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Are there Bubbles in Exchange Rates?
Some New Evidence from G10 and Emerging Markets Countries

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Abstract

We apply the generalized sup ADF (GSADF), unit root tests of Phillips, Shi and Yu (2015b, PSY) to investigate exchange rate bubbles in some G10, Asian and BRICS countries between March 1991 and December 2014. We present results based upon tests of the unit root null with and without an intercept. We show, with an intercept, that we can identify equivalent periods of collapse episodes, collapse and recovery episodes and bubbles. Whereas without an intercept in the null leads to identification of bubbles (if they exist) but sometimes are spurious. We test for bubbles in the nominal exchange rate. Bubbles are then tested whether they are driven by either exchange rate fundamentals (the relative price of traded or non-traded goods) or rational bubbles. Of particular interest is that we conclude that the US Dollar-Mexican Peso crisis of 1994-95 was a bubble.

Keywords

bubbles
rational bubbles
GSADF test
G10 countries
emerging markets countries

JEL Classifications

C12, C15, F31

1. Introduction

Despite theoretical arguments against the existence of bubbles for finitely lived assets in rational markets, experiences from the Global Financial Crisis have once again put the possibility that bubbles exist, at least empirically, back into the spotlight where a simple and straightforward definition of a bubble is a deviation of the market price from (the asset's) fundamental value. Much of this recent interest in bubbles has focused on housing markets (see e.g., Phillips & Yu (2011), Homm & Breitung (2012), Phillips, Shi & Yu (2014), Greenaway-McGrevy & Phillips (2015), Pavlidis et al. (2015), Shi et al. (2015)) and has been invigorated by recent developments in right-tailed only unit root tests (e.g., Phillips, Wu & Yu (2011), Phillips, Shi & Yu (2015a), Phillips, Shi & Yu (2015b)). In two recent papers (Bettendorf & Chen (2013) and Jiang et al. (2015)), the authors tested for the existence of bubbles in the Sterling-US Dollar and Chinese RMB-US Dollar exchange rates, respectively. Their results suggest that the explosiveness identified in the nominal exchange rate is likely driven by either exchange rate fundamentals (the relative prices of traded goods or nontraded goods) or the formation of rational bubbles [1].

These two papers are some of the latest in a long line of papers that have tested for the existence of exchange rate bubbles see for example, Huang (1981), Evans (1986), West (1987), Kearney & MacDonald (1990), Wu (1995), Van Norden (1996), Chan et al. (2003), Jarrow & Protter (2011), Mark & Sul (2001), Ferreira (2006), Torres (2007), Maldonado et al. (2012).

This paper has three main aims and contributions. Firstly, we apply the generalized sup ADF (GSADF) test of Phillips, Shi & Yu (2015b, PSY) to investigate the presence of exchange rate bubbles in a wide range of countries in particular some G10 and a range of emerging markets countries (including some Asian and the BRICS). This allows us to consider whether exchange rate bubbles might be more likely to arise in certain countries (perhaps those with less well developed trading relationships or those where governments retain a role in trading behavior), rather than in the highly developed countries of for example, the UK and US. The second aim is to study the importance of model formulation issues highlighted by Phillips, Shi & Yu (2014) in right-tailed unit root tests. In particular, the model specification for constructing the null hypothesis with/without an intercept is considered. By comparing two model formulations, our results show the inclusion of the intercept term for model specification under the null hypothesis affects the theory and date-stamping strategy of the PSY approach. This also allows us to show, quite clearly, situations where the typical use of the PSY

[1] Diba & Grossman (1988) defined a rational bubble as a belief that an asset's price depends on a variable (variables) which is not relevant to the fundamentals.

approach fails to distinguish (without further analysis) periods of collapse from periods of recovery, where it is only the former case that relates to the growth and ultimate collapse of a bubble. Thirdly, we examine not only the evidence of explosive behaviour in *nominal exchange rates*, but also explosive behavior in *exchange rate fundamentals* to explore the possible causes of the explosiveness.

The remainder of the paper is organized as follows. Section 2 provides a review of the theory of the role of fundamentals in determining the nominal exchange rate and Section 3 provides a brief description of the GSADF and SADF tests of Phillips, Shi & Yu (2015b) and Phillips, Wu & Yu (2011). Section 4 describes the data. Section 5 provides empirical results for G10 and emerging markets countries and Section 6 concludes.

2. Exchange rates: Theoretical background

The economic fundamental for the nominal exchange rate is the price differential:

$$f_t = p_t - p_t^*, \tag{1}$$

where p_t denotes the log level of the domestic price index. Asterisks denote foreign counterparts. To decompose the price index into indexes of nontraded and traded goods, Engel (1999) considers a price index for a country as a weighted average of traded and nontraded goods

$$p_t = (1-\alpha)p_t^T + \alpha p_t^N. \tag{2}$$

where p_t^T denotes the log of the traded goods price index and p_t^N the log of the nontraded goods price index and α the share of the nontraded goods component. For the foreign country, one can write:

$$p_t^* = (1-\beta)p_t^{T*} + \beta p_t^{N*}. \tag{3}$$

It follows that the price differential (f_t) can be decomposed into two components, the traded goods component (f_t^T), and the nontraded goods component (f_t^N):

$$p_t - p_t^* = (p_t^T - p_t^{T*}) + \alpha(p_t^N - p_t^T) - \beta(p_t^{N*} - p_t^{T*}). \tag{4}$$

The producer price index (PPI) is the most broadly available and frequently used index to represent the price level of traded goods. Though there are some producer goods that are not traded, PPI is measured from the production side and thus excludes marketing and other nontraded consumer services. Thus we construct the traded goods component using the PPI following Engel (1999):

$$f_t^T = \ln(PPI_t) - \ln(PPI_t^*). \tag{5}$$

The relative nontraded goods component is constructed from the aggregate consumer price indices (CPI) relative to aggregate PPI:

$$f_t^N = \ln(CPI_t) - \ln(PPI_t) - (\ln(CPI_t^*) - \ln(PPI_t^*)). \tag{6}$$

3. Method

Phillips, Wu & Yu (2011) proposed a sup ADF (SADF) test based procedure that can test for evidence of price exuberance and date stamp its origination and collapse. Such a test procedure makes use of a right-tailed unit root and a sup test in a recursive way. One highlight of this new approach is the ability to capture explosive behavior and even the periodically collapsing bubbles of Evans (1991). The SADF test is recursively applied to the sample data and is implemented as follows. For each time series x_t, we apply the Augmented Dickey-Fuller (ADF) test for a unit root against the alternative of an explosive root (right-tailed). The following autoregressive specification for x_t is estimated by least squares:

$$x_t = \mu_x + \delta x_{t-1} + \sum_{j=1}^{J} \phi_j \Delta x_{t-j} + \varepsilon_{x,t}, \qquad \varepsilon_{x,t} \sim \text{NID}(0, \sigma_x^2), \tag{7}$$

for some given value of the lag parameter J, where NID denotes independent and normally distributed. The null hypothesis of this test is $H_0 : \delta = 1$ and the alternative hypothesis is $H_1 : \delta > 1$. Equation (7) is estimated repeatedly using subsets of the sample data incremented by one additional observation at each pass in the forward recursive regression. Thus the SADF test is constructed by repeatedly estimating the ADF test. Let r_w be the window size of the regression. The window size r_w expands from r_0 to 1, where r_0 is the smallest sample window width fraction and 1 is the largest window fraction (the full sample). The starting point r_1 is fixed at 0, and the end point of each sample (r_2) equals r_w and changes from r_0 to 1. The ADF statistic for a sample that runs from 0 to r_2 is therefore denoted by $ADF_0^{r_2}$. The SADF statistic is defined as the sup value of the ADF statistic sequence:

$$SADF(r_0) = \sup_{r_2 \in [r_0, 1]} ADF_0^{r_2}$$

Unlike the SADF test, the GSADF test is extended by using a more flexible window size. The end point r_2 varies from r_0 (the minimum window size) to 1. The start point r_1 is also allowed to vary from 0 to $r_2 - r_0$. The GSADF statistic is the largest ADF statistic over range of r_1 and r_2. The key difference between the SADF and GSADF is the window size of starting point r_1. The GSADF statistic is therefore defined as:

$$GSADF(r_0) = \sup_{\substack{r_2 \in [r_0, 1] \\ r_1 \in [0, r_2 - r_0]}} ADF_{r_1}^{r_2}$$

In general, a number of factors can affect the bubble detection results for example, the full sample/subsample, the minimum window size r_0, the lag length, and model specification under the null hypothesis. Firstly, the bubble detection results may differ if the GSADF test is applied to a subsample of (truncated) data rather than the full sample. This phenomenon is more obvious for the SADF test. Secondly, as stated in Phillips, Shi & Yu (2015b), the asymptotic GSADF distribution depends on the smallest window size r_0. The minimum window size r_0 needs to be large enough to allow initial estimation, but it should not be too large to miss the chance of detecting an early bubble period. We therefore follow Phillips, Shi & Yu (2015b) and let $r_0 = 0.01 + 1.8/\sqrt{T}$, where T is number of observation [2]. They recommend this rule for empirical use as it provides satisfactory size and power performance. Thirdly, the choice of the lag length is also crucial. If the lag order is over-specified, then the size distortion would be more severe for the GSADF test than the SADF test. A small fixed lag order approach is used in this study as suggested by Phillips, Shi & Yu (2015b). The finite critical values are obtained from Monte Carlo simulation with 2000 replications. Finally, the model specification under the null hypothesis plays an important role in assessing the evidence of bubbles. Phillips, Shi & Yu (2014) have investigated different formulations of the null and alternative hypothesis in the right-tailed unit root test of Phillips, Wu & Yu (2011). These formulations use various specifications of the regression models (e.g., with/without a intercept or with/without a trend) for constructing the empirical tests to assess the evidence of explosiveness. Model specification was shown to affect both the finite sample and the asymptotic distributions and they suggested an empirical model specification with an intercept only for practical use. The model specification issue is not discussed in either Bettendorf & Chen (2013) or Jiang et al. (2015).

