

Gold Price and Exchange Rates: A Panel Smooth Transition Regression Model for the G7 Countries

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Abstract: In this paper we investigate whether the price of gold is affected by internal and external macroeconomic performance, which is reflected in exchange rate movements. Based on the G7 countries and using annual data for the period 1980-2016, we test the impact of the real effective exchange rate and the interest rate on the price of gold. Departing from previous studies, we propose that the observed exchange rate should be taken into account in accordance with the equilibrium value of the currency and the implied misalignment. The equilibrium real effective exchange rate is estimated using recent panel cointegration techniques, which are strengthened with the theoretical assumptions of an external balance model. Next, we estimate a two-regime Panel Smooth Transition Regression model with a monotonic transition function to capture the nonlinear dependency between the gold price and the macroeconomic variables. Our results show that investors tend to invest in gold as the misalignment rate of the real effective exchange rate increases. Furthermore, when the interest rate increase is rather high, investors are less willing to sell gold for higher return assets. Overall, our evidence confirms that gold serves as a hedge only when financial risk is high.

Keywords: G7, external balance model, panel cointegration, misalignment rate, panel smooth transition regression model.

JEL Classification: E42, F31, F41

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1. Introduction

Gold is one of the most valuable metals with many applications in daily life. First of all, its shiny view makes gold quite attractive as jewellery. It is also used in industry, in electronics and computers manufacture, in medicine, in aerospace, and of course, it is used as a financial asset. Traditionally, gold was used as a hedging tool against inflation. Moreover, there is evidence in the literature that gold serves as a hedge against financial risk.¹ Previous studies have reported no evidence of correlation between gold and other financial assets, such as stocks and bonds (see, *inter alia*, Summer *et al.*, 2010). This implies that investors can use gold to diversify their portfolios. Similarly, there is evidence that gold serves as a hedge against currency risk. Most of the empirical studies in the related literature find negative relationship between gold price and fundamental currencies, such as the US dollar, the Japanese yen etc. (see, Capie *et al.*, 2005; Joy, 2011; Reboredo, 2013). Serving as a financial asset, gold is sensitive to developments in money markets. For example, an increase in the interest rate causes a decrease in demand for gold because investors realise that the opportunity cost of holding gold increases.

Like any other asset, the price of gold is shown to be volatile. Focusing on the financial features of gold, we can easily understand that the price of gold is sensitive to worldwide economic conditions. For example, in periods of financial distress, investors tend to invest in gold because they are anxious about financial risk. Similarly, the negative relationship between the price of gold and the exchange rate implies that investors prefer to invest in gold rather than in a depreciating currency. Equivalently, this implies that demand for gold declines as currencies appreciate. It seems that there is a negative, but straightforward, relationship between gold price and exchange rates. However, this does not mean that gold price can be easily predicted since the exchange rates are highly unstable.

This paper revisits the relationship between the gold price and several fundamental financial variables, such as the exchange rate and the interest rate. Based on the G7 countries, namely Canada, France, Germany, Italy, Japan, the UK and the USA, and employing annual data for the period 1980-2016, we test the impact of the real effective exchange rate and the interest rate on the price of gold. This paper contributes to the related literature in a number of ways: Firstly, besides the baseline model, we estimate an alternative model in which the observed exchange rate is replaced by its estimated equilibrium exchange rate and the corresponding misalignment rate. In line with the evidence from previous studies, we argue

¹ Regarding the economics of gold, see O'Connor *et al.* (2015) for an extensive literature review.

that investment in the appreciating currency will be beneficial to investors only if the appreciating trend of the currency is consistent with equilibrium. Otherwise, the exchange rate is expected to be unstable in the future (see Giannellis and Papadopoulos, 2011). Equivalently, this means that investors will be willing to invest in the appreciating currency only if the exchange rate is not significantly misaligned. Thus, there is an indication that the observed exchange rate may not alone determine the relationship between the value of the currency and the gold price. What is proposed is that the observed exchange rate should be taken into account in accordance with its equilibrium value and the implied misalignment rate.

Secondly, departing from the existing studies in this literature, we employ a Panel Smooth Transition Regression (PSTR) model in order to explore the possibility that the impact of the independent variables on the gold price may be nonlinear. As the linearity hypothesis is rejected and the parameters of the PSTR model are identified (as it is reported in section 5 of this paper), we estimate a two-regime PSTR model with a monotonic transition function. The results show that the impact of the equilibrium exchange rate on the gold price changes as the magnitude of the misalignment rate (threshold variable) changes.

Thirdly, by utilising the nonlinear characteristics of the PSTR model we distinguish two effects, which may drive the relationship between the gold price and the equilibrium exchange rate. The first one is the substitution effect: investors may substitute gold investment with currency investment when the value of the currency follows an increasing trend. The second one is a positive income effect: an increase in the real value of the currency (reflecting positive macroeconomic performance) may lead to higher investment not only in currency but also in gold. To preview our results, there is evidence that for low misalignment rates, the income effect (*i.e.*, the positive relationship) is shown to be more important, but as the misalignment rate moves close to the upper regime, the substitution effect prevails.

The rest of the paper is organised as follows. The next section presents the theoretical background, while section 3 shows the econometric methodology. Section 4 describes the data, section 5 reports the empirical findings and a final section concludes.

2. Theoretical Considerations

2.1 Baseline Model

Based on the relative theoretical and empirical literature, it is shown that the gold price is associated with a number of macroeconomic and financial variables, such as the exchange

rate, the interest rate and the inflation rate. In this study, we mainly investigate the conjecture that the price of gold is affected by internal and external macroeconomic performance, which is reflected in exchange rate movements. We capture the overall macroeconomic performance with the real effective exchange rate (REER), which allows us to consider both the effects of the nominal exchange rate and the inflation rate. Even though we focus on the REER in our analysis, we also test the impact of the nominal interest rate (i) on the gold price. Thus, our starting model is the following:

$$P_G = f(REER, i), \quad (1)$$

where P_G is the gold price.

Since gold is basically traded in US dollars, most of the empirical studies examine the relationship between the gold price and the US dollar. When examining the demand-side of gold, most researchers find a negative relationship between the gold price and the US dollar. Namely, a decrease in the value of the US dollar makes gold cheaper for worldwide buyers and thus, the demand for gold increases (Tully and Lucey, 2007; Sari *et al.*, 2010). However, this does not mean that the US dollar dominates the relationship between the gold and the exchange rate. For instance, Sjaastad and Scacciavillani (1996) confirm the negative relationship between the gold price and an extended set of currencies. Moreover, a negative relationship is also reported when considering gold as a hedge asset. According to this view, investors prefer gold when foreign exchange markets are unstable (Capie *et al.*, 2005; Joy, 2011; Reboredo, 2013).

