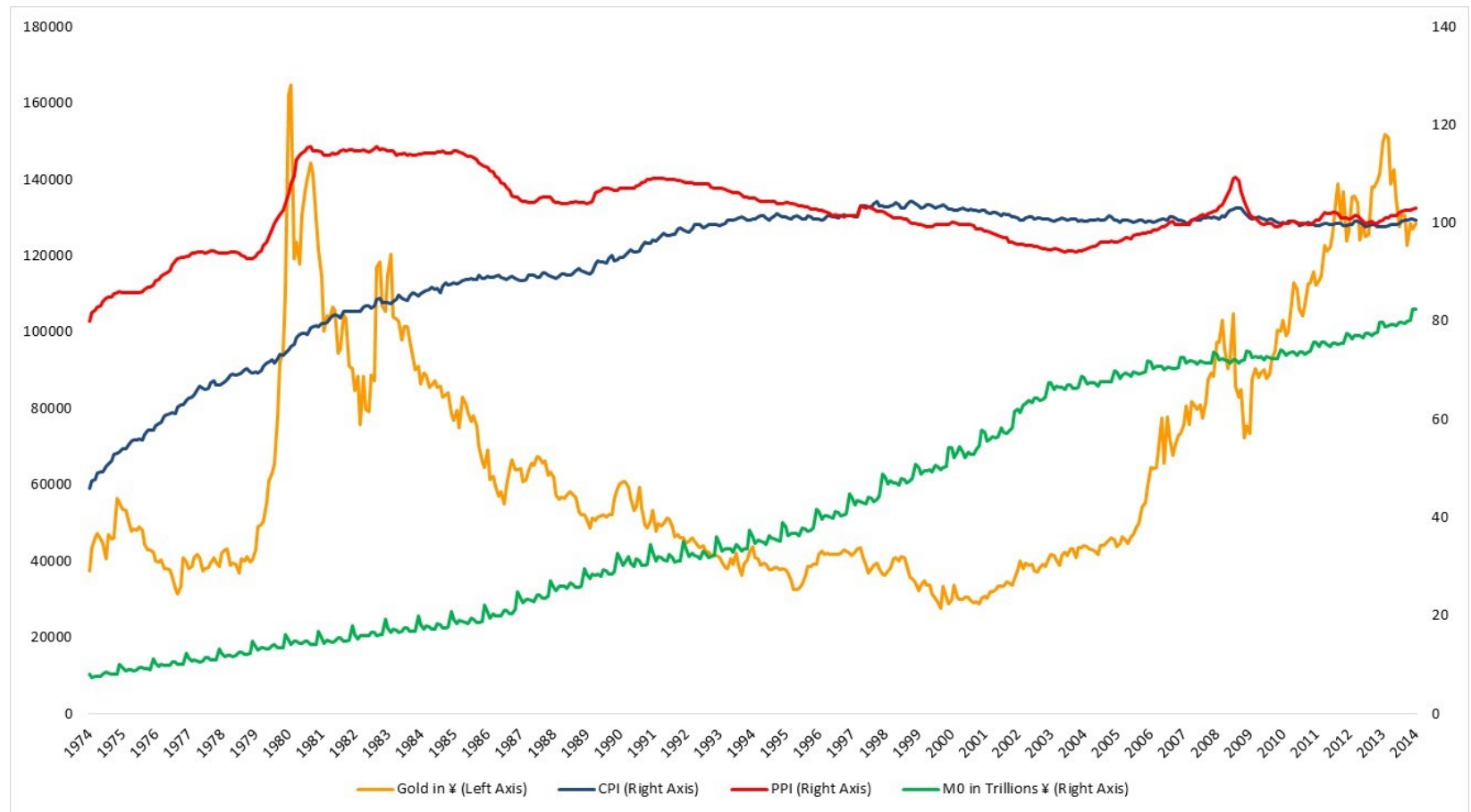
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Note: The above figure displays the price of gold in Pound Sterling against the nominal UK CPI, the UK PPI and UK Liquid Money.