A number of studies have followed Phillips, Shi & Yu (2014)'s suggestion to include an intercept in the right-tailed unit root test. Hence, many empirical papers have reported rejections of the null suggesting periods of rapid increase in prices associated with a growing bubble, when in fact the data identifies a 'collapse' or a 'collapse and recovery' phase and not a bubble. Visual inspection can usually resolve these cases, although it also seems that false (positive) bubbles also seem to be reported when an intercept is included. An example of 'collapse episode' and 'collapse and recovery episode' can be seen in Figure 1 below. The backward SADF statistic (blue line) and its 95% critical value (red line) for Figure 1a suggests a number of 'bubbles' as the test statistic exceeds the relevant critical value. However, the plot of the actual data (green line) shows that the data is continuously declining (a collapse period and not a series of bubbles). Figure 1b presents data and test results consistent that relate to a 'collapse and recovery' episode and a genuine 'bubble'. In this paper, we consider two different model specifications for the null hypothesis in the right-tailed unit root tests (a model without an intercept [3] as in Equation (8) and a model with an intercept in Equation (9)) to explore the evidence of bubbles and compare the results obtained from both formulations. The model specification

[2] We use this rule for choosing r_0 for most exchange rates except the US Dollar against the Mexican Peso.

[3] When an intercept is excluded, the procedure detects only 'bubbles'.

(a) Collapse episode (b) Collapse and recovery episode and bubble

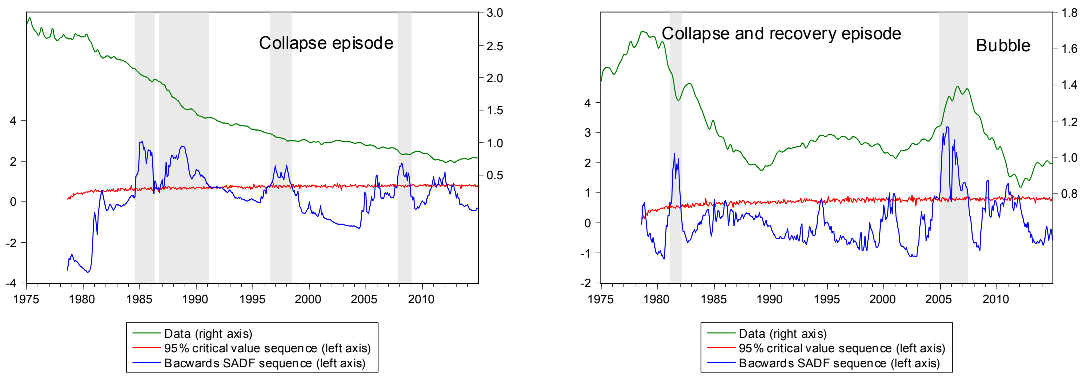


Figure 1: Examples of collapse episode, collapse and recovery episode and bubble.

is explained as follows. In PWY of Phillips, Wu & Yu (2011), the null hypothesis is:

$$H_{01} : y_t = y_{t+1} + \varepsilon_t, \qquad \varepsilon_{x,t} \sim \text{NID}(0, \sigma^2). \tag{8}$$

The second specification for the null is obtained from Diba & Grossman (1988):

$$H_{02} : y_t = \alpha + y_{t+1} + \varepsilon_t, \qquad \text{where } \alpha \text{ is the constant.} \tag{9}$$

4. Data

The time series of the exchange rate are from Quandl (`https://www.quandl.com/`) and the IMF International Financial Statistics. Following the work of Bettendorf & Chen (2013) and Jiang et al. (2015), the time series of the consumer price index (CPI) and producer price index (PPI) are obtained from the IMF International Financial Statistics and used for constructing the fundamentals of the exchange rates. The monthly sample data used for our analysis are from March 1991 to December 2014[4]. All series have been transformed into logarithms.

5. Results

We present our results in four sections. Section 5.1, Section 5.2, Section 5.3, Section 5.4 provide the empirical results for G10, Asian, BRICS and other emerging markets countries, respectively.

[4]The modern Brazilian Real was introduced in 1994. The sample data for Brazil from June 1994 to December 2014 is used for our analysis. The data for Mexico and the Philippines ranges from January 1993 to December 2014.

5.1. *Results for G10 Countries*

We firstly test for the existence of exchange rate bubbles in the following G10 currencies (e.g., British Pound (GBP), Canada Dollar (CAD), Japanese Yen (JPY), Norwegian Krone (NOK), Swedish Krona (SEK), Swiss Franc (CHF)). Results for the nominal exchange rate s_t are presented in Table 1, Table 2 and Table 3 using different model specifications (with/without an intercept) under the null hypothesis [5]. Under the model specification 'without an intercept', no strong evidence of explosiveness is detected in these currency pairs. If the model specification allows an intercept term, we do not find significant evidence of explosive behavior in these currencies except for the Sterling-Swiss Franc (GBP/CHF) and Sterling-Japanese Yen (GBP/JPY) based on the test statistic. We therefore only discuss the bubble-detection results for these two exchange rates.

5.1.1. *GBP/CHF*

The left panel of Figure 2 compares the backward SADF statistic with the 95% critical value sequences for nominal exchange rate s_t, the relative ratio of the exchange rate to the traded goods fundamental $s_t - f_t^T$ and the relative ratio of the exchange rate to the non-traded goods fundamental $s_t - f_t^N$ using a model specification with an intercept for assessing the evidence of bubbles, respectively. The right panel of Figure 2 presents the bubble detection results for s_t, $s_t - f_t^T$ and $s_t - f_t^N$ using a model specification without an intercept. Table 1 suggests the existence of explosive behavior in the nominal exchange rate s_t at the 1% significance level, which indicates the existence of explosive subperiods. Figure 2a compares the backward SADF statistic with 95% critical value sequences for the nominal exchange rate. The backward SADF statistic sequences indicate the presence of multiple episodes including 1995M05-1995M07, 2008M02-2008M04, 2008M09-2009M01 and 2011M05-2011M08, and most of these episodes are just 'collapse' episodes.

Figure 2c and Figure 2e display the backward SADF statistic sequences for the nominal exchange rate to relative prices of traded goods fundamentals $s_t - f_t^T$ and relative prices of non-traded goods fundamentals $s_t - f_t^N$, respectively. We find a 'collapse and recovery' episode between 2008M09 and 2009M01 in both Figure 2c and Figure 2e. In addition, a 'collapse and recovery' episode from 2011M04 to 2011M09 and a 'collapse' episode from 1995M02 to 1996M01 are also identified in Figure 2e. On a close inspection of the date-stamping outcomes using a model specification with an intercept, we find little evidence of bubble. One of the take home messages is that the rejection of the null hypothesis

[5] The critical values for the null hypothesis with an intercept: 1.8569 (90%), 2.0977 (95%), 2.6217 (99%). The critical values for the null hypothesis without an intercept: 3.1247 (90%), 3.5343 (95%), 4.2359 (99%). When the intercept term is added, the critical values get larger.

Table 1: The GSADF test for exchange rate in G10 countries.

Exchange rate	Test Stat under H_0 with an intercept	Bubble Episodes	Test Stat under H_0 without an intercept	Bubble Episodes
GBP/CAD				
s_t	1.9283* [a]	13M12-14M05	1.9787	
$s_t - f_t^N$	1.8906*	13M12-14M05	2.1902	98M07-99M01, 14M01-14M04
$s_t - f_t$	1.7400	13M12-14M03	2.0057	
GBP/CHF				
s_t	2.9084*** [b]	95M05-95M07, 08M02-08M04	2.0548	97M11-98M04
		08M09-09M01, 11M05-11M08		
$s_t - f_t^N$	2.3762** [c]	95M02-96M01, 08M09-09M01	2.0789	07M05-07M08
		11M04-11M09		
$s_t - f_t$	2.6425***	96M10-97M08, 08M11-09M01	2.6425	97M11-98M07, 99M10-00M05
GBP/JPY				
s_t	3.0534***	08M10-09M03	3.0184	97M10-98M09, 07M05-07M07
		13M11-14M01		14M04-14M12
$s_t - f_t^N$	2.5985**	06M12-07M02, 07M04-07M07	3.0699	97M11-98M10, 06M10-07M11
		08M10-09M03, 13M11-14M01		14M04-14M12
$s_t - f_t$	2.8423***	96M10-97M04, 98M03-98M09	3.3178*	96M10-97M05, 97M10-98M10
		08M09-09M02, 13M11-13M12		06M12-07M10, 14M04-14M12
GBP/NOK				
s_t	1.2835	97M05-97M08	1.9141	
$s_t - f_t^N$	0.9729	97M06-97M08	2.1358	00M08-00M11
$s_t - f_t$	1.3922	97M06-97M08, 08M04-08M09	2.2619	
		10M01-12M04		

[a] * indicates significance at 10% level.
[b] *** indicates significance at 1% level.
[c] ** indicates significance at 5% level.

Table 2: The GSADF test for exchange rate in G10 countries.