On the other hand, a positive relationship between the gold price and the inflation rate is also reported in the literature. From a theoretical point of view, Fortune (1987) explains that as inflation is expected to increase, rational investors substitute fixed return assets with gold. Levin *et al.* (2006) provide an alternative explanation. They state that the positive relationship between the gold price and the inflation rate is due to supply-side reasons. Extraction costs are higher when inflation is high and thus, gold price increases to cover the increased cost. Overall, there is strong empirical evidence in the literature in favour of this positive relationship (see, *inter alia*, Beckmann and Czudaj, 2013; Silva, 2014; Batten *et al.*, 2014).

Regarding the interest rate, it is considered as the opportunity cost of holding gold. This means that if the interest rate increases, investors exchange gold with other assets (with higher expected return). Namely, a negative relationship between the gold price and the interest rates may exist. However, the empirical evidence in the literature is mixed. Fortune (1987) finds a negative relationship, but Lawrence (2003), Tully and Lucey (2007) and Silva (2014) find no

relationship between the gold price and the interest rate. Baur (2011) argues that a positive relationship exists for short-term interest rates, while it turns into a negative one for long-term interest rates. Since we use long-term interest rates in this study, we expect that the sign of the interest rate will be negative.

2.2 Alternative Model

The function of gold as a hedge asset implies that the gold price increases due to the substitution effect. Investors substitute other assets with gold in periods of financial distress. Moreover, the negative relationship between the nominal exchange rate and the gold price implies that as a currency depreciates, investors prefer to invest in gold rather than in the depreciating currency. To invert the case, this also implies that the demand for gold declines as a currency appreciates. However, this statement does not enclose the whole story. What is missing is that investment in the appreciating currency will be beneficial to investors only if the appreciating trend of the currency is consistent with equilibrium. Otherwise, the exchange rate is expected to be unstable in the future (Giannellis and Papadopoulos, 2011). Equivalently, this means that investors will be willing to invest in the appreciating currency only if the exchange rate is not significantly misaligned.

As a consequence, there is an indication that the observed exchange rate may not alone determine the relationship between the value of the currency and the gold price. What is implied is that the observed exchange rate should be taken into account in accordance with the equilibrium value of the currency and the implied misalignment. Thus, we propose the estimation of the following alternative model, in which the observed REER is substituted by the equilibrium REER (EqREER):

$$P_G = f(EqREER, i). \quad (2)$$

Since we are interested in the linkage between the macroeconomic performance and the gold price, the alternative model described in equation (2) seems to be more appropriate in capturing the above relationship. Considering gold as an asset, we can now distinguish two effects, which may drive the relationship between the gold price and the exchange rate. The first one is the aforementioned substitution effect: investors may substitute gold investment with currency investment when the value of the currency follows an increasing trend. In this case, the sign of the equilibrium exchange rate is expected to be negative. The second one is a positive income effect: when the real value of the currency increases (reflecting positive

macroeconomic performance), this may lead to higher investment not only in currency but also in gold. In this case, the sign of the equilibrium exchange rate is expected to be positive.

Thus, the sign of the equilibrium exchange rate is ambiguous. However, we expect that the income effect should prevail when the misalignment rate is low, while the substitution effect will be stronger when the real value of the currency is highly misaligned. The former reflects the increased confidence on macroeconomic performance and stability, while the latter reflects investor's anxiety about future stability even though the value of the currency is currently increasing. Finally, as in the standard model, the sign of the interest rate is expected to be negative.

2.3 A Theoretical Model for the Equilibrium REER

The equilibrium exchange rate can be considered as the exchange rate at which external balance is achieved. Based on the balance of payments approach, we follow Giannellis and Koukouritakis (2018), who extended the balance of payments exchange rate equation introduced by MacDonald (2000). The balance of payments (*BP*) is described by the following expressions:

$$BP_t = CA_t + KA_t, \quad (3)$$

$$CA_t = (X_t - M_t) + r_t NFA_t, \quad (4)$$

$$NX_t = (X_t - M_t) = -\alpha_1 REER_t - \alpha_2 y_t + \alpha_3 y_t^*, \quad (5)$$

$$KA_t = \theta(r_t - r_t^* + E_t[REER_{t+k}] - REER_t), \quad (6)$$

where CA_t is the current account, KA_t is the capital account, X_t and M_t represent exports and imports, respectively, $r_t NFA_t$ stands for net interest payments on net foreign assets, NX_t represents net exports, y_t (y_t^*) is the home (foreign) income and r_t (r_t^*) is the home (foreign) real interest rate.

Regarding net exports in equation (5), an increase in the REER (*i.e.*, real appreciation of the home currency) is expected to decrease net exports due to the lower competitiveness of home products. On the other hand, the impact of income is not straightforward. Traditional theory implies decrease of net exports when home income increases more than foreign income. However, it ignores the fact that high-income countries have greater access to capital, which allows them to develop new and high quality products. Thus, a higher home income does not necessarily imply a negative impact on net exports. Also, regarding capital account

in equation (6), a higher home real interest rate yield is expected to increase capital inflow at home, thereby improving the domestic capital account.

In order to get the real exchange rate which is consistent with balance of payments equilibrium, we substitute (4), (5) and (6) into (3):

$$REER_t = \left(\frac{1}{\alpha_1 + \theta} \right) r_t NFA_t - \left(\frac{\alpha_2}{\alpha_1 + \theta} \right) y_t + \left(\frac{\alpha_3}{\alpha_1 + \theta} \right) y_t^* + \left(\frac{\theta}{\alpha_1 + \theta} \right) (r_t - r_t^*) + \left(\frac{\theta}{\alpha_1 + \theta} \right) E_t[REER_{t+k}]. \quad (7)$$

Assuming that $\alpha_2 = \alpha_3 = \varphi$, equation (7) can be written as follows:

$$REER_t = \left(\frac{1}{\alpha_1 + \theta} \right) r_t NFA_t - \left(\frac{\varphi}{\alpha_1 + \theta} \right) (y_t - y_t^*) + \left(\frac{\theta}{\alpha_1 + \theta} \right) (r_t - r_t^*) + \left(\frac{\theta}{\alpha_1 + \theta} \right) E_t[REER_{t+k}]. \quad (8)$$

The next step is to extend the balance of payments exchange rate equation by formulating the future value of the REER. For the next period ($t+1$), the expected value of the REER is:

$$E_t[REER_{t+1}] = \left(\frac{1}{\alpha_1 + \theta} \right) E_t[r_{t+1} NFA_{t+1} - \varphi(y_{t+1} - y_{t+1}^*)] + \left(\frac{\theta}{\alpha_1 + \theta} \right) E_t[(r_{t+1} - r_{t+1}^*)] + \left(\frac{\theta}{\alpha_1 + \theta} \right) E_t[REER_{t+2}]. \quad (9)$$

After k periods, the REER becomes:

$$REER_t = \left(\frac{1}{\alpha_1 + \theta} \right) \sum_{i=0}^{k-1} \left(\frac{\theta}{\alpha_1 + \theta} \right)^i E_t[r_{t+i} NFA_{t+i} - \varphi(y_{t+i} - y_{t+i}^*)] + \sum_{i=0}^{k-1} \left(\frac{\theta}{\alpha_1 + \theta} \right)^k E_t[(r_{t+i} - r_{t+i}^*)] + \left(\frac{\theta}{\alpha_1 + \theta} \right)^k E_t[REER_{t+k}]. \quad (10)$$