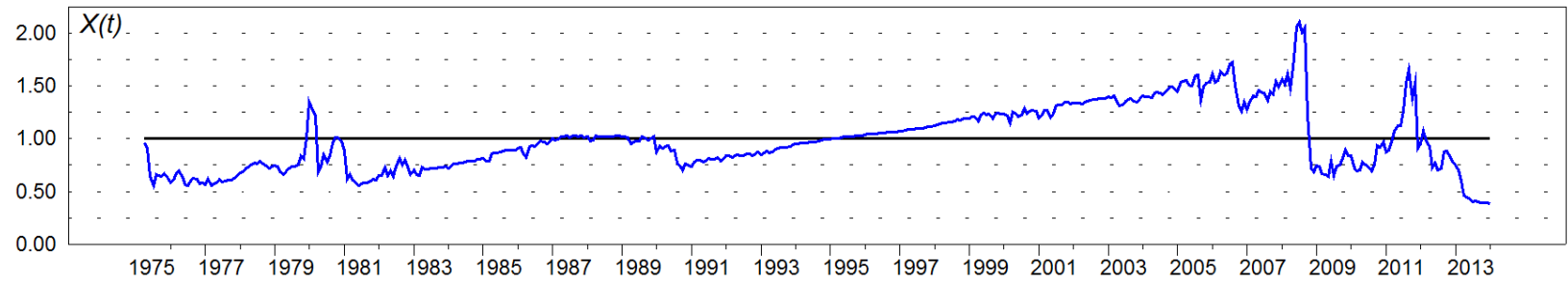
Figure 3: Gold and Japanese Indices

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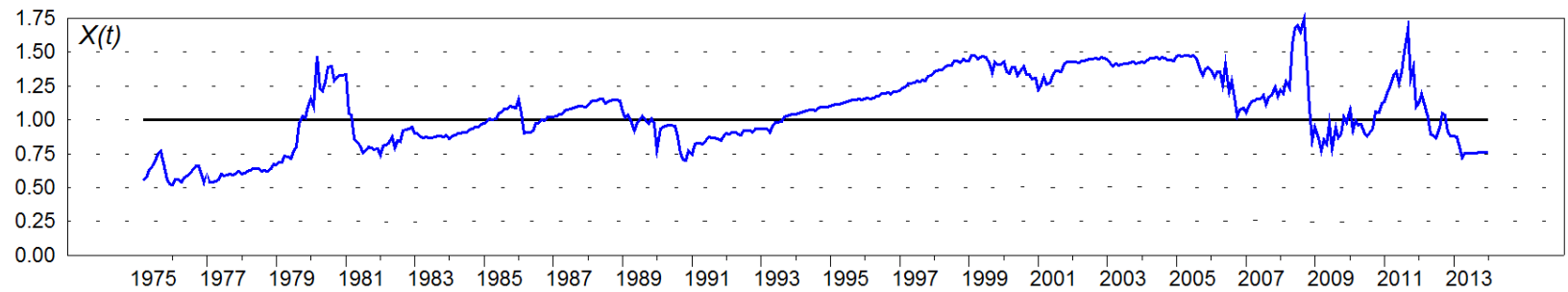
Note: The above figure displays the price of gold in Japanese Yen against the nominal Japanese CPI, the Japanese PPI and Japanese Liquid Money.

Figure 4: Recursive Plot of Johansens Trace Statistic for the US CPI (scaled by the 5% critical value)



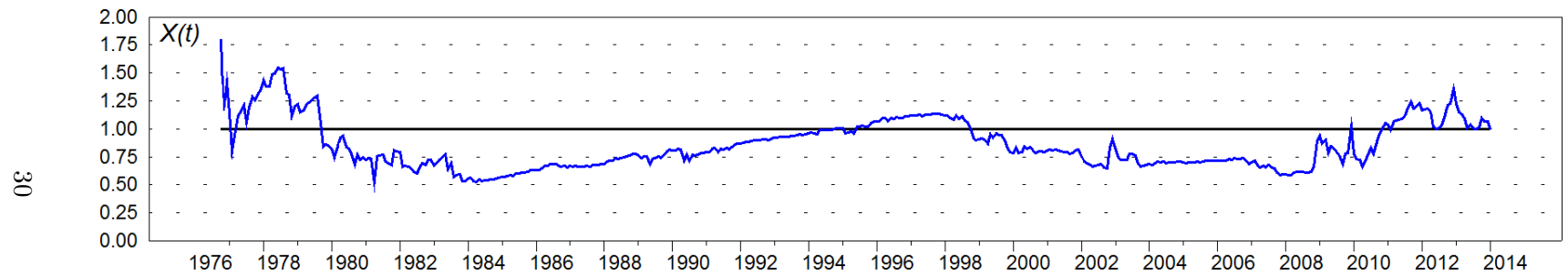
Note: Plotting the Trace Statistic of the Johansen (1995) test allows an easy visualization of the changing cointegration relationship between gold and inflation. When the Trace Statistic is above the horizontal scale, the two series are not cointegrated.

Figure 5: Recursive Plot of Johansens Trace Statistic for the US PPI (scaled by the 5% critical value)



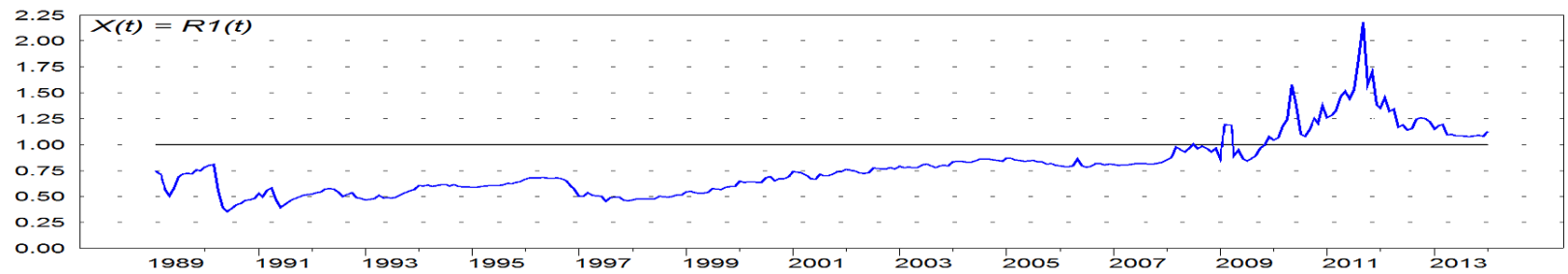
Note: Plotting the Trace Statistic of the Johansen (1995) test allows an easy visualization of the changing cointegration relationship between gold and inflation. When the Trace Statistic is above the horizontal scale, the two series are not cointegrated.

Figure 6: Recursive Plot of Johansens Trace Statistic for the US MZM (scaled by the 5% critical value)



Note: Plotting the Trace Statistic of the Johansen (1995) test allows an easy visualization of the changing cointegration relationship between gold and money supply. When the Trace Statistic is above the horizontal scale, the two series are not cointegrated.