Exchange rate	Test Stat under H_0 with an intercept	Bubble Episodes	Test Stat under H_0 without an intercept	Bubble Episodes
GBP/SEK				
s_t	1.1704	95M10-95M11, 08M02-08M04	2.2646	98M06-98M12, 99M03-99M06
				99M01-00M04, 00M08-02M04
$s_t - f_t^N$	0.5572		2.6073	98M07-98M12, 99M11-02M10
$s_t - f_t$	1.6099	95M10-95M11	2.6115	98M05-00M01
CAD/JPY				
s_t	0.6021		2.3830	97M11-98M09, 07M04-07M11
$s_t - f_t^N$	0.8551	94M02-94M08, 95M02-95M06	2.6121	97M12-98M08, 05M10-08M01
$s_t - f_t$	0.6871		2.6392	97M11-98M09, 05M09-07M12
CAD/NOK				
s_t	1.6490	02M07-03M01	1.9936	
$s_t - f_t^N$	1.0078	00M08-00M10	2.1232	
$s_t - f_t$	1.0078		1.5926	
CAD/SEK				
s_t	0.5654		2.3567	01M05-01M08
$s_t - f_t^N$	0.8100		2.6194	01M02-02M01
$s_t - f_t$	0.1236		1.9971	01M05-01M07
CHF/CAD				
s_t	0.4434		0.9985	
$s_t - f_t^N$	0.8767	95M01-95M07	1.2186	
$s_t - f_t$	0.4805		0.5891	

Table 3: The GSADF test for exchange rate in G10 countries.

Exchange rate	Test Stat under H_0 with an intercept	Bubble Episodes	Test Stat under H_0 without an intercept	Bubble Episodes
CHF/JPY				
s_t	0.5931		2.2867	03M03-03M07, 06M11-08M08
$s_t - f_t^N$	0.3783		2.3967	03M03-03M07, 06M04-08M09
$s_t - f_t$	0.7452		2.5739	02M12-03M09, 06M06-08M08
CHF/NOK				
s_t	1.5892	96M12-97M03	2.5214	94M07-96M09
$s_t - f_t^N$	1.3422	93M11-94M03, 95M02-95M05 10M11-12M04	3.1743* [a]	94M07-96M10, 10M11-12M11 13M06-14M12
$s_t - f_t$	3.0592*** [b]	96M10-97M04	2.0150	94M06-96M01
CHF/SEK				
s_t	1.8713*	93M11-94M01, 01M08-01M11 08M11-09M03	2.6662	93M11-95M10
$s_t - f_t^N$	1.8988*	93M11-94M03, 95M02-95M06 01M09-01M10, 08M11-09M03	3.0832	93M11-96M05, 00M08-03M05 05M04-06M09, 08M09-12M06
$s_t - f_t$	1.0940	08M11-08M12	1.7937	95M02-95M05
NOK/JPY				
s_t	1.0718	08M11-09M01	2.4754	02M11-03M07, 07M01-07M11
$s_t - f_t^N$	1.2103	08M10-09M01	1.7607	
$s_t - f_t$	1.0280	96M09-97M02, 08M04-08M09	2.8433	96M05-97M03, 02M12-03M03 05M03-08M09
NOK/SEK				
s_t	0.5022		1.9339	
$s_t - f_t^N$	0.6544		1.7466	
$s_t - f_t$	0.4901		1.6884	

[a] * indicates significance at 10% level.
[b] *** indicates significance at 1% level.

under the assumption 'with an intercept' in the PSY approach could lead to false positive identification of bubbles. In this example, the PSY approach identifies several 'collapse' episodes but not bubbles.

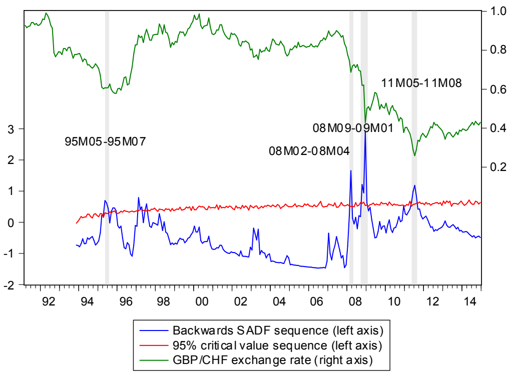
However, under the null hypothesis without an intercept term, we find no significant evidence of explosiveness in all three series (s_t, $s_t - f_t^T$ and $s_t - f_t^N$) as the null hypothesis of explosive behavior cannot be rejected at the 10% significance level. Moreover, the backward SADF statistic sequences no longer detect the 'collapse and recovery' episode in 2008-2009. These results suggest that the intercept term can potentially affect the asymptotic distributions of the PSY approach.

5.1.2. GBP/JPY

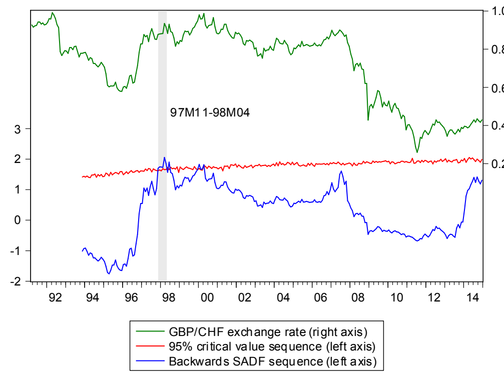
Under the null hypothesis 'with an intercept', Table 1 provides strong evidence of explosive behavior in the nominal exchange rate s_t for GBP/JPY at the 1% significance level. As shown in Figure 3a, there is an episode between 2008M10 and 2009M03 in the nominal exchange rate s_t and the nominal exchange rate s_t remains explosive if exchange rate fundamentals are accounted for. If we look at all three series (s_t, $s_t - f_t^T$ and $s_t - f_t^N$) in Figure 3a, Figure 3c and Figure 3e, all three series are declining and then recovering between 2008M10 and 2009M03 and rather than growing are collapsing. We may regard this special type of episodes as a 'collapse and recovery' episode but not a bubble. There is a short-lived bubble during 2013M11-2014M01 in Figure 3a. Both the relative prices of traded goods f_t^T and the relative prices of non-traded goods f_t^N play no role in explaining the explosiveness, suggesting evidence of rational bubbles during this period. Overall, there is no significant evidence of bubbles in the nominal exchange rate although the test statistic suggests explosive bubble-like behaviors.

By comparing the left panel of Figure 3 and right panel of Figure 3, we obtain different date-stamping strategies for GBP/JPY using the two model specifications. Under the model specification of the null hypothesis 'without an intercept', the null hypothesis of no explosive behavior cannot be rejected at the 10% significance level for s_t and $s_t - f_t^N$ while the null hypothesis of no explosive behavior in $s_t - f_t^T$ is rejected at the 10% level. Three episodes have been identified from s_t in Figure 3b: 1997M10-1998M09, 2007M05-2007M07 and 2014M04-2014M12. All episodes identified from the right panel of Figure 3 correspond to a 'genuine' bubble. The episode between 2014M04 and 2014M12 suggests that the GBP/JPY exchange rate is experiencing a bubble. The nominal exchange rate series remains explosive after both traded and non-traded goods components are taken into account in Figure 3d and Figure 3f. We do not detect the 'collapse and recovery' type of episodes between 2008M10 and 2009M03. Our findings indicate some evidence of rational bubbles in the nominal exchange rate as they are not explained by exchange rate fundamentals.

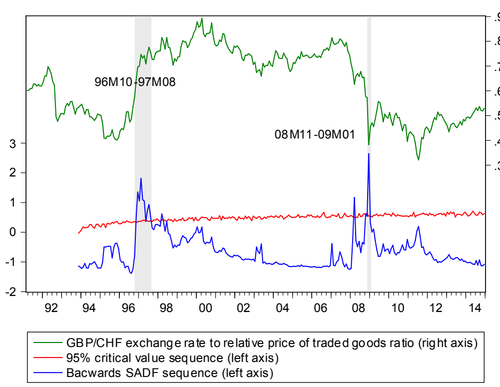
(a) GBP/CHF s_t with an intercept



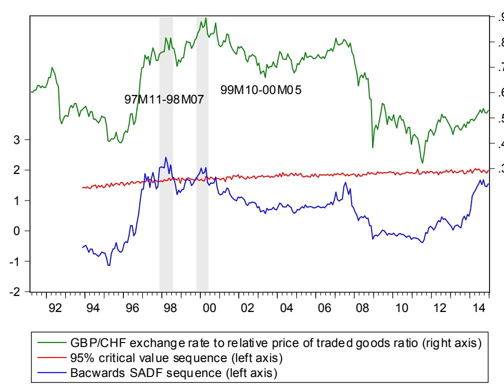
(b) GBP/CHF s_t without an intercept



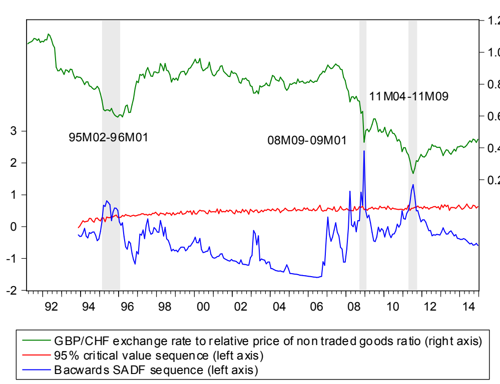
(c) GBP/CHF $s_t - f_t^T$ with an intercept