If $k \rightarrow \infty$, then $\lim_{k \rightarrow \infty} \left(\frac{\theta}{\alpha_1 + \theta} \right)^k E_t[REER_{t+k}] = 0$.² Thus, the REER can be written as:

$$REER_t = \left(\frac{1}{\alpha_1 + \theta} \right) \sum_{i=0}^{k-1} \left(\frac{\theta}{\alpha_1 + \theta} \right)^i E_t[r_{t+i} NFA_{t+i} - \varphi(y_{t+i} - y_{t+i}^*)] + \sum_{i=0}^{k-1} \left(\frac{\theta}{\alpha_1 + \theta} \right)^k E_t[(r_{t+i} - r_{t+i}^*)]. \quad (11)$$

Equation (11) shows that the REER is forward-looking and depends on current and future values of real income differential, real interest rate differential and net foreign asset position. Thus, an increase in the net foreign asset position is expected to appreciate the

² This expression is true under the condition that Purchasing Power Parity (PPP) condition holds in the long run.

REER due to higher net interest receipts. Regarding the real income differential, its impact on REER is not straightforward. As noted above, traditional theory implies a decrease of net exports when home income increases, but recent studies have reported evidence that this is not always the case. According to this view, high-income countries can exploit new capabilities (*i.e.*, greater access to capital) so that to develop high quality products and increase their exports. The latter may cause real appreciation of the REER. Thus, we can consider the impact of income differential on the real exchange rate as ambiguous. Finally, a higher home real interest rate yield is expected to increase capital inflows at home and thus to cause home currency appreciation. Assuming that current fundamentals, which are assumed to follow a random walk process, are a good forecast of future fundamentals, the equilibrium REER equation along with expected signs is the following:

$$REER_t = \delta_0 + \underset{+}{\delta_1} NFA_t + \underset{+/-}{\delta_2} (y_t - y_t^*) + \underset{+}{\delta_3} (r_t - r_t^*). \quad (12)$$

3. Econometric Methodology

3.1 Panel Smooth Transition Regression (PSTR) model

In order to explore the possibility that the impact of the (equilibrium) exchange rate on the gold price may be nonlinear, we estimate a PSTR model, which has been originally proposed by Gonzales *et al.* (2005). This model can be seen as a generalisation of the Panel Threshold Regression (PTR) model, originally presented by Hansen (1999). As in the PTR model, regression coefficients can take different values in different regimes (or states). However, the key characteristic of the PSTR model is that the regression coefficients change smoothly when moving from one regime to another. According to Gonzales *et al.* (2005), the PSTR model has a dual application. It can be seen as a linear heterogeneous panel model or/and as a nonlinear homogeneous panel. The basic PSTR model with two regimes can be shown as follows:

$$P_{G_{j,t}} = \mu_j + \lambda_t + \beta_{01} REER_{j,t} + \beta_{02} i_{j,t} + (\beta_{11} REER_{j,t} + \beta_{12} i_{j,t}) g(q_{j,t}; \gamma, c) + u_{j,t}, \quad (13)$$

for $j = 1, \dots, N$ and $t = 1, \dots, T$, where N and T are the cross-sectional and time dimensions of the panel, respectively. μ_j stands for fixed individual effects, λ_t denotes time effects and $u_{j,t}$ represents the residuals. Gold price (P_G) is the dependent variable, while regressors ($REER$ and i) are assumed to be exogenous.³

³ For the alternative model, $REER$ in equation (13) is replaced by its equilibrium value ($EqREER$).

The transition function $g(q_{j,t}; \gamma, c)$ is a continuous and bounded function of the threshold variable ($q_{j,t}$). Following Gonzales *et al.* (2005), the transition function is written as: $g(q_{j,t}; \gamma, c) = \left[1 + \exp\left(-\gamma \prod_{n=1}^m (q_{j,t} - c_n)\right) \right]^{-1}$ with $\gamma > 0$ and $c_1 < c_2 < \dots < c_m$. γ is the slope parameter and indicates the smoothness of the transition, while $c = (c_1, c_2, \dots, c_m)'$ is a vector of location parameters. For $m=1$, the PSTR model becomes a two-regime model with a monotonic transition of regressor coefficients as the threshold variable increases. The two regimes correspond to low and high values of the threshold variable, while the critical point is located in c_1 . When $\gamma \rightarrow \infty$, the PSTR model is identical to Hansen's two-regime PTR model and the transition function switches between zero and one. For $m=2$ and $\gamma \rightarrow \infty$, the PSTR model becomes a three-regime model with identical outer regimes. The minimum value of the transition function is $(c_1 + c_2)/2$, while the maximum value of one can be reached in low and high values of the transition variable. If $\gamma \rightarrow 0$, the transition function is constant and the PSTR model becomes a linear panel model.

The impact of the regressors on the dependent variable can be captured by the estimated coefficients $\beta_{01}, \beta_{02}, \beta_{11}, \beta_{12}$. As mentioned by Fouquau *et al.* (2008), the estimated parameters have a direct interpretation only when the threshold variable tends towards the extreme regimes. For example, the estimated parameters β_{01} and β_{02} represent the REER and interest rate coefficients, respectively, only when the transition function tends towards zero. On the other hand, when the transition function tends towards unity, the REER coefficient is given by the sum of the parameters β_{01} and β_{11} , while the interest rate coefficient is given by the sum of the parameters β_{02} and β_{12} . When the transition function ranges between the bounds (*i.e.*, zero and one), the interpretation of the above parameters is not that straightforward. For example, the REER coefficient is considered as the weighted average of the parameters β_{01} and β_{11} . Similarly, the interest rate coefficient corresponds to the weighted average of the parameters β_{02} and β_{12} . However, the value of the weighted average of the parameters depends on the properties of the transition function. Since these properties are not constant, the interpretation of the values of the REER and interest rate coefficients is not clear-cut. Although we cannot interpret these values as elasticities, we can interpret the sign of the parameters, which shows the changing impact of the regressors as the threshold variable increases.

3.2 Tests for Panel Unit Root, Cross-sectional Dependence, Linearity and Cointegration

Before estimating the model described in equation (12), we test each series for unit roots. Initially, we implemented the test proposed by Levin *et al.* (2002) for common unit roots, and the test proposed by Im *et al.* (2003) for individual unit roots. Both tests test the null hypothesis of a unit root and they assume cross-sectional independence. However, when cross-sectional dependence exists the results of the above tests are no longer accurate due to inference distortions. For this reason, we also applied the Pesaran (2007) and the Palm *et al.* (2011) panel unit root tests that assume cross-sectional dependence. Again, the null hypothesis for both tests is the unit root hypothesis.