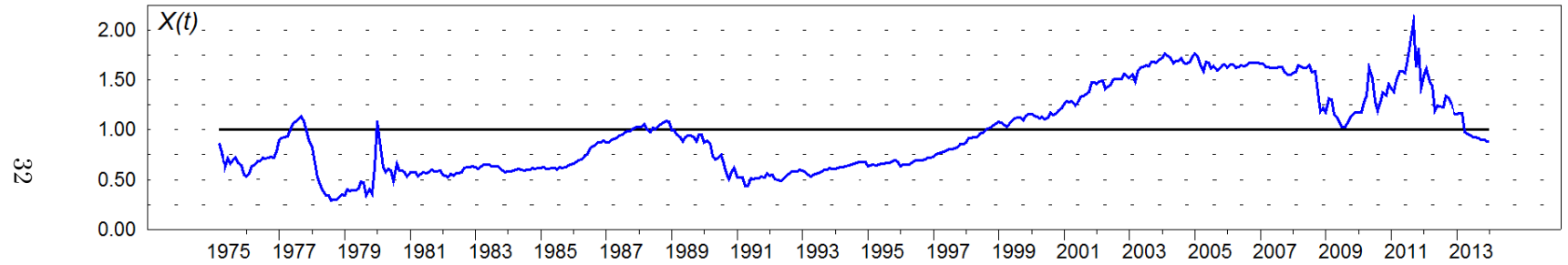
Figure 7: Recursive Plot of Johansens Trace Statistic for the UK CPI (scaled by the 5% critical value)



Note: Plotting the Trace Statistic of the Johansen (1995) test allows an easy visualization of the changing cointegration relationship between gold and inflation. When the Trace Statistic is above the horizontal scale, the two series are not cointegrated.

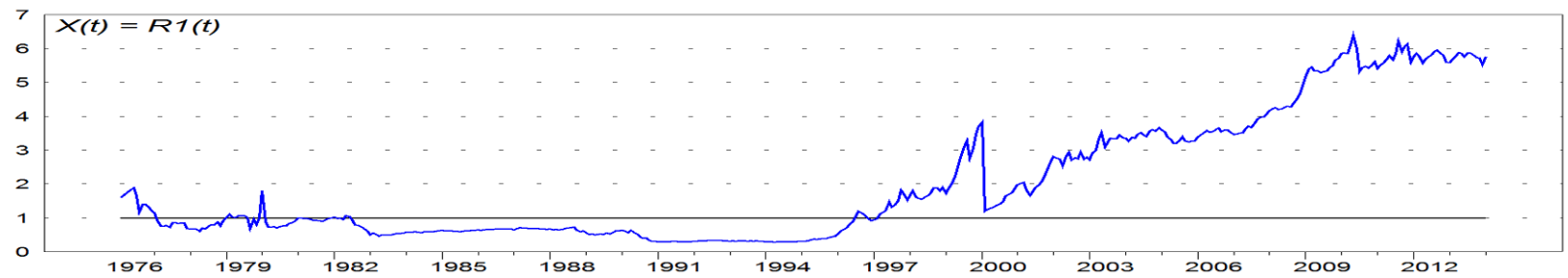


Figure 8: Recursive Plot of Johansens Trace Statistic for the UK PPI (scaled by the 5% critical value)



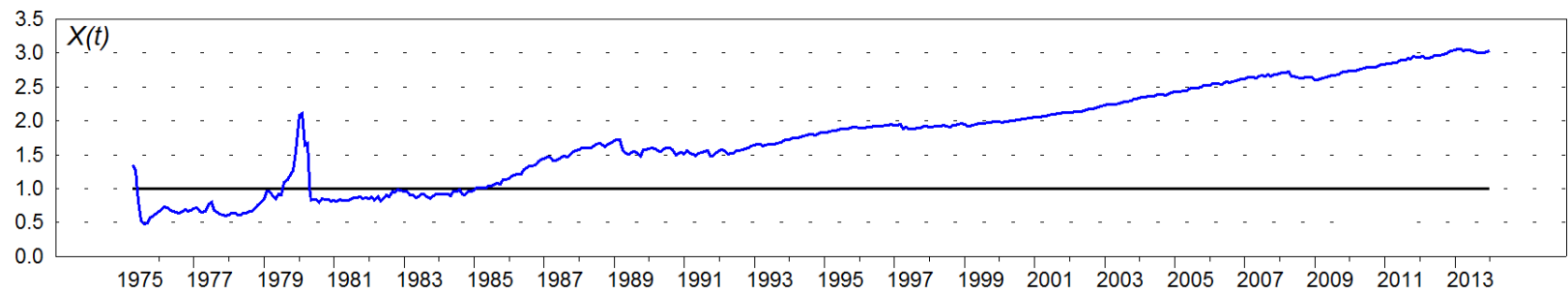
Note: Plotting the Trace Statistic of the Johansen (1995) test allows an easy visualization of the changing cointegration relationship between gold and inflation. When the Trace Statistic is above the horizontal scale, the two series are not cointegrated.