(d) GBP/CHF $s_t - f_t^T$ without an intercept



(e) GBP/CHF $s_t - f_t^N$ with an intercept



(f) GBP/CHF $s_t - f_t^N$ without an intercept

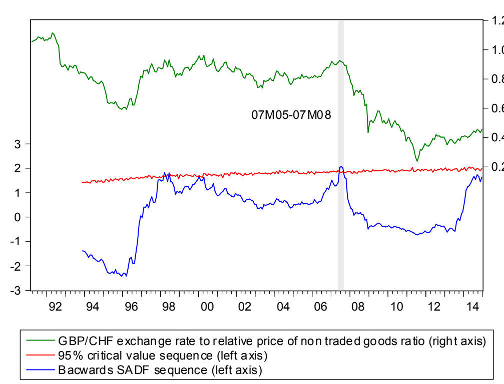
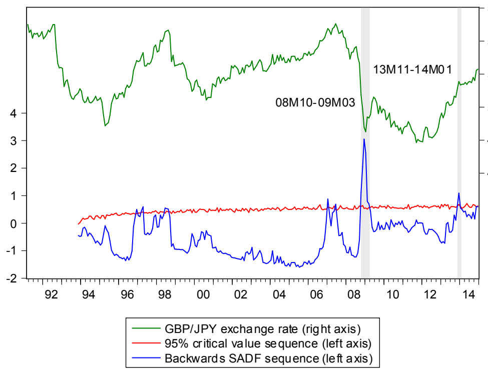
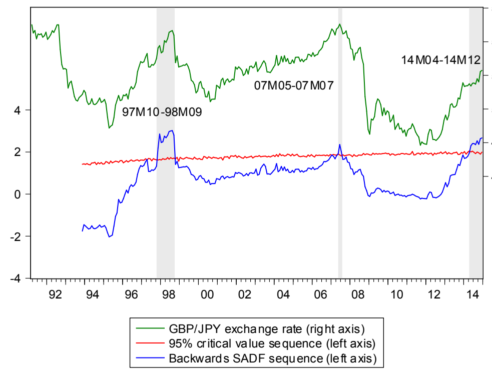


Figure 2: Dating strategy for GBP/CHF nominal exchange rate s_t, the relative ratio of the exchange rate to the traded goods fundamental $s_t - f_t^T$ and the relative ratio of the exchange rate to the non-traded goods fundamental $s_t - f_t^N$.

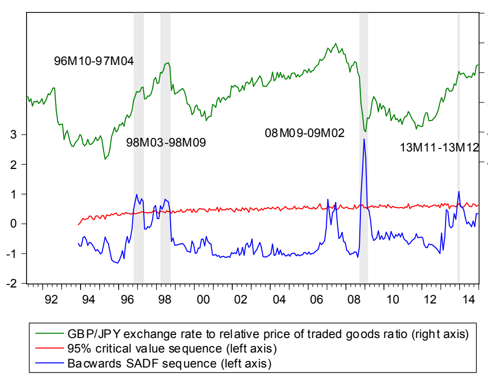
(a) GBP/JPY s_t with an intercept



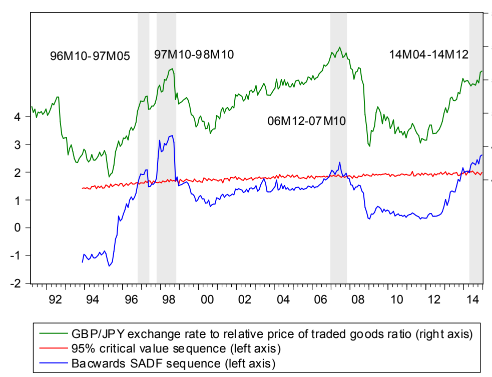
(b) GBP/JPY s_t without an intercept



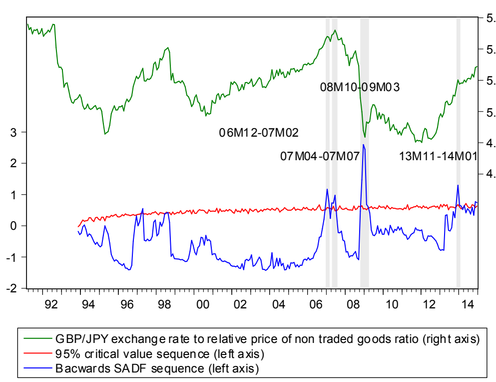
(c) GBP/JPY $s_t - f_t^T$ with an intercept



(d) GBP/JPY $s_t - f_t^T$ without an intercept



(e) GBP/JPY $s_t - f_t^N$ with an intercept



(f) GBP/JPY $s_t - f_t^N$ without an intercept

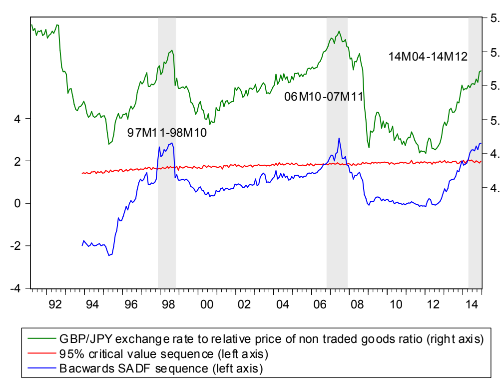


Figure 3: Dating strategy for GBP/JPY nominal exchange rate s_t, the relative ratio of the exchange rate to the traded goods fundamental $s_t - f_t^T$ and the relative ratio of the exchange rate to the non-traded goods fundamental $s_t - f_t^N$.

5.2. Results for Asian Countries

In this section, we consider the existence of exchange rate bubbles in several Asian currencies with particular interest in the 1997 Asian Financial Crisis period. We also consider several emerging market exchange rates in Asia against the US Dollar including the Indonesian Rupiah (IDR), Korean Won (KRW), Malaysian Ringgit (MYR), Philippine Peso (PHP), Singapore Dollar (SGD) and Thai Baht (THR). The 1997 Asian Financial Crisis originated in Thailand in July 1997 when the Thai baht was allowed to float and soon spread to most Southeast Asian countries including Indonesia, Malaysia, the Philippines, Singapore and South Korea.

5.2.1. Thai Baht (THB)

The Baht was pegged at 25 to the US Dollar between 1986 and 1995. In May 1997, a major speculative attack took place against the Baht. Due to the lack of foreign currency to defend the currency, the Thai government was forced to float against US Dollar in July 1997. The Baht depreciated to 55 to the US Dollar by the end of January of 1998 losing more than 50% of its value.

According to Table 4, the null hypothesis of no explosive behavior for s_t is rejected at the 1% significance level under the assumption of model specification with an intercept. From Figure 4a, there is a bubble during 1997M07-1998M02 and a 'collapse and recovery' episode in 2008 in the nominal exchange rate. However, the explosiveness in 1997-1998 is driven by neither the relative prices of traded goods nor non-traded goods. The exchange rate remains explosive even if the relative prices of traded goods f_t^T and the relative prices of non-traded goods f_t^N are considered in Figure 4c and Figure 4e, respectively. We therefore conclude that neither the relative prices of traded goods nor non-traded goods could explain the explosiveness during 1997-1998 in the Dollar-baht exchange rate s_t, which suggest the existence of rational bubbles. A 'collapse and recovery' episode in 2008 can be found in the left panel of Figure 4, which is likely related with the Global Financial Crisis (GFC). An additional 'collapse and recovery' episode is observed during 2010 in Figure 4c.

The right panel of Figure 4 provides the date-stamping strategy under the model specification without an intercept. All three series (s_t, $s_t - f_t^T$ and $s_t - f_t^N$) are no longer explosive as the null hypothesis cannot be rejected at the 10% level. We find a bubble from 1997M09 to 1998M02 in all three series, which is related to the Asian Financial Crisis.

Table 4: The GSADF test for exchange rate in emerging markets countries.

Exchange rate	Test Stat under H_0 with an intercept	Bubble Episodes	Test Stat under H_0 without an intercept	Bubble Episodes
USD/THB				
s_t	7.9539*** [a]	97M07-98M02, 08M01-08M05	2.8066	97M09-98M02
$s_t - f_t^N$	8.1865***	97M08-98M02, 08M02-08M04	2.7707	97M09-98M02
$s_t - f_t$	4.6063***	95M03-95M07, 97M07-98M02 08M01-08M05, 10M08-10M12	2.4169	97M10-98M02
USD/IDR				
s_t	9.1720***	94M08-96M08, 96M11-98M09 13M07-14M02	15.7484***	93M11-98M02, 98M05-98M08 13M08-14M12
$s_t - f_t^N$	11.0643***	95M04-98M09, 13M08-14M02	4.6668***	94M06-98M02, 98M05-98M08 13M09-14M12
$s_t - f_t$	8.6602***	97M07-98M02, 08M03-08M08 13M08-13M09	2.0424	97M10-98M01
USD/KRW				
s_t	9.9778***	95M03-95M08, 96M12-98M02 08M08-08M11, 09M01-09M02	4.5216***	93M11-95M04, 96M05-98M02
$s_t - f_t^N$	9.5177***	95M02-95M08, 97M01-98M03 04M11-05M05, 05M12-06M06 08M08-08M11, 09M01-09M02	2.3598	93M11-94M05, 97M02-98M02
$s_t - f_t$	9.9778***	95M03-95M08, 97M09-98M02 08M08-08M11	2.9672	93M11-94M11, 97M08-97M12 08M09-08M11

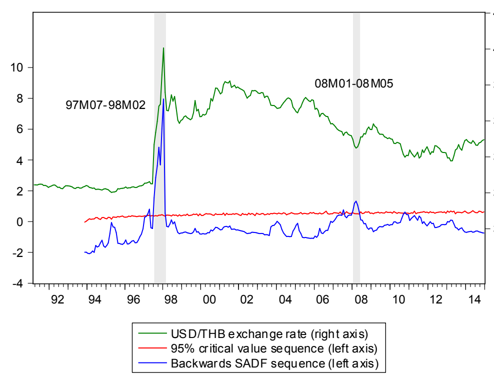
[a] *** indicates significance at 1% level.