The next step is to explore if there is any evidence of nonlinearities in the possible long-run relationship among the variables. Thus, we tested the null hypothesis of linearity against a TV-PSTR model. This test addresses the same issues (*i.e.*, the presence of nuisance parameters) as in Hansen's PTR model (Hansen 1996, 1999). We follow Colletaz and Hurlin (2006) and Fouquau *et al.* (2008) and provide three alternative statistics: a Wald statistic, a Fisher statistic and a LRT statistic. The Wald and LRT statistics are distributed as $\chi^2_{(k-1)}$, while the Fisher statistic is distributed as F . As shown in section 5.2, the linearity hypothesis cannot be rejected regardless the choice of the threshold variable.

Thus, we investigate the possible existence of a linear long-run relationship among the variables of the G7 countries, by implementing a linear cointegration test. In order to choose the appropriate cointegration technique, we need to test for cross-sectional dependence. To do so, we implemented four tests: the Breusch-Pagan (1980) LM test, the Pesaran (2004) scaled LM test, the Pesaran (2004) CD test and the Baltagi *et al.* (2012) bias-corrected scaled LM test. As also shown in section 5.2, all four tests reject the null hypothesis of cross-sectional independence. Thus, cross-sectional dependence should be taken into account in our analysis.

To account for cross-sectional dependence in the context of cointegration, we implemented the Westerlund and Edgerton (2007) panel cointegration test, which modifies the residual-based LM test of McCoskey and Kao (1998). In brief, the McCoskey and Kao test assumes the following data generating process for a series $x_{i,t}$:

$$x_{i,t} = a_i + z'_{i,t} b_i + \xi_{i,t}, \quad (14)$$

where regressors $z_{i,t}$ are pure random walk processes and the error term $\xi_{i,t}$ is decomposed into $e_{i,t}$ (stationary component) and $v_{i,t} = \sum_{j=1}^t \eta_{i,j}$, where $\eta_{i,j}$ is an i.i.d. process with zero

mean and $\text{var}(\eta_{i,j}) = \sigma_i^2$. The null hypothesis of cointegration is $H_0 : \sigma_i^2 = 0$ for all i against the alternative of no cointegration that is $H_1 : \sigma_i^2 > 0$ for some i . With cross-sectional independence the cointegration hypothesis is tested using the following LM test statistic:

$$LM = \frac{1}{NT^2} \sum_{i=1}^N \sum_{t=1}^T \hat{\omega}_i^{-2} S_{i,t}^2, \quad (15)$$

where $S_{i,t}^2$ is the partial sum process of $\hat{\xi}_{i,t}$, and $\hat{\omega}_i^2$ is the estimated long-run variance of $e_{i,t}$ conditional on $\Delta z_{i,t}$. Also, it holds that $\sqrt{N} (LM - E(LM)) \sim N(0, \text{var}(LM))$. To deal with cross-sectional dependence, Westerlund and Edgerton (2007) suggest bootstrapping. This requires the computation of the empirical distribution. Assuming an $AR(\infty)$ representation for the residuals and using $e_{i,t}$ and $\Delta z_{i,t}'$ (stationary by definition), they define the vector $w = (e_{i,t}, \Delta z_{i,t}')'$. Thus, the infinite autoregressive representation is:

$$\sum_{j=0}^{\infty} \psi_{i,j} w_{i,t-j} = \varepsilon_{i,t} \quad (16)$$

where $\varepsilon_{i,t}$ is a stationary process. By approximating equation (16) with an $AR(p)$ model, a sieve bootstrap scheme is obtained and new bootstrap values for $x_{i,t}$ and $z_{i,t}$ are produced. By replicating the whole process N times and computing each time the LM test, the bootstrap distribution is obtained.

Once there is evidence of a valid cointegration relationship, the long run relationship between the variables of interest needs to be estimated. Since OLS estimators are biased as they depend on nuisance parameters, we implement the Fully-Modified OLS (FMOLS) approach in the context of panel cointegration (Phillips and Moon, 1999; Kao and Chiang, 2000; Pedroni, 2000).⁴ To choose between pooled or grouped mean estimation, we test for slope homogeneity using two tests. The first test is the modified Hausman test (Pesaran *et al.*, 1996). Under the null hypothesis of slope homogeneity, the respective statistic is distributed as $\chi_{(k)}^2$. The second test is the Δ test (Pesaran and Yamagata, 2008) and examines the cross section dispersion of individual slopes weighted by their relative precision. Its size and power

⁴ The FMOLS is a nonparametric approach that corrects for bias and endogeneity. An alternative (parametric) approach is the Dynamic OLS (DOLS). The FMOLS is superior to DOLS since the former sets fewer restrictions and tends to be more robust. Pedroni (2000) argues that the FMOLS estimator is robust even for small panels. Additionally, it should be preferred when the panel contains more than one regressor.

properties are better than those of the Hausman test, while under the null hypothesis of slope homogeneity, both $\hat{\Lambda}$ and $\tilde{\Lambda}$ -adjusted statistics are distributed normally.

4. Data Description

In our analysis, we use annual data for the gold price (P_G), the real effective exchange rate (REER), the net foreign asset position as a percentage of the GDP (NFA), the GDP differential ($y - y^*$), the nominal interest rate (i), as well as the real interest rate differential ($r - r^*$) for the G7 countries, namely Canada, France, Germany, Italy, Japan, the UK and the USA. The time span covers the period from 1980 to 2016. Annual average gold price data refer to gold fixing price 3:00 P.M. (London time) in London Bullion Market. They are expressed in USD per troy ounce and have been obtained by the Federal Reserve Bank of St. Louis. Gold price data have been transformed into natural logarithms.

REER data for all G7 countries have been obtained from the Bank for International Settlements (BIS). They are calculated as weighted averages of bilateral exchange rates (based on the narrow index of 27 countries⁵) adjusted by relative consumer prices. The weighting pattern reflects the bilateral trade between countries.⁶ As in gold price, REER data have been transformed into natural logarithms and by construction, an increase in the real effective exchange rate implies the real appreciation of the home currency.

Data for the NFA positions up to 2011 have been obtained from the updated and extended version of the dataset constructed by Lane and Milesi-Ferretti (2007).⁷ As a change in NFA equals the current account plus some valuation effects, the rest of the series has been filled by cumulating the current account (in USD) to the previous net foreign asset position. To express net foreign asset position as a share of GDP, we divide NFA by GDP in USD.

GDP differential for each of the G7 countries is constructed as the difference between home and foreign real GDP. We use real GDP per capita in USD (at constant 2010 prices), which has been obtained from the World Development Indicators of the World Bank. For each of the G7 countries, foreign real GDP is constructed as a weighted average of its trade partners' real GDP. We have used the same index of countries and weighting patterns as the

⁵ We did not use REER data based on the broad index of 61 countries because these data are available since 1994. The narrow index consists of Australia, Austria, Belgium, Canada, Chinese Taipei (Taiwan), Denmark, Euro area, Finland, France, Germany, Greece, Hong Kong, Ireland, Italy, Japan, Korea, Mexico, The Netherlands, New Zealand, Norway, Portugal, Singapore, Spain, Sweden, Switzerland, the UK and the USA.