Figure 9: Recursive Plot of Johansens Trace Statistic for the UK MB (scaled by the 5% critical value)



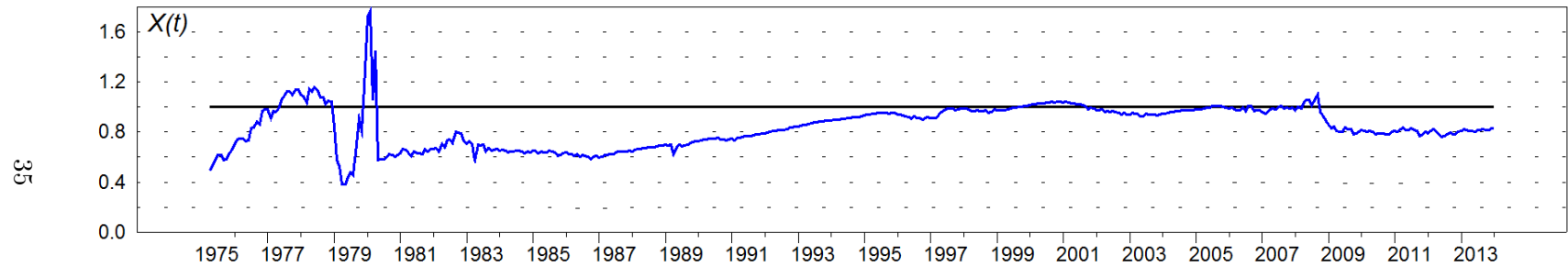
Note: Plotting the Trace Statistic of the Johansen (1995) test allows an easy visualization of the changing cointegration relationship between gold and money supply. When the Trace Statistic is above the horizontal scale, the two series are not cointegrated.

Figure 10: Recursive Plot of Johansens Trace Statistic for the Japanese CPI (scaled by the 5% critical value)



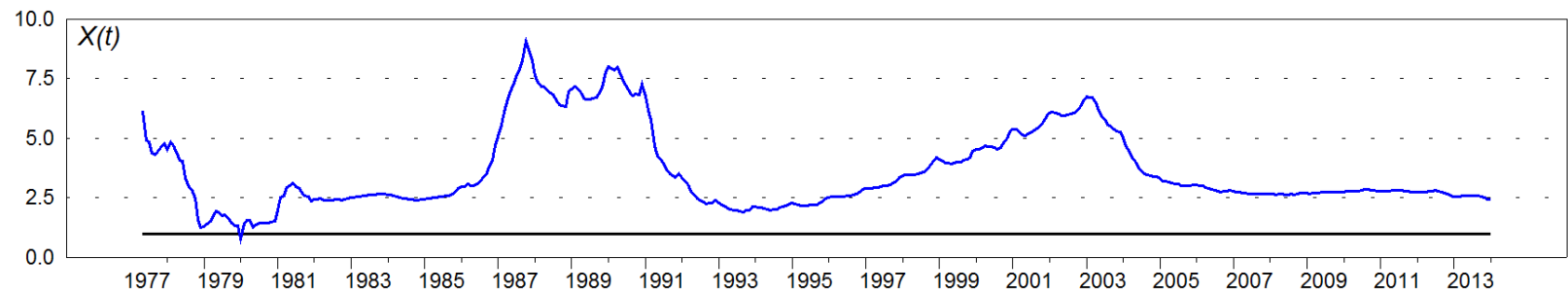
Note: Plotting the Trace Statistic of the Johansen (1995) test allows an easy visualization of the changing cointegration relationship between gold and inflation. When the Trace Statistic is above the horizontal scale, the two series are not cointegrated.

Figure 11: Recursive Plot of Johansens Trace Statistic for the Japanese PPI (scaled by the 5% critical value)



Note: Plotting the Trace Statistic of the Johansen (1995) test allows an easy visualization of the changing cointegration relationship between gold and inflation. When the Trace Statistic is above the horizontal scale, the two series are not cointegrated.

Figure 12: Recursive Plot of Johansens Trace Statistic for the Japanese MB (scaled by the 5% critical value)



Note: Plotting the Trace Statistic of the Johansen (1995) test allows an easy visualization of the changing cointegration relationship between gold and money supply. When the Trace Statistic is above the horizontal scale, the two series are not cointegrated.

Table 1: Research examining the relation between Gold and Inflation

Author (date)	Span of Study	Inflation Rate(s) used	Origin of Inflation Rate(s)	Main Finding
Adrangi et al. (2003)	1968 - 1999	Industrial Production Index and CPI	IMF	Real gold returns are a hedge against expected inflation, but not against unexpected inflation
Artigas (2010)	1971 - 2009	Root	Money Supply and Velocity of Money	Increases in the price of gold predict future inflation
Awokuse and Yang (2003)	1975 - 2001	US CPI	Commodity Research Bureau	Commodity prices signal future direction of economy
Baker and Van Tassel (1985)	1973 - 1984	US CPI & World CPI	N/A	The future rate of the US CPI explains movements in the price of gold
Bampinas and Panagiotidis (2015)	1791 - 2010	UK & US CPI	Reinhart and Rogoff (2011)	Gold is a superior hedge than silver in both countries
Batten et al. (2014)	1985 - 2012	US CPI	Federal Reserve Bank of St. Louis Fred	No cointegration relationship if the early 1980's are excluded
Baur (2013)	1968 - 2013	US CPI and Global CPI	N/A	Inflation is, amongst others, a key driver of the gold price
Beckmann and Czudaj (2013)	1970 - 2011	CPI & PPI (US, UK, Euro Area, Japan)	IMF, OECD & ECB	Gold is partially able to hedge against inflation
Bekaert and Wang (2010)	1980 - 2010	CPI	IMF	Suggests that working with TIPS is misleading due to the liquidity premium
Blose (2010)	1988 - 2008	US CPI	Wall Street Journal Surveys	Surprises in the CPI do not affect gold spot prices
Bruno and Chincarini (2010)	1930 - 2009	Official Inflation	N/A	Gold is a necessary asset in a portfolio that beats inflation
Cai et al. (2001)	1994 - 1997	CPI & PPI	Official Announcements	CPI announcements have a significant effect on the volatility of the gold market
Cecchetti et al. (2000)	1975 - 1996	Multiple	N/A	An increase in the price of gold precedes future declines in inflation
Chua and Woodward (1982)	1975 - 1980	US CPI	IMF	The US inflation rate has the biggest impact on the gold price
Christie-David et al. (2000)	1992 - 1995	CPI & PPI	Official Announcements	Gold responds strongly to the release of CPI, GDP and PPI announcements
Ciner (2011)	1983 - 2010	US CPI	Bloomberg	Long term positive relation between commodity prices and inflation
Dempster and Artigas (2009)	1997 - 2009	TIPS	Barclays' Aggregate US Treasury Inflation-Protected Securities Index	Gold is the most effective portfolio diversifier against assets held by a typical US investor