Table 5: The GSADF test for exchange rate in emerging markets countries.

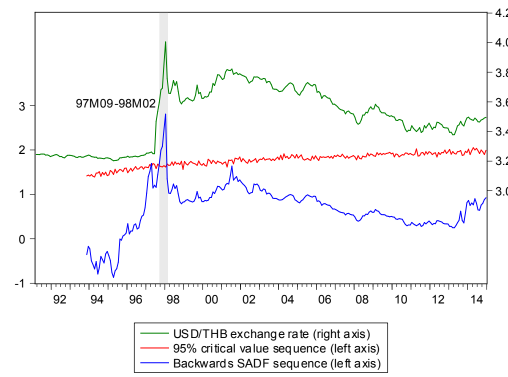
Exchange rate	Test Stat under H_0 with an intercept	Bubble Episodes	Test Stat under H_0 without an intercept	Bubble Episodes
USD/MYR				
s_t	6.8802*** [a]	97M08-98M08, 03M03-03M06	3.3746**	97M09-98M02, 98M05-98M08
		06M02-06M06, 06M11-08M08		
$s_t - f_t^N$	8.3895***	97M08-98M09	3.4557** [b]	97M09-98M02, 98M05-98M08
$s_t - f_t$	4.4348***	97M08-98M02, 07M12-08M05	2.9921	97M09-98M02
USD/PHP				
s_t	5.8052***	97M08-98M10, 06M12-08M05	2.8246	97M05-99M01, 99M07-07M02
$s_t - f_t^N$	5.1539***	97M08-98M10, 00M07-02M03	3.5298**	97M09-98M03, 98M05-98M10
		07M10-08M07, 11M03-11M09		00M03-07M09
		12M07-13M06		
$s_t - f_t$	3.3214***	97M08-98M02	2.2802	97M08-98M02, 14M01-14M11
USD/SGD				
s_t	4.7261***	94M07-95M08, 97M09-98M02	3.1190	97M11-98M02
		07M09-08M08, 11M01-11M09		
$s_t - f_t^N$	3.7030***	94M07-95M11, 97M10-98M01	2.5260	97M12-98M02
		08M02-08M04, 08M11-09M01		
		10M08-11M09		
$s_t - f_t$	3.0141***	97M07-98M02, 98M05-98M09	3.2448* [c]	97M08-98M02, 98M05-98M09
				14M10-14M12

[a]*** indicates significance at 1% level.
[b]** indicates significance at 5% level.
[c]* indicates significance at 10% level.

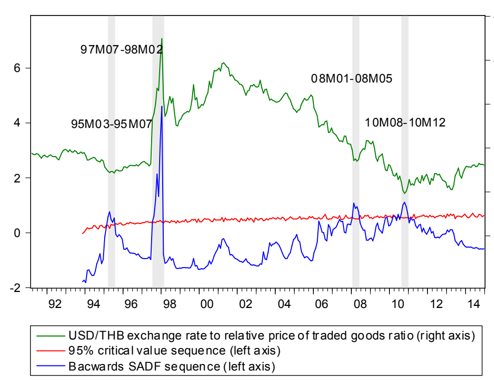
(a) USD/THB s_t with an intercept



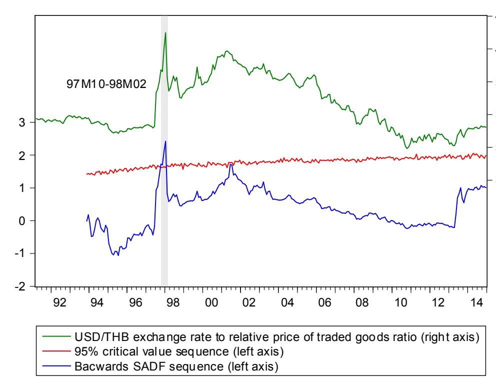
(b) USD/THB s_t without an intercept



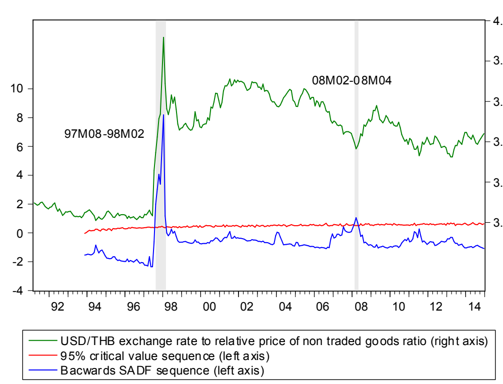
(c) USD/THB $s_t - f_t^T$ with an intercept



(d) USD/THB $s_t - f_t^T$ without an intercept



(e) USD/THB $s_t - f_t^N$ with an intercept



(f) USD/THB $s_t - f_t^N$ without an intercept

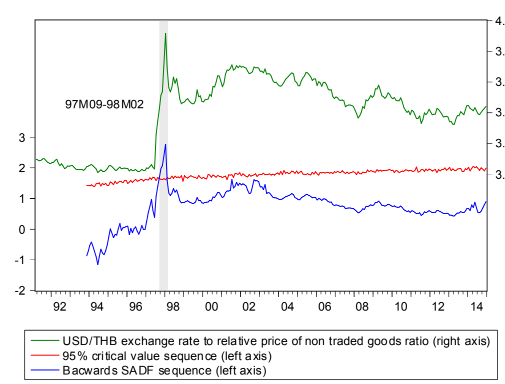


Figure 4: Dating strategy for USD/THB nominal exchange rate s_t, the relative ratio of the exchange rate to the traded goods fundamental $s_t - f_t^T$ and the relative ratio of the exchange rate to the non-traded goods fundamental $s_t - f_t^N$.

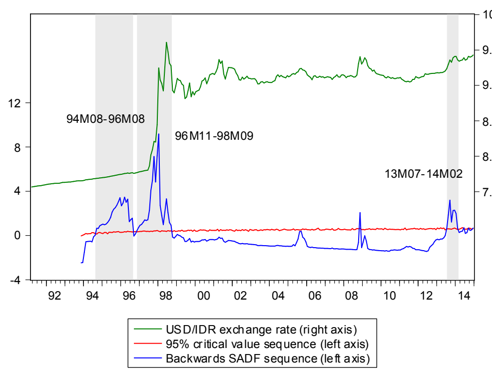
5.2.2. Indonesian Rupiah (IDR)

Following the collapse of the Baht, Indonesia widened the Rupiah currency trading band from 8% to 12% in July 1997. In August 1997, the managed floating exchange rate was abandoned and the Rupiah was allowed to float freely. The nominal exchange rate remained almost constant before the 1997 Asian Financial Crisis but it had some initial falls immediately after the crisis occurred. The Rupiah traded at 2600 to the US Dollar in July 1997 and it depreciated to 14900 per US Dollar in June 1998. The Indonesian Rupiah was one of the most volatile currencies during the East Asian currency crisis as it depreciated to near one-sixth of its pre-crisis level (Ito, 2007).

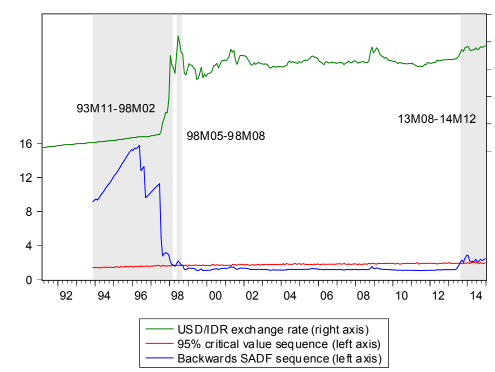
Under the model specification with an intercept, the null hypothesis of no explosive behavior in the nominal Indonesian Rupiah-Dollar exchange rate is rejected at the 1% significance level as listed in Table 4. We find the presence of multiple bubbles in the nominal exchange rate including 1994M08-1996M08, 1996M11-1998M09 and 2013M07-2014M02 from Figure 5*a*. The first episode in the nominal exchange rate is driven by the relative prices of traded goods f_t^T as the nominal exchange rate is no longer explosive once the relative prices of traded goods fundamentals are taken into account. The f_t^T also explains the part of movements in explosiveness in 1998 and 2013. These results seem to suggest that the relative prices of traded goods have explained the majority of the movements in the nominal exchange rate. Additionally, a 'collapse and recovery' episode is observed in Figure 5*c* between 2008M03 and 2008M08.

Bubble detection results under the model specification 'without an intercept' are provided in the right panel of Figure 5. We find significant evidence of bubbles in the nominal exchange rate at the 1% significance level with three explosive subperiods including 1993M11-1998M02, 1998M05-1998M08 and 2013M08-2014M12 in Figure 5b. The most recent episode (2013M08-2014M12) suggests that USD/IDR exchange rate is experiencing a bubble. The $s_t - f_t^N$ series is also significant at the 1% level, which indicates strong evidence of explosive subperiods in Figure 5f (e.g., 1994M06-1998M02, 1998M05-1998M08 and 2013M09-2014M12). The nominal exchange rate series remains explosive even if the relative prices of non-traded goods are considered. Thus the relative prices of non-traded goods component f_t^N plays no role in explaining the explosiveness. On the other hand, the null hypothesis of no explosive bubbles for $s_t - f_t^T$ cannot be rejected at the 10% significance level. As suggested in Figure 5d, the nominal exchange rate s_t is explosive from 1997M10 to 1998M01 only. Unlike f_t^N, the relative prices of traded goods component f_t^T plays an important role in explaining the volatility of exchange rates. Our empirical results from USD/IDR exchange rates suggest that the relative prices of traded goods f_t^T have explained the majority of the movements in s_t, which are in line with Engel (1999) and Betts & Kehoe (2005).