⁶ We used bilateral trade data that are reported in the BIS. As BIS mentions, the trade weights are derived from manufacturing trade flows (SITC-rev.3 classification 5 to 8) and obtained from the UN Commodity Trade Statistics Database (UN Comtrade), OECD International Trade by Commodity Statistics and the Directorate General of Budget, Accounting and Statistics of Taiwan.

⁷ <http://www.philiplane.org/EWN.html>.

one used in the construction of REER. As in gold price and REER data, GDP differentials are expressed in natural logarithms.

Regarding nominal interest rates, we obtain 10-year government bond yields from the Eurostat for all countries except Canada. For Canada, these data have been obtained from the Statistics Canada. Finally, real interest rate differential stands for the difference between home and foreign real interest rates. Initially, we calculate each country's inflation rate from the corresponding GDP deflator, which has been obtained from the World Development Indicators of the World Bank. By subtracting each country's inflation rate from the respective 10-year government bond yield, we get the real interest rates for the G7 countries. Unlike the case of foreign real GDP, each country's foreign real interest rate cannot be calculated as a weighted average of its trade partners' real interest rates. The reason is that capital flows are not dictated by the degree of trade flows between countries. In contrast, investors compare expected yields and risk and invest in countries even if there are minimal trade flows with the home country. Thus, as foreign real interest rate we use the average (with equal weights) of the real interest rates of the G7 countries.⁸

5. Empirical Findings

5.1 Baseline Model

The estimation procedure starts with the specification of the PSTR model. We should first select the threshold variable, then test the linearity hypothesis and finally define the number of regimes. The threshold variable can be exogenously determined if there is a theoretical model that describes clearly the transition process and the variable that determines the classification of the regimes. If there is not such a theoretical indication, we consider all variables as possible threshold variables and choose this variable with the strongest rejection of the linearity hypothesis.

Although there is a theoretical background behind our baseline model, we have no clear exogenous indication about the mechanism of the transition process. Hence, we need to test the linearity hypothesis for the REER and the interest rate (i) and then choose the threshold variable. The null hypothesis of a linear process is $H_0 : \gamma = 0$ or equivalently, $H_0 : \beta_{0k} = \beta_{1k}$, where $k = 1, 2$. Due to the presence of nuisance parameters under the null hypothesis, the transition function in equation (13) is replaced by its first-order Taylor expansion. The LM_F

⁸ We use equal weights because (a) the G7 countries are advanced economies that move closely with each other, and (b) the relative economic size of each of them does not necessarily determine the amount of capital inflows and outflows.

test statistics are shown in table 1. Under both candidate variables, the linearity hypothesis is strongly rejected. However, the strongest evidence is reported when the interest rate (i) is used as a threshold variable. This implies that there is an endogenous indication that the interest rate determines the transition process of this PSTR model. Namely, the way the gold price is affected by its regressors changes as the interest rate switches between low and high values.

Since the threshold variable has been defined, we need to determine the number of the transition functions or, in other words, the number of thresholds. To do so, we follow a sequential procedure. At a first stage, we test the null hypothesis of linearity (no threshold) against the alternative that there is one threshold. As shown in table 2, the null hypothesis is strongly rejected. Next, we test the null hypothesis of one threshold against the alternative of two thresholds. The results in table 2 report that the null hypothesis cannot be rejected. This result implies that the baseline model is a two-regime PSTR model with a monotonic transition function.

As the model has been fully specified, we estimate the parameters of the model by nonlinear least squares. As shown in table 2, the slope parameter (γ), which shows the smoothness of the transition process, is equal to 2.924, while the location parameter (c) is equal to 4.089. These values imply that the transition from the bottom regime (low nominal interest rate) to the upper regime (high nominal interest rate) is quite smooth and the change in the interest rate is located around the value of 4.089. Regarding the estimated parameters $\hat{\beta}_{01}, \hat{\beta}_{02}, \hat{\beta}_{11}, \hat{\beta}_{12}$, the REER variable is shown to be statistically significant only when the transition is taken into account. The parameter $\hat{\beta}_{01}$ is found to be negative but not statistically different from zero, while the parameter $\hat{\beta}_{11}$ is negative and statistically significant. This finding would imply that the impact of the REER variable on the gold price decreases as the interest rate moves from the bottom to the upper regime. Nonetheless, the overall impact of the REER variable cannot be defined because of the insignificant parameter $\hat{\beta}_{01}$.

On the other hand, the results in table 2 indicate that the sign of the interest rate (parameter $\hat{\beta}_{02}$) is found to be negative and statistically different from zero. Namely, as the interest rate increases, investors exchange gold with higher return assets and the price of gold declines. It is really interesting to test how this impact is affected when the threshold variable ranges between the extreme regimes. The sign of the parameter $\hat{\beta}_{12}$ is found to be positive and statistically significant. Although we cannot interpret this value as elasticity, we can at

least interpret its sign. Having in mind the aforementioned negative relation between the interest rate and the gold price, the positive sign of the $\hat{\beta}_{12}$ parameter implies that the overall negative influence of the interest rate on the gold price is getting less strong as the threshold variable (*i.e.*, the interest rate) switches from the bottom to the upper regime. This means that when the interest rate is already high, investors are less willing to exchange gold with other assets even though the interest rate increases. In other words, investors are less sensitive to interest rate changes when the interest rate is high. Although the opportunity cost of holding gold rises, any further increase in the already high interest rate is associated with higher risk. Thus, investors hold gold to avoid this extra risk.

5.2 Alternative Model

Based on the theoretical considerations shown above, as well as on the inconclusive evidence regarding the effect of the REER on the gold price, we turn into the estimation of our alternative model. The main theoretical argument is that the observed exchange rate may not alone determine the relationship between the exchange rate and the price of gold. Instead, we argue that investors are influenced not only by the actual trend of the exchange rate but also by its equilibrium value. Consequently, we argue that the degree of exchange rate misalignment determines the relationship between the exchange rate and the gold price and controls the transition process of the PSTR model. Under this theoretical framework, the estimation of the alternative model entails a two-stage procedure. Firstly, we estimate the equilibrium exchange rate and the implied misalignment rate and at the second stage we test whether the above estimated series affect the price of gold.