Author (date)	Span of Study	Inflation Rate(s) used	Origin of Inflation Rate(s)	Main Finding
Dempster and Artigas (2010)	1997 - 2009	TIPS	Barclays' Aggregate US Treasury Inflation-Protected Securities Index	Gold is likely to outperform traditional assets in an inflationary scenario
Erb and Harvey (2012)	1975 - 2012	CPI	IMF	Gold reports inflation more objectively than State institutions
Erb and Harvey (2013)	1975 - 2012	US CPI	IMF	Finds little evidence that gold has been an effective hedge whether measured in the short or in the long term
Feldstein (1980)	N/A	N/A	N/A	An increase in expected inflation leads to an increase in the gold price
Ghosh et al. (2004)	1975 - 1999	US Retail Price Index & World CPI	Bureau of Labor Statistics & IMF	The US Retail Price Index has an influence on the long-run relationship between gold and inflation
Hoang et al. (2016)	1955 - 2015	China, India, Japan, France, UK and US CPI	OECD	Gold is never a hedge in the long-run but it is in the short-run for the UK, the US and India
Jaffe (1989)	1971 - 1987	N/A	N/A	Assumes that the price of gold rise during inflationary periods; but fails to provide evidence
Kolluri (1982)	1968 - 1980	CPI of Industrialized Nations	N/A	Gold is a good hedge against inflation
Kutan and Aksoy (2004)	1996 - 2001	Turkish CPI	State Institute of Statistics of Turkey	The Istanbul gold market is not a hedge against inflation
Larsen and McQueen (1995)	1972 - 1992	N/A	N/A	Gold acted as a hedge against inflation but gold stocks did not
Lawrence (2003)	1975 - 2001	US PPI	EcoWin	No statistical significant correlation between gold returns and inflation
Mahdavi and Zhou (1997)	1958 - 1994	US CPI	IMF	Finds evidence for cointegration between commodity prices and the US CPI
Malliaris (2006)	1970 - 2002	US CPI	Bureau of Labor Statistics	The most commonly used measure of inflation is the percentage change in the CPI
Moore (1990)	1970 - 1988	Inflation Index	Inflation Index compiled by the Columbia University Business School's Centre for International Business Cycle Research (CIBCR)	Following trade signals from the customized inflation index, an investor could have outperformed the market with gold investments
Neill Fortune (1987)	1973 - 1980	US CPI & US WPI	IMF	The price of gold will rise in response to an increase of expected future prices

Author (date)	Span of Study	Inflation Rate(s) used	Origin of Inflation Rate(s)	Main Finding
Ranson and Wainwright (2005a)	1949 - 1999	CPI	IMF	Using the CPI to formulate a sound strategy for protecting against inflation is bound to fail
Ranson and Wainwright (2005b)	1951 - 2005	US CPI	Bureau of Labor Statistics	Gold is a better predictor of inflation than oil because it can't be consumed
Starr and Tran (2008)	1992 - 2003	CPI of 21 countries	The World Bank	Inflation is not a systematic determinant of physical gold demand
Tandon and Urich (1987)	1977 - 1982	Expected US CPI & Expected US PPI	Money Market Services	Unanticipated changes in the PPI have a positive effect on the price of gold; not so unanticipated changes in the CPI
Taylor (1998)	1914 - 1996	CPI	N/A	Gold was a hedge against inflation before World War II but only had partial hedging abilities around the two 1970s oil crises
Tkacz (2007)	1994 - 2005	CPI	N/A	Gold price movements might contain useful information regarding the future path of inflation
Wang et al. (2011)	1971 - 2010	US CPI & Japanese CPI	IMF	Changes in the price of gold reflect inflationary pressure

Note: From the table above, one can clearly see that the most commonly used proxy for inflation is the CPI issued from an *official source* such as the IMF or the US Bureau of Labor Statistics. The Main Finding highlighted in the above table is the main finding of the paper relative to this paper, and should not be taken as necessarily being the main finding of the paper itself.



Table 2: Description of the Data

Name	Time Span	Frequency	Source
Gold London Bullion Market US \$ / Troy Ounce, Official Price	Jan. 1974 - Jan. 2014	Monthly	ICE Benchmark Administration Ltd.
Gold Bullion LBMA / Troy Ounce, Official Price	Jan. 1974 - Jan. 2014	Monthly	ICE Benchmark Administration Ltd.
Japanese Yen to USD	Jan. 1974 - Jan. 2014	Monthly	Bank of England
United States Consumer Price Index, All Items	Jan. 1974 - Jan. 2014	Monthly	Bureau of Labor Statistics
United States Producer Price Index, Finished Goods	Jan. 1974 - Jan. 2014	Monthly	Bureau of Labor Statistics
United States Money Zero Maturity	Jan. 1974 - Jan. 2014	Monthly	St. Louis FRED
United Kingdom Consumer Prices, All Items	Jan. 1988 - Jan. 2014	Monthly	Office for National Statistics
United Kingdom Output Prices, All Manufactured Products	Jan. 1974 - Jan. 2014	Monthly	Office for National Statistics
United Kingdom, Notes and Coins in Circulation Outside Bank of England	Jan. 1974 - Jan. 2014	Monthly	Bank of England
Japan, Consumer Price Index, National Measure	Jan. 1974 - Jan. 2014	Monthly	Ministry of Internal Affairs and Communication, Japan
Japan, Producer Prices, Domestic	Jan. 1974 - Jan. 2014	Monthly	Bank of Japan
Japan, Money Supply M1, Cash Currency in Circulation	Jan. 1974 - Jan. 2014	Monthly	Bank of Japan