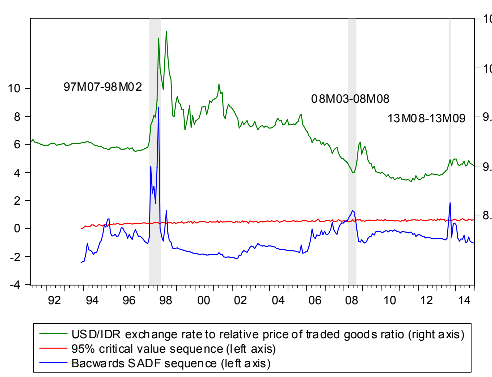
(a) USD/IDR s_t with an intercept



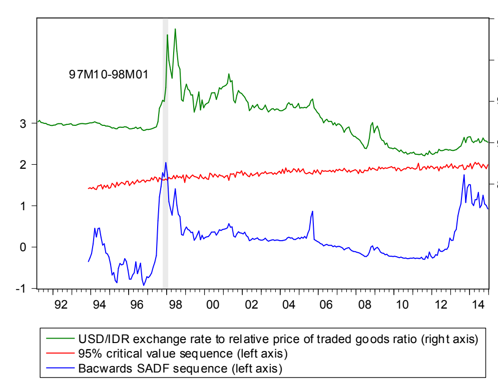
(b) USD/IDR s_t without an intercept



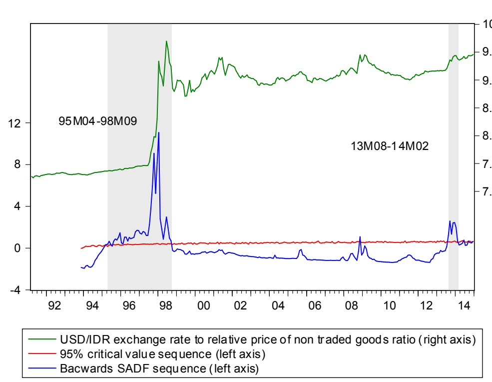
(c) USD/IDR $s_t - f_t^T$ with an intercept



(d) USD/IDR $s_t - f_t^T$ without an intercept



(e) USD/IDR $s_t - f_t^N$ with an intercept



(f) USD/IDR $s_t - f_t^N$ without an intercept

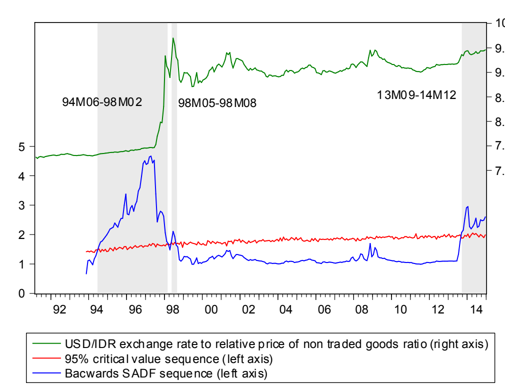


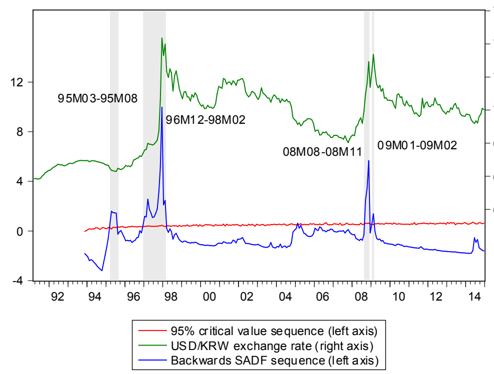
Figure 5: Dating strategy for USD/IDR nominal exchange rate s_t, the relative ratio of the exchange rate to the traded goods fundamental $s_t - f_t^T$ and the relative ratio of the exchange rate to the non-traded goods fundamental $s_t - f_t^N$.

5.2.3. Korean Won (KWR)

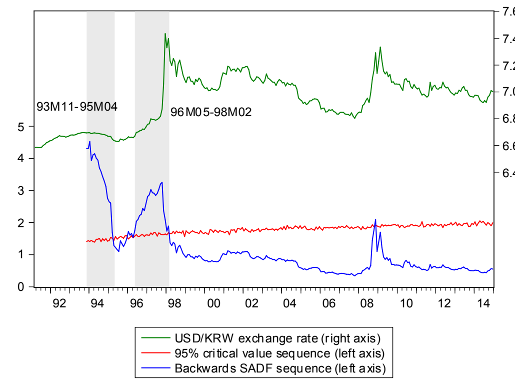
The exchange rate between the Korean Won and US Dollar was one of the most affected pairs during the 1997 Asian Financial Crisis. The null hypothesis of no bubbles under the model specification with an intercept is rejected for s_t, $s_t - f_t^T$ and $s_t - f_t^N$ at the 1% level and the corresponding bubble detection results are shown in Table 4. Figure 6a, Figure 6c and Figure 6e shows the date-stamping outcomes in s_t, $s_t - f_t^T$ and $s_t - f_t^N$ under the model specification with an intercept, respectively. Four bubbles episodes are identified from Figure 6a including 1995M03-1995M08, 1996M12-1998M02, 2008M08-2008M11 and 2009M01-2009M02. Firstly, we find the evidence of explosiveness between March 1995 and August 1995 in all three series. The exchange rate s_t remains explosive after both the relative prices of traded goods f_t^T and non-traded goods f_t^N are taken into account. Thus f_t^T and f_t^N play no role in explaining the explosive behavior in 1995. Secondly, both s_t and $s_t - f_t^N$ detect the explosiveness from the late 1996 or early 1997 to the early 1998 while $s_t - f_t^T$ suggests a bubble episode starting from September 1997 until the early of 1998. It appears that the relative prices of traded goods have partially explained the explosive behaviour from the early to mid 1997. These bubble episodes correspond to the 1997 Asian Financial Crisis where the Korean Won has depreciated sharply from the pre-crisis level of 800 per US Dollar to 1700 per US Dollar at the end of 1997. In order to avoid the worst case scenario of a sovereign default, the IMF provided a \$58.4 billion bailout plan to South Korea in December 1997 (Koo & Kiser, 2001). Thirdly, two more short-lived bubbles in 2008-2009 are likely related to the 2008 Global Financial Crisis. Both f_t^T and f_t^N have no effect in explaining the explosiveness in the nominal exchange rate s_t in 2008 while the relative prices of traded goods can explain the explosiveness in early 2009. Unlike the existing studies from Engel (1999) and Betts & Kehoe (2005), our results indicate that the relative prices of traded goods f_t^T play little role in explaining the movements of Korean Won-Dollar exchange rate and the relative prices of non-traded goods f_t^N contribute little in explaining the explosiveness either.

As suggested in Table 4, the nominal exchange rate series s_t remain explosive with two explosive subperiods (1993M11-1995M04 and 1996M05-1998M02) even if the intercept term is removed from the model specification under the null hypothesis. However, $s_t - f_t^T$ and $s_t - f_t^N$ series are non explosive as both series are not significant at the 10% level. Both f_t^T and f_t^N could not explain the majority of the explosiveness. We are more convinced by the fact that the episode between 1996M05 and 1998M02 is a bubble, which is caused by the Asian Financial Crisis. A short-lived bubble is also detected in Figure 6f. These results are consistent with the early findings under the assumption of the inclusion of an intercept. The exclusion of an intercept for constructing the hypothesis affects the date-stamping strategy of the PSY approach.

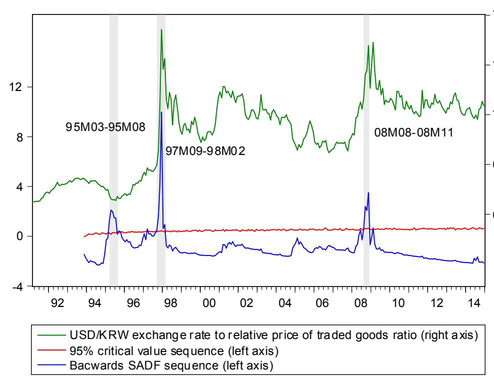
(a) USD/KRW s_t with an intercept



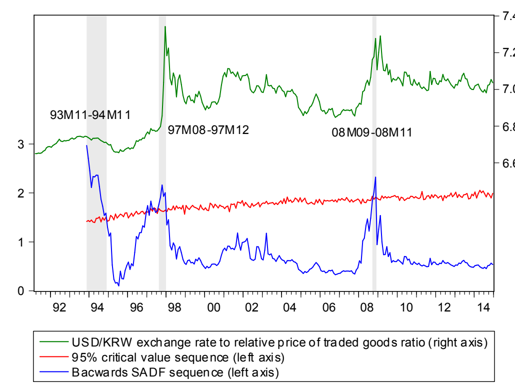
(b) USD/KRW s_t without an intercept



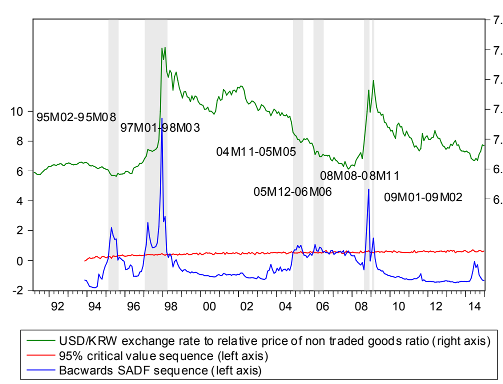
(c) USD/KRW $s_t - f_t^T$ with an intercept