5.2.1 Estimates of Equilibrium Real Effective Exchange Rates

Regarding the order of integration of the variables under consideration, all unit root tests (both these that assume cross-sectional independence and these that take cross-sectional dependence into account) indicate that all variables are $I(1)$, as the unit root hypothesis cannot be rejected for any variable at the 5 per cent level of significance.⁹ As noted previously, before choosing the appropriate estimation method we need to investigate if there exist any nonlinearities in the possible long-run relationship. The results for the linearity test against the nonlinear PSTR model are reported in table 3, for alternative choices of the threshold variable. As shown, the null hypothesis of linearity cannot be rejected for any threshold

⁹ For saving space, the unit root test results are not reported here but are available under request.

variable. Having established linearity in the model and before proceeding with cointegration, we also need to test for cross-sectional dependence among the variables of our model. As shown in table 4, all four tests reject the null hypothesis of cross-sectional independence. Following the above evidence, we proceed with the cointegration analysis under the presence of linearity and cross-sectional dependence. Table 5 presents the results of the Westerlund and Edgerton (2007) panel cointegration test and provide both asymptotic and bootstrap p -values. As shown, the evidence suggests the existence of a linear long-run (cointegrating) relationship among the variables under consideration.¹⁰

Then, we derive a robust FMOLS estimator for equation (12) and we get the equilibrium REER as follows:

$$\widehat{REER}_{i,t} = \hat{\delta}_{0,i} + \hat{\delta}_1 NFA_{i,t} + \hat{\delta}_2 (y_{i,t} - y_{i,t}^*) + \hat{\delta}_3 (r_{i,t} - r_{i,t}^*), \quad (17)$$

where $\widehat{REER}_{i,t}$ is the estimated equilibrium REER for country i , $\hat{\delta}_{0,i}$ stands for the estimated fixed effects for country i , while $\hat{\delta}_1, \hat{\delta}_2$ and $\hat{\delta}_3$ are the parameter estimates of the fundamentals. The pooled panel estimator has been chosen, as the null hypothesis of slope homogeneity cannot be rejected. Also, a constant and a linear trend have been included into the deterministic part of the model, based on several F -test statistics. The above results are reported in the bottom section of table 6. Finally, two dummy variables are also included in the deterministic part of the model. The first one captures the effects of the 1990-1993 period during which several important events took place, such as the German unification, the ratification of the Treaty for the European Union and the ERM crisis. The second one captures the turmoil of the global financial crisis between 2007 and 2010.

The FMOLS estimation results are reported in the upper section of table 6. As shown, all three variables are statistically significant at the 5 per cent level of significance. Thus, all three variables should be taken into account when estimating the equilibrium REER. Also, all three variables have a strong positive effect on the REER of the G7 countries. Regarding the NFA position and the real interest rate differential, these positive effects are theoretically expected. However, the positive effect of the GDP differential on the REER contradicts the standard balance of payments theory, which suggests that a higher home GDP (in relation to the foreign one) is expected to depreciate the home currency. Although our result seems to be a bit paradox, it can be sufficiently explained by fact that advanced economies have greater

¹⁰ Notice that when both intercept and trend are included, the asymptotic p -value indicates rejection of the cointegration. However, the inference based on bootstrap p -values, which account for cross-sectional dependence, implies that the cointegration hypothesis cannot be rejected no matter what deterministic components are included.

access to capital. Easier access to capital along with knowledge accumulation allows advanced economies to develop new and high quality products, stimulating their exports. This fact militates in favour of the positive relation between the REER and the GDP differential.¹¹

Once the equilibrium REER for each sample country is calculated, we construct the misalignment rate as the percentage difference between the estimated equilibrium REER and the actual REER. Positive misalignment rates correspond to currency overvaluation, while negative rates stand for currency undervaluation. The misalignment rates for the G7 countries are reported in figures 1 to 3. As shown in these figures, the misalignment rates for France, Germany and the USA are very close to zero for the whole sample period. This means that for these three countries, the actual REER is very close to its equilibrium value. For Italy and the UK, our results indicate high misalignment rates at the early 1990s, probably due to the ERM crisis. For the former country, there is also a high negative misalignment rate between 2010 and 2012, when the sovereign debt crisis in the Eurozone took place. Regarding Canada and Japan, our evidence suggests high misalignment rates during the years of the recent financial crisis. For the latter country, there is also a high positive misalignment rate in the 1990s, which can be probably attributed to the prolonged recession that the Japanese economy suffered during this decade after the collapse of the fabled economic bubble of the 1980s.

5.2.2 Alternative PSTR model

Having estimated the equilibrium exchange rate and the implied misalignment rate, we turn to the estimation of the alternative PSTR model, which can be written as follows:

$$P_{G_{j,t}} = \mu_j + \lambda_t + \beta_{01} EqREER_{j,t} + \beta_{02} i_{j,t} + (\beta_{11} EqREER_{j,t} + \beta_{12} i_{j,t}) g(q_{j,t}; \gamma, c) + u_{j,t}, \quad (18)$$

where *EqREER* stands for the estimated equilibrium real effective exchange rate. Based on the theoretical arguments that presented in section 2.2, there is a theoretical indication that the transition process may be driven by the exchange rate misalignment rate. Low misalignment rates imply that exchange rates follow an equilibrium process in consistency with overall macroeconomic stability. In contrast, high misalignment rates may cause future instability. Thus, we exogenously set the estimated misalignment rate as the threshold variable of the alternative PSTR model.

The rest of the estimation procedure is the same as in section 5.1. We test the linearity hypothesis and through a sequential approach we define the number of the thresholds (*i.e.*, the type of the transition function). The results are reported in table 7 and show that the null

¹¹ The empirical evidence of Giannellis and Koukouritakis (2018) also suggests a positive relation between the REER and the GDP differential.

hypothesis of a linear process is strongly rejected. Next, the null hypothesis of only one threshold against the alternative of two thresholds cannot be rejected. Thus, the results show that there is a nonlinear two-regime process with a monotonic transition function. The slope parameter (γ) is equal to 0.61, which implies that the transition is much smoother compared to the baseline model. Next, the estimated location parameter (c) shows that the regime change is located around the value 4.325 of the misalignment rate.

Table 7 also presents the estimated parameters $\hat{\beta}_{01}, \hat{\beta}_{02}, \hat{\beta}_{11}, \hat{\beta}_{12}$, which are all found to be statistically different from zero. Recall that we cannot consider these values as elasticities, but we can derive useful implications based on their sign. Starting from the impact of the equilibrium REER on the price of gold, the parameter $\hat{\beta}_{01}$ is found to be positive, while the estimated sign of the parameter $\hat{\beta}_{11}$ is negative. The positive sign denotes that as the equilibrium REER increases, or equivalently the currency appreciates, the gold price increases as well. This outcome implies that the income effect drives the relationship between the exchange rate and the price of gold. In other words, the appreciating trend of the exchange rate, which is consistent with equilibrium, reflects good macroeconomic performance and confidence on economy. Under these circumstances, investment in gold and in other assets increases. However, the negative sign of the parameter $\hat{\beta}_{11}$ implies that this positive impact on the gold price declines as the threshold variable switches between the extreme regimes. To put it differently, as the misalignment rate increases and moves from the low misalignment regime to the high misalignment regime, anxiety about future stability increases and the income effect is weakened. As the misalignment rate moves close to the upper regime (*i.e.*, the transition function is close to one), the substitution effect prevails. Thus, there is evidence that the gold serves as a hedge only when the exchange rate misalignment is significantly high.