Table 3: Results of the Unit Root tests for the United States of America, the United Kingdom and Japan

	US CPI	US PPI	US MZM	UK CPI	UK PPI	UK MB	Japan CPI	Japan PPI	Japan MB
<b>Gold</b>	-0.206+++	-0.206+++	-0.323+++	0.045+++	-0.112+++	-0.181+++	-1.361+++	-1.361+++	-1.361+++
<b>D_Gold</b>	-24.135***	-24.135***	-23.379***	-19.557***	-23.649***	-23.542***	-21.681***	-21.681***	-21.681***
<b>Inflation</b>	-2.201+++	-1.681+++	0.501+++	-1.330+++	-2.042+++	2.882+++	-2.521+++	-2.637+	-2.524+++
<b>D_Inflation</b>	-11.158***	-12.317***	-2.873***	-2.371***	-10.928***	-4.825***	-3.132***	-7.159***	-2.817***

Note: We report the Test Statistic of the Dickey et al. (1979) test in which the lag length is selected via the Schwarz Bayesian Information Criterion (SBIC). \*\*\*, \*\* and \* denote rejection of the null-unit root hypothesis at the 1%, 5% and 10% level respectively. +++, ++ and + denote failure of rejecting the null-unit root hypothesis at the 1%, 5% and 10% level respectively.

Table 4: Narayan et al. (2010) Structural Break Unit Root Test Results

Panel A: M1	Variable (T)	First Break	Second Break	Break Fraction (t-statistics)		Unit Root Coefficient (t-statistics)	Lag Length
				$\lambda_1$	$\lambda_2$		
USA	CPI (481)	15/07/1997	15/03/1998	0.588*** (15)	0.605*** (15)	-0.0019 (-0.298)	5
	PPI (481)	15/02/1982	15/06/1996	0.204*** (83.4)	0.561*** (121.9)	-0.0421 (-1.616)	5
	MS (481)	01/08/1987	01/08/2005	0.341*** (1216)	0.79*** (2898)	0.0014 (0.1214)	2
UK	CPI (313)	15/11/1995	15/02/2006	0.304*** (81.3)	0.697*** (92.09)	-0.0389 (-1.626)	2
	PPI (481)	15/02/1983	15/05/1999	0.229*** (35.5)	0.634*** (67.2)	-0.0034 (-0.2255)	5
	MS (481)	30/05/1986	26/02/1999	0.309*** (1170)	0.6279*** (1822)	0.0312 (2.194)	5
Japan	CPI (481)	15/05/2001	15/11/2003	0.684 (0.000)	0.746 (0.000)	-0.6076*** (-5.045)	4
	PPI (481)	15/09/1995	15/09/2000	0.543*** (15.00)	0.667*** (15.00)	-0.369* (-4.016)	4
	MS (481)	15/05/1990	15/02/2004	0.409*** (2348)	0.7526*** (4839)	-0.0319 (-1.324)	4
Panel B: M2	Variable (T)	First Break	Second Break	Break Fraction t-statistics)		Unit Root Coefficient (t-statistics)	Lag Length
				$\lambda_1$	$\lambda_2$		
USA	CPI (481)	15/07/1997	15/03/1998	0.588*** (15.00)	0.605 (15.00)	-0.0012 (-0.1376)	5
	PPI (481)	15/06/1996	15/02/2000	0.561*** (121.9)	0.653*** (125.1)	-0.0176 (-1.12)	5
	MS (481)	01/08/1987	01/08/2005	0.341*** (1216)	0.79*** (2898)	-0.0975 (-3.005)	2
UK	CPI (313)	15/11/1994	15/02/2006	0.265*** (80.2)	0.697*** (92.09)	-0.0499*** (-5.360)	2
	PPI (481)	15/02/1983	15/05/1999	0.2287*** (35.5)	0.6341*** (67.2)	-0.0582 (-2.601)	5
	MS (481)	30/05/1986	28/02/2001	0.309*** (1170)	0.678*** (1869)	-0.079 (-2.081)	5
Japan	CPI (481)	15/05/2001	15/11/2003	0.684 (0.000)	0.746 (0.000)	-1.527*** (-9.052)	5
	PPI (481)	15/09/1995	15/09/2000	0.543*** (15.0)	0.667*** (15.0)	-0.813*** (-6.482)	4
	MS (481)	15/05/1990	15/02/2004	0.409*** (2348)	0.7526*** (4839)	-0.1646 (-2.456)	4

Note: This table reports the Narayan et al. (2010) structural break unit root test results. The first and second break dates are reported in columns 3 and 4. Column 5 reports the break fraction  $[\lambda_1, \lambda_2]$ , and in parenthesis, we report the t-statistics which determine the statistical significance of the breaks. In Column 6, we report the coefficient of unit root beta and in parenthesis the t-statistics. Results reported in column 6 examine the unit root null hypothesis. The Critical values which determine the statistical significance of the null hypothesis of unit root can be found in Narayan et al. (2013). \*\*\*, \*\*, and \* indicate statistical significance at 1%, 5%, and 10% levels.