(d) USD/KRW $s_t - f_t^T$ without an intercept



(e) USD/KRW $s_t - f_t^N$ with an intercept



(f) USD/KRW $s_t - f_t^N$ without an intercept

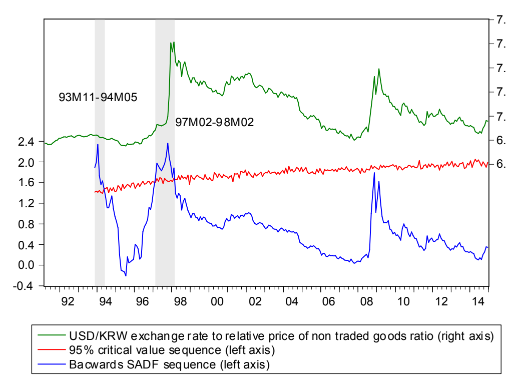


Figure 6: Dating strategy for USD/KRW nominal exchange rate s_t, the relative ratio of the exchange rate to the traded goods fundamental $s_t - f_t^T$ and the relative ratio of the exchange rate to the non-traded goods fundamental $s_t - f_t^N$.

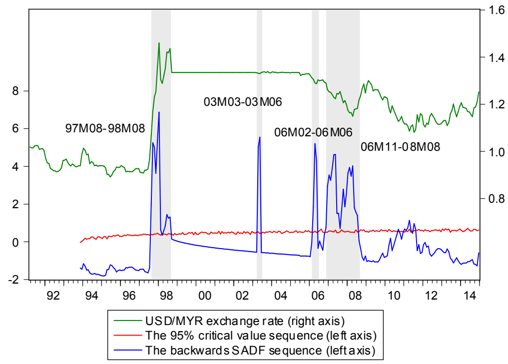
5.2.4. Malaysian Ringgit (MYR)

We find strong evidence of explosive behavior in s_t, $s_t - f_t^T$ and $s_t - f_t^N$ at the 1% level based on the model specification under the null hypothesis in Table 5. As indicated in Figure 7a, there is evidence of multiple episodes in the nominal exchange rate s_t including 1997M08-1998M08, 2003M03-2003M06, 2006M02-2006M06 and 2006M11-2008M08. The Malaysian Ringgit traded at 2.5 US Dollar before the 1997 Asian Financial Crisis and it depreciated sharply to 3.8 US Dollars by the end of 1997. There is a bubble period between August 1997 and August 1998 in the nominal exchange rate as shown by Figure 7a and the ratio of the exchange rate to the non-traded goods fundamental $s_t - f_t^N$ of Figure 7e while a shorter bubble episode is detected in the ratio of the exchange rate to the traded goods fundamental $s_t - f_t^T$ starting at August 1997 and ending at February 1998 in Figure 7c. Such a bubble corresponds to the 1997 Asian Financial Crisis. The relative prices of traded goods f_t^T have partially explained the explosiveness in s_t while such a explosive behavior is not driven by the relative prices of non-traded goods f_t^N.

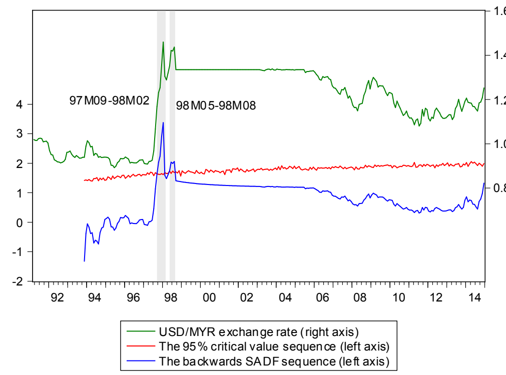
It is perhaps noteworthy to compare findings from the GSADF test using the two model specifications. First, we find a spurious episode in 2003 for nominal exchange rate s_t in Figure 7a. The Malaysian Ringgit was pegged to the US Dollar in September 1998 keeping the exchange rate around 3.8 per US Dollar until the end of 2005. Thus we would not expect any explosive behavior during this seven-year period. However, as shown in Figure 7a, there is a spurious episode dated from March 2003 to June 2003 in the series. We could not explain the reason behind this 'collapse' episode. Second, we notice two 'collapse and recovery' episodes (2006M02-2006M06 and 2006M11-2008M08) in Figure 7a in the nominal exchange rate s_t. This spurious 'collapse' episode in 2003 and two 'collapse and recovery' episodes (2006M02-2006M06 and 2006M11-2008M08) are likely caused by the inclusion of an intercept in the model specification under the null hypothesis as seen by comparing Figure 7a and Figure 7b. Overall, under the assumption 'with an intercept', the PSY approach could lead to the false positive identification of bubbles as it cannot distinguish between 'collapse' type of episodes and bubbles.

However, we obtain different results if the intercept is excluded in the model formulation. The null hypothesis of no bubbles under model specification 'without an intercept' for s_t and $s_t - f_t^N$ are rejected at the 5% significance level, which indicates strong evidence of bubbles. We find two explosive episodes (1997M09-1998M02 and 1998M05-1998M08) from s_t in Figure 7b and $s_t - f_t^N$ in Figure 7f. The test statistics for $s_t - f_t^T$ is slightly lower than the 10% significance level. As exchange rate fundamentals (f_t^T and f_t^N) could not explain the bubble in 1997-1998, we therefore conclude the evidence of rational bubbles. When the intercept term is removed from the model specification for null hypothesis, the backward SADF statistic sequences and 95% critical value sequences do not "detect" the 'collapse' episode in 2003 and 'collapse and recovery' episodes any longer in the right panel of Figure 7.

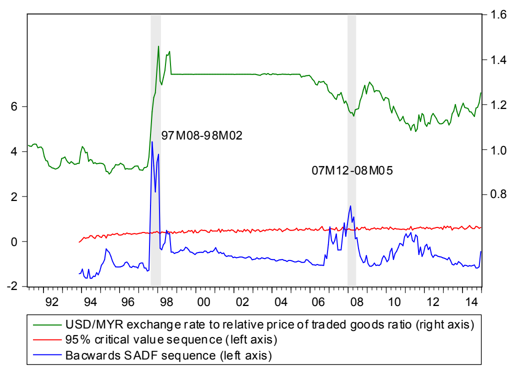
(a) USD/MYR s_t with an intercept



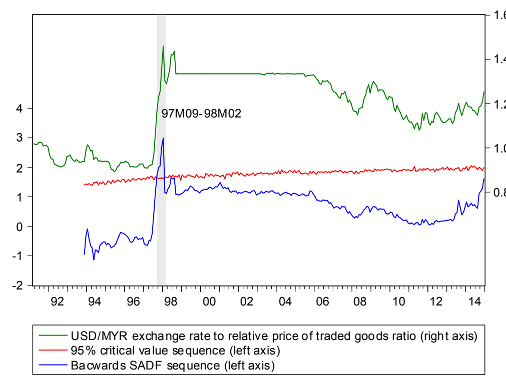
(b) USD/MYR s_t without an intercept



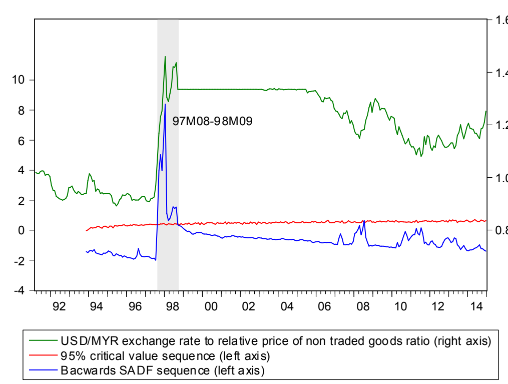
(c) USD/MYR $s_t - f_t^T$ with an intercept



(d) USD/MYR $s_t - f_t^T$ without an intercept



(e) USD/MYR $s_t - f_t^N$ with an intercept



(f) USD/MYR $s_t - f_t^N$ without an intercept

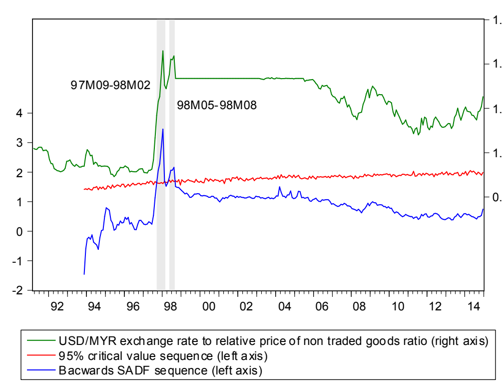


Figure 7: Dating strategy for USD/MYR nominal exchange rate s_t, the relative ratio of the exchange rate to the traded goods fundamental $s_t - f_t^T$ and the relative ratio of the exchange rate to the non-traded goods fundamental $s_t - f_t^N$.