Finally, the signs of the estimated parameters $\hat{\beta}_{02}$ and $\hat{\beta}_{12}$ are the same as in the baseline model. No matter the choice of the threshold variable, the relationship between the interest rate and the gold remains the same as reported in the previous model. Namely, as the interest rate increases, the opportunity cost of holding gold increases and investors exchange gold with other assets. But, when the transition function tends towards the upper regime, investors express less willingness to sell gold for higher return assets. Although the threshold variable is different, the driving force behind the transition process is quite similar. As the exchange rate misalignment increases, investors worry about future financial instability and

invest in gold to offset the increased risk. Likewise, this indicates that gold serves a hedge only when financial risk is high.¹²

6. Conclusions

In this paper we investigated the conjecture that the price of gold is affected by the internal and external macroeconomic performance of the G7 countries, namely Canada, France, Germany, Italy, Japan, the UK and the USA. This overall macroeconomic performance is proxied by the REER, which embodies the critical issue of competitiveness. However, the use of the REER may not tell the whole story. As a currency depreciates, investors prefer to invest in gold rather than in the depreciating currency. However, as a currency appreciates, investors will prefer this currency instead of gold only if this appreciating trend is consistent with equilibrium. Thus, the equilibrium values of the REERs and their implied misalignment rates have been taken into account, along with the nominal interest rates.

For estimating the equilibrium REER, we used panel cointegration techniques that have been strengthened with the theoretical assumptions of an external balance model. We also incorporated some dummy variables for capturing the effects of several important events took place during the sample period. For exploring the possibility that the impact of the equilibrium REER on the gold price may be nonlinear, we estimated a Panel Smooth Transition Regression model.

Our evidence suggests that the impact of the exchange rate on the price of gold changes as the magnitude of the misalignment rate (threshold variable) changes. For low misalignment rates, the income effect is shown to be more important, but as the misalignment rate moves close to the upper regime (*i.e.*, the transition function is close to one), the substitution effect prevails. The income effect reflects good macroeconomic performance and confidence which arise from stable and not highly misaligned currencies. As a consequence, investment in gold and in other assets increases. On the other hand, the substitution effect implies that investors avoid investing in highly misaligned currencies. In such a case, they substitute currency investment with gold investment. Regarding the relationship between the interest rate and gold, our evidence shows that when the interest rate increases normally, investors exchange gold with other assets due to the higher opportunity cost of holding gold. In contrast, when the interest rate increase is rather high (*i.e.*, the transition function tends towards the upper

¹² Under both models, financial risk is considered either as significantly high (extreme) interest rates or as significantly high (extreme) misalignment rates of the exchange rates.

regime), investors are less willing to sell gold for higher return assets. Investors worry about future financial instability and invest in gold to offset the increased risk.

The above findings provide a clear-cut answer to the main question this paper aims to answer. What should matter for investors is not just the appreciating trend of exchange rates, but whether this trend is consistent with equilibrium. If the latter is the case, economic stability is enhanced and investment in gold and other financial assets increases.

Overall, there is evidence that gold serves as a hedge only in periods of economic turmoil, which, however, may be harmful for several economies. This implies that domestic authorities (*i.e.*, central banks and governments) should implement suitable monetary and fiscal policies in order to prevent high misalignment rates for their currencies, especially in periods of economic and financial instability.

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Table 1: PSTR (basic model): choosing the threshold variable

<i>Null hypothesis</i>	<i>Threshold: REER</i>	<i>Threshold: i</i>
	<i>LM_F statistic</i>	<i>LM_F statistic</i>
Linearity	7.867* (0.00)	47.658* (0.00)

Notes: Numbers in parentheses are *p*-values. * denotes rejection of the linearity hypothesis at the 5% level of significance.

Table 2: PSTR estimation: basic model (actual REER)

<i>Estimated slope parameters of transition functions</i>	
Parameter β_{01}	-0.232 (-0.88)
Parameter β_{02}	-0.081** (-11.69)
Parameter β_{11}	-0.295* (-1.80)
Parameter β_{12}	0.096* (2.29)
<i>Specification of the model</i>	
Threshold variable	Interest rate (<i>i</i>)
Number of Regimes	2 regimes (1 threshold)
Location parameter (<i>c</i>)	4.089
Slope Parameter (γ)	2.924
<i>Linearity tests (LM_F statistics)</i>	
Linear model against one threshold	47.658* [0.00]
One threshold against two thresholds	1.269 [0.283]

Notes: Numbers in parentheses are *t*-statistics, which have been calculated based on standard errors corrected for heteroscedasticity. Numbers in brackets are *p*-values. 3. **(*) denotes rejection of the null hypothesis at the 5% (10%) level of significance. The number of regimes (thresholds) is determined by the procedure shown in the linearity tests.

Table 3: Linearity tests

Threshold variable: <i>NFA</i>	Wald test	1.155 (0.56)
	Fisher test	0.560 (0.57)
	LRT test	1.157 (0.56)
Threshold variable: $y - y^*$	Wald test	1.245 (0.54)
	Fisher test	0.604 (0.55)
	LRT test	1.248 (0.54)
Threshold variable: $r - r^*$	Wald test	0.026 (0.99)
	Fisher test	0.013 (0.99)
	LRT test	0.026 (0.99)

Notes: The null hypothesis of linearity is tested against the nonlinear PSTR model. The test is performed for alternative choices of the threshold variable. Numbers in parentheses are *p*-values.

Table 4: Cross-sectional dependence tests

Breusch-Pagan (1980) LM test	100.07* (0.00)
Pesaran (2004) scaled LM test	12.20* (0.00)
Pesaran (2004) CD test	-2.02* (0.04)
Baltagi <i>et al.</i> (2012) bias-corrected scaled LM test	12.10* (0.00)

Notes: Numbers in parentheses are p -values. * denotes rejection of the null hypothesis of independence at the 5% level of significance.

Table 5: Westerlund and Edgerton (2007) panel cointegration test

Intercept	Intercept and trend
0.406	1.823
(0.34)	(0.03)
[0.98]	[0.50]

Notes: The Westerlund and Edgerton test tests the null hypothesis of cointegration against the alternative of no cointegration. Numbers in parentheses are asymptotic p -values. Numbers in brackets are bootstrapped p -values (using 10,000 replications).

Table 6: FMOLS estimation results, tests for deterministic and slope homogeneity tests

<u>FMOLS estimation results</u>	
NFA	0.054 (0.00)
$y - y^*$	0.486 (0.00)
$r - r^*$	0.128 (0.02)
<u>Slope homogeneity tests</u>	
Pesaran <i>et al.</i> (1996) modified Hausman test	3.3895 (0.335)
Pesaran and Yamagata (2008) $\hat{\Delta}$ test	-1.890 (0.97)
Pesaran and Yamagata (2008) $\tilde{\Delta}$ -adjusted test	-2.028 (0.98)
<u>Tests for deterministic</u>	
F test (R: constant, UNR: linear trend)	26.3916* (0.000)
F test (R: linear trend, UNR: quadratic trend)	1.6336 (0.211)

Notes: R is for restricted model and UNR is for unrestricted model. Numbers in parentheses are p -values. * denotes statistical significance at the 5% level of significance.