Table 5: Johansen (1991) Cointegration Test for the United States of America, the United Kingdom and Japan

	Maximum Rank	LL	Trace Statistic	5% Critical Value
<b>US CPI</b>	0	-2656.9807	64.2346	12.53
	1	-2625.1941	0.6615*	3.84
	2	-2624.8634		
<b>US PPI</b>	0	-2971.489	33.6891	12.53
	1	-2955.1882	1.0874*	3.84
	2	-2954.6444		
<b>US MZM</b>	0	-4515.3721	26.924	12.53
	1	-4505.0392	6.2581	3.84
	2	-4501.9102		
<b>UK CPI</b>	0	-1605.3804	81.147	12.53
	1	-1565.0662	0.5185*	3.84
	2	-1564.8069		
<b>UK PPI</b>	0	-2141.3357	39.8912	12.53
	1	-2121.7015	0.6228*	3.84
	2	-2121.3901		
<b>UK MB</b>	0	-5353.9299	439.0339	12.53
	1	-5135.8045	2.7832*	3.84
	2	-5134.4129		
<b>Japan CPI</b>	0	-5037.4025	24.268	12.53
	1	-5025.9425	1.3480*	3.84
	2	-5025.2685		
<b>Japan PPI</b>	0	-4947.7477	3.1601+	12.53
	1	-4946.418	0.5006	3.84
	2	-4946.1677		
<b>Japan MB</b>	0	-7979.7812	7.3225+	12.53
	1	-7977.5784	2.9168	3.84
	2	-7976.12		

Note: + and \* respectively stand for the acceptance or rejection of the null hypothesis of no cointegration. The lag length is selected according to the Schwarz Bayesian Information Criterion (SBIC) and the time series are not restricted by any specifications following the approach set out in Johansen (1991).

Table 6: Bierens and Martins (2010) Test for Time-Varying Cointegration in the United States of America, the United Kingdom and Japan

	Chebyshev Time Polyno- mials	Test Statistic	10% Critical Value	5% Critical Value	P Value
US CPI	m = 1	6.44***	4.61	5.99	0.03991
	m = 2	13.12***	7.78	9.49	0.01069
	m = 4	17.28***	13.36	15.51	0.02735
US PPI	m = 1	8.44***	4.61	5.99	0.0147
	m = 2	10.61***	7.78	9.49	0.03128
	m = 4	13.15	13.36	15.51	0.10675
US MZM	m = 1	2.08	4.61	5.99	0.35278
	m = 2	4.08	7.78	9.49	0.39498
	m = 3	7.81	10.64	12.59	0.25252
	m = 4	16.11***	13.36	15.51	0.04078
UK CPI	m = 1	2.46	4.61	5.99	0.29253
	m = 2	13.79***	7.78	9.49	0.00801
	m = 4	33.52***	13.36	15.51	0.00005
UK PPI	m = 1	0.88	4.61	5.99	0.64464
	m = 2	4.33	7.78	9.49	0.36339
	m = 3	17.12***	10.64	12.59	0.00885
	m = 4	18.27***	13.36	15.51	0.01929
UK MB	m = 1	4.05	4.61	5.99	0.13186
	m = 2	5.76	7.78	9.49	0.21787
	m = 3	9.84	10.64	12.59	0.1316
	m = 4	14.39**	13.36	15.51	0.07208
Japan CPI	m = 1	0.65	4.61	5.99	0.7242
	m = 2	20.95***	7.78	9.49	0.00032
	m = 4	30.27***	13.36	15.51	0.00019
Japan PPI	m = 1	No Cointegration	No Cointegration	No Cointegration	No Cointegration
	m = 2				
	m = 4				
Japan MB	m = 1	No Cointegration	No Cointegration	No Cointegration	No Cointegration
	m = 2				
	m = 4				

Note: \*\*\* and \*\* stand for the rejection of the null hypothesis of time-invariance at the 5% and 10% level respectively, depending on a 10% confidence level p-value. The Bierens and Martins (2010) test approximates the cointegrating vector in the Johansen (1991) test by a finite number of Chebyshev time polynomials and can be used to determine whether or not the cointegrating vector varies with time. We follow Bampinas and Panagiotidis (2015) in reporting results for m up to four and conclude that time-variation is observed unless at least one m fails to reject the null hypothesis.

Table 7: Gregory and Hansen (1996) Test results for the United States of America, the United Kingdom and Japan