Table 7: PSTR estimation: alternative model (equilibrium REER)

<i>Estimated slope parameters of transition functions</i>	
Parameter β_{01}	0.615* (2.43)
Parameter β_{02}	-0.116* (-10.75)
Parameter β_{11}	-0.099* (-1.97)
Parameter β_{12}	0.119* (5.13)
<i>Specification of the model</i>	
Threshold variable	Misalignment rate
Number of Regimes	2 regimes (1 threshold)
Location parameter (c)	4.325
Slope Parameter (γ)	0.610
<i>Linearity tests (LM_F statistics)</i>	
Linear model against one threshold	6.862* [0.00]
One threshold against two thresholds	0.597 [0.55]

Notes: Numbers in parentheses are t -statistics, which have been calculated based on standard errors corrected for heteroscedasticity. Numbers in brackets are p -values. 3. * denotes rejection of the null hypothesis at the 5% level of significance. The number of regimes (thresholds) is determined by the procedure shown in the linearity tests.

Figure 1: Misalignment rates for the Eurozone countries

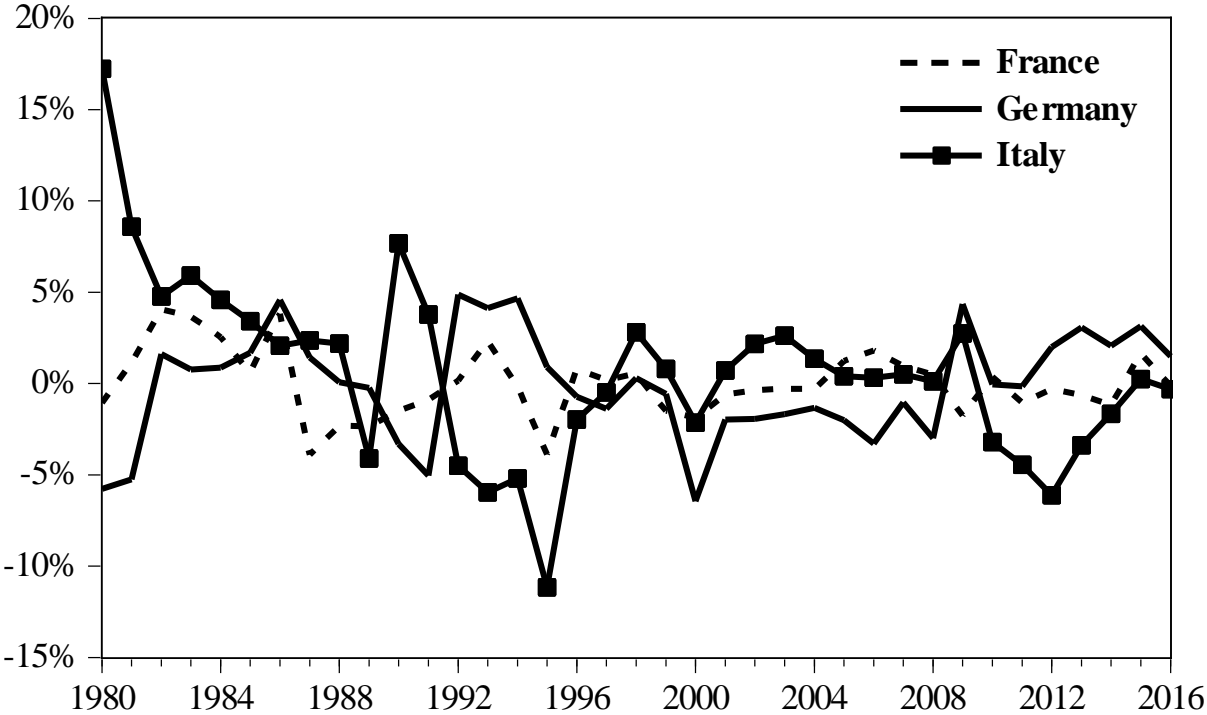


Figure 2: Misalignment rates for the UK and the USA

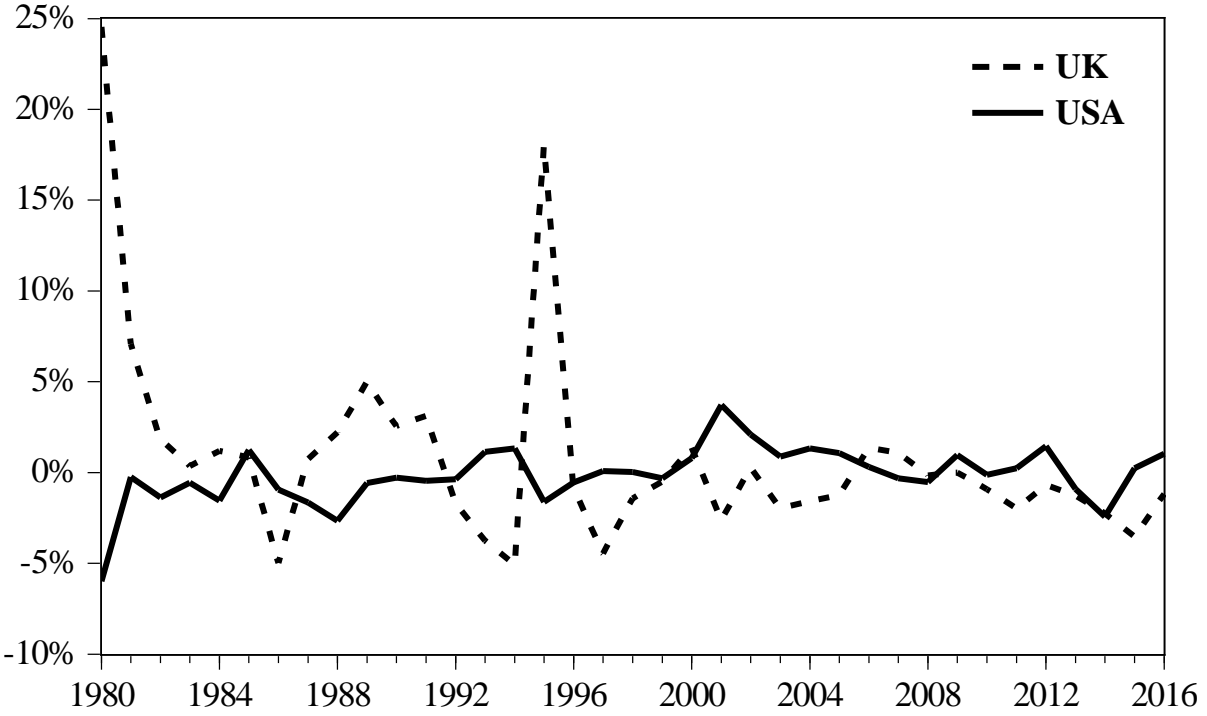


Figure 3: Misalignment rates for Canada and Japan