	Test	Test Statistic	Date	1% Critical Value	5% Critical Value	10% Critical Value
<b>US CPI</b>	ADF	-3.07	Oct. 1999	-5.47	-4.95	-4.68
	$Z_t$	-3.05	Aug. 1999	-5.47	-4.95	-4.68
	$Z_\alpha$	-20.09	Aug. 1999	-57.17	-47.04	-41.85
<b>US PPI</b>	ADF	-3.11	Aug. 1998	-5.47	-4.95	-4.68
	$Z_t$	-3.24	Aug. 1999	-5.47	-4.95	-4.68
	$Z_\alpha$	-24.19	Aug. 1999	-57.17	-47.04	-41.85
<b>US MZM</b>	ADF	-4.67	Oct. 2007	-5.47	-4.95	-4.68
	$Z_t$	-2.46	Sep. 1999	-5.47	-4.95	-4.68
	$Z_\alpha$	-15.78	Sep. 1999	-57.17	-47.04	-41.85
<b>UK CPI</b>	ADF	-3.09	Apr. 2009	-5.47	-4.95	-4.68
	$Z_t$	-3.39	Apr. 2009	-5.47	-4.95	-4.68
	$Z_\alpha$	-22.83	Apr. 2009	-57.17	-47.04	-41.85
<b>UK PPI</b>	ADF	-3.16	Aug. 1995	-5.47	-4.95	-4.68
	$Z_t$	-3.08	Oct. 1995	-5.47	-4.95	-4.68
	$Z_\alpha$	-22.96	Oct. 1995	-57.17	-47.04	-41.85
<b>UK MB</b>	ADF	-2.51	Sep. 1998	-5.47	-4.95	-4.68
	$Z_t$	-2.6	Aug. 1999	-5.47	-4.95	-4.68
	$Z_\alpha$	-16.93	Aug. 1999	-57.17	-47.04	-41.85
<b>Japan CPI</b>	ADF	-2.82	Oct. 2006	-5.47	-4.95	-4.68
	$Z_t$	-3.4	Jan. 2007	-5.47	-4.95	-4.68
	$Z_\alpha$	-20.48	Jan. 2007	-57.17	-47.04	-41.85
<b>Japan PPI</b>	ADF	-3.17	May 2007	-5.47	-4.95	-4.68
	$Z_t$	-3.57	Feb. 2007	-5.47	-4.95	-4.68
	$Z_\alpha$	-23.61	Feb. 2007	-57.17	-47.04	-41.85
<b>Japan MB</b>	ADF	-3.37	Sep. 2000	-5.47	-4.95	-4.68
	$Z_t$	-3.62	Sep. 2001	-5.47	-4.95	-4.68
	$Z_\alpha$	-24.84	Sep. 2001	-57.17	-47.04	-41.85

Note: In contrary to popular tests for cointegration, the Gregory and Hansen (1996) test allows the cointegrating vector to change at a single unknown time during the period considered. The authors developed residual-based tests that do not require information in regard to timing or occurrence of a break; these tests are augmentations of the  $Z_\alpha$  and  $Z_t$  unit root tests proposed by Phillips (1987) and the augmented Dickey-Fuller (ADF) recommended by Engle and Granger (1987).

Table 8: Bai and Perron (2003) Test results for the United States of America, the United Kingdom and Japan

	Variable	Coefficient	Std. Error	T Statistic	Significance	Break-point	Lower 95%	Upper 95%
<b>US CPI</b>	DZ(1,1)	2.5761	0.0475	54.2235	0	September 2007	June 2007	July 2009
	DZ(1,2)	4.3458	0.1094	39.714	0	—	—	—
	DZ(1,3)	6.558	0.0858	76.4525	0	April 2010	October 2009	June 2010
<b>US PPI</b>	DZ(1,1)	3.0655	0.0479	63.9998	0	August 2007	April 2007	October 2008
	DZ(1,2)	5.2997	0.1138	46.5616	0	—	—	—
	DZ(1,3)	7.7888	0.0876	88.9265	0	April 2010	September 2009	July 2010
<b>US MZM</b>	DZ(1,1)	0.2354	0.007	33.4539	0	February 1991	December 1990	September 1992
	DZ(1,2)	0.0831	0.0017	48.0272	0	—	—	—
	DZ(1,3)	0.1356	0.0018	73.1468	0	October 2009	March 2009	December 2010
<b>UK CPI</b>	DZ(1,1)	2.5749	0.0477	53.9567	0	December 2007	August 2007	April 2008
	DZ(1,2)	5.0598	0.1168	43.3214	0	—	—	—
	DZ(1,3)	7.7289	0.0787	98.2347	0	February 2010	August 2009	May 2010
<b>UK PPI</b>	DZ(1,1)	4.807	0.1264	38.0183	0	November 1988	June 1987	September 1989
	DZ(1,2)	2.9853	0.0565	52.8636	0	—	—	—
	DZ(1,3)	8.3978	0.0877	95.7094	0	December 2008	August 2008	February 2009
<b>UK MB</b>	DZ(1,1)	0.0139	0.0003	47.206	0	May 1996	January 1996	May 1998
	DZ(1,2)	0.0068	0.0001	43.67	0	—	—	—
	DZ(1,3)	0.0145	0.0001	95.7725	0	November 2008	June 2008	January 2009
<b>Japan CPI</b>	DZ(1,1)	1013.3397	21.4816	47.1723	0	January 1986	October 1985	March 1988
	DZ(1,2)	456.7328	12.2058	37.4192	0	—	—	—
	DZ(1,3)	1091.1689	20.8127	52.428	0	January 2007	May 2006	April 2007
<b>Japan PPI</b>	DZ(1,1)	706.6235	13.5473	52.1596	0	January 1988	August 1987	March 1992
	DZ(1,2)	429.228	11.9125	36.0316	0	—	—	—
	DZ(1,3)	1075.1934	19.5061	55.121	0	December 2006	April 2006	January 2007
<b>Japan MB</b>	DZ(1,1)	5.3299	0.1266	42.0983	0	November 1985	October 1985	October 1986
	DZ(1,2)	0.9602	0.02498	38.4325	0	—	—	—
	DZ(1,3)	1.6212	0.0388	41.7435	0	September 2009	July 2009	November 2011

Note: Working with a sub $F$ -type test, a binary maximum test and a  $\sup F_t(l+1|l)$  test, Bai and Perron (2003) focus on internal and multiple breaks by forecasting break points together with regression coefficients. DZ(i,j) stands for the explanatory variable i in regime j, where the inflation measure considered is the explanatory variable and three regimes are identified matching to the two breakpoints identified.