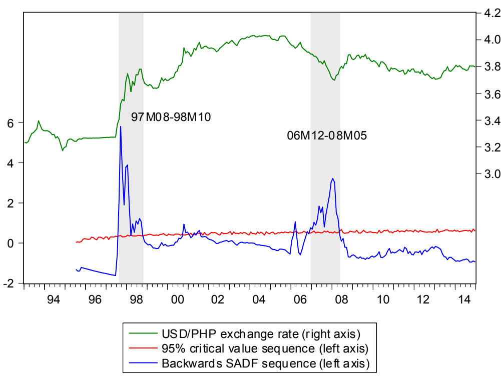
5.2.5. Philippine Peso (PHP)

Table 5 suggests that the null hypothesis of no explosive behavior in the nominal exchange rate s_t is rejected at the 1% significance level based on the GSADF test. As shown in Figure 8a, there is evidence of a bubble in the US Dollar-Philippine Peso exchange rate s_t during 1997M08-1998M10 and a 'collapse and recovery' episode during 2006M12-2008M05. The first explosive bubble is clearly related to the 1997 Asian Financial Crisis. The non-traded goods f_t^N could not explain this explosiveness while the traded goods f_t^T explain some movements in the exchange rates.

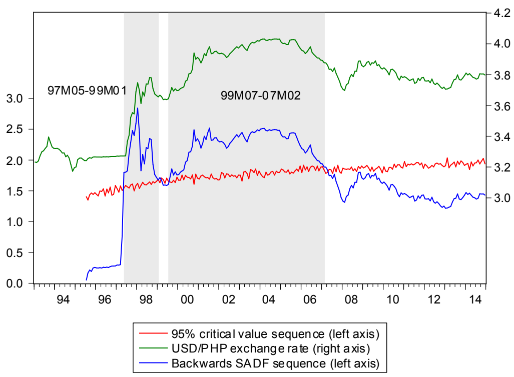
As can be seen in Figure 8c, we find no evidence of explosiveness in the $s_t - f_t^T$ series for the second explosive period in 2007-2008, which is likely associated with the 2008 Global Financial Crisis. According to Figure 8e, the exchange rate still remains explosive after the relative prices of non-traded goods are taken into account although the time duration of the explosive behaviour in the $s_t - f_t^N$ series is shorter than those from the s_t series. On the other hand, we also observe three additional bubble periods from the $s_t - f_t^N$ series. Overall, the above results seem to suggest that the relative prices of traded goods play a crucial role in explaining the explosiveness in the nominal US Dollar-Philippine Peso exchange rate.

The exclusion of the intercept term for model formulation of hypothesis yields quite different results as indicated in the right panel of Figure 8. The null hypothesis of no explosive behavior for s_t and $s_t - f_t^T$ are not rejected at the 10% significance level while the hypothesis for $s_t - f_t^N$ is rejected at the 5%. The episode in 1997-1998 is identified in all three series (s_t, $s_t - f_N^T$ and $s_t - f_t^T$). There are two long-lasting episodes in s_t (1999M07-2007M02) and $s_t - f_N^T$ (2000M03-2007M09) in Figure 8b and Figure 8f, respectively and these results are not expected and may be spurious. These two episodes are not detected under the model specification 'with an intercept'. It seems that the relative prices of traded goods f_t^T explain the majority of exchange rate movements.

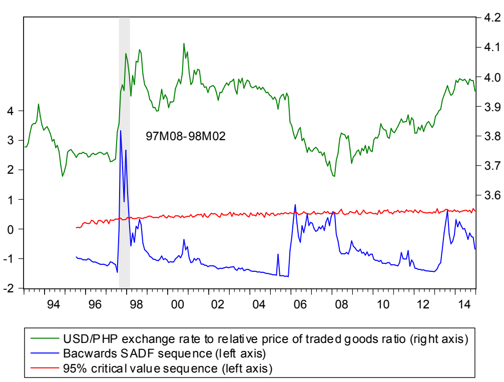
(a) USD/PHP s_t with an intercept



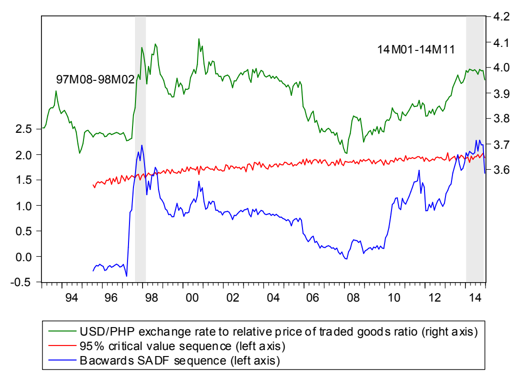
(b) USD/PHP s_t without an intercept



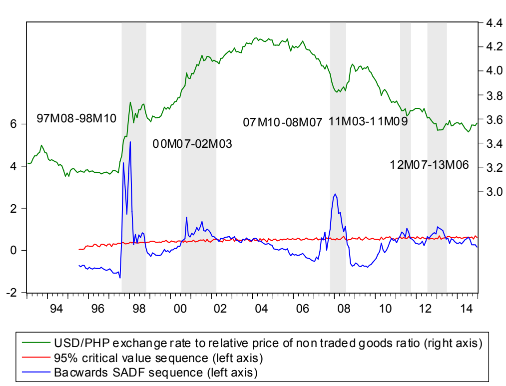
(c) USD/PHP $s_t - f_t^T$ with an intercept



(d) USD/PHP $s_t - f_t^T$ without an intercept



(e) USD/PHP $s_t - f_t^N$ with an intercept



(f) USD/PHP $s_t - f_t^N$ without an intercept

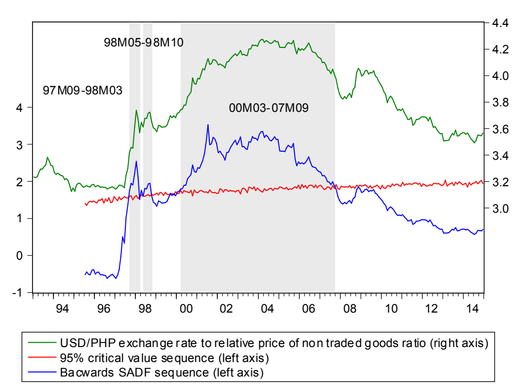


Figure 8: Dating strategy for USD/PHP nominal exchange rate s_t, the relative ratio of the exchange rate to the traded goods fundamental $s_t - f_t^T$ and the relative ratio of the exchange rate to the non-traded goods fundamental $s_t - f_t^N$.

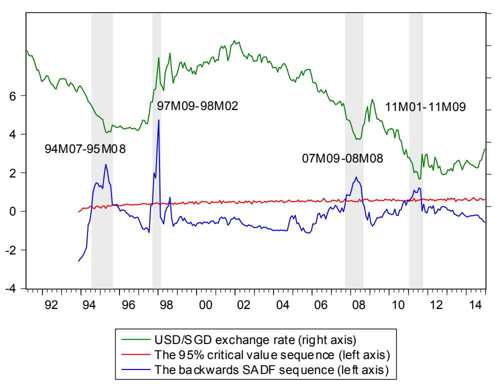
5.2.6. Singapore Dollar (SGD)

Unlike most Asian currencies, a managed floating exchange rate regime was adopted by the Singapore government in 1973 (Lu & Yu, 1999). In 1967, the Board of Commissioners of Currency of Singapore (BCCS) was established to issue currency. The Monetary Authority of Singapore (MAS) established in 1971 manages the Singapore Dollar against a trade-weighed basket of currencies. The Board of Commissioners of Currency of Singapore merged with the Monetary Authority of Singapore in October 2002.

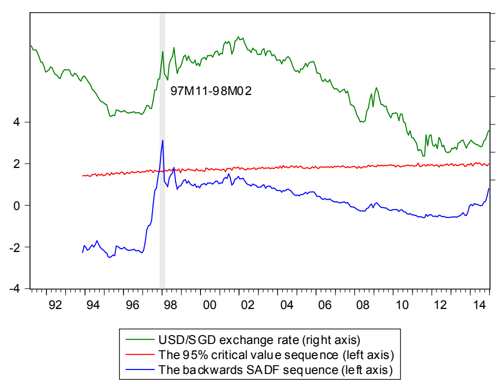
As can be seen from Table 5, under the assumption 'with an intercept', we find strong evidence of explosive behaviour in the nominal exchange rate s_t, the ratio of the exchange rate to the traded goods fundamental $s_t - f_t^T$ and the ratio of the exchange rate to the non-traded goods fundamental $s_t - f_t^N$ at the 1% significance level. As shown in Figure 9a, a bubble episode between 1997M09 and 1998M02 as well as several 'collapse and recovery' episodes (e.g., 1994M07-1995M08, 2007M09-2008M08 and 2011M01-2011M09) are observed in the nominal exchange rate s_t. The bubble episode during 1997-1998 is associated with the 1997 Asian Financial Crisis. Neither the relative prices of traded goods nor the relative prices of non-traded goods explain the explosiveness during the Asian financial downturn, suggesting evidence of rational bubbles. More 'collapse' episodes have been found in Figure 9e (e.g., 1994M07-1995M11, 2008M02-2008M04 and 2010M08-2011M09). Overall, we find significant evidence of bubbles during the Asian Financial Crisis.

It seems that the exclusion of the intercept for constructing the null hypothesis has affected the limit theory of the PSY approach. We obtain quite different results in the two model specifications. When the intercept is removed in the model specification of null hypothesis, s_t and $s_t - f_t^N$ series are no longer explosive and the test statistics are lower than the 10% significance level. $s_t - f_t^T$ remains explosive at the 5% significance level. These results seem to suggest that there is little evidence of bubbles. The episode in 1997-1998 is explosive in Figure 9b, Figure 9d and Figure 9f, which suggests the evidence of rational bubbles again. Once the intercept is removed, we no longer find 'collapse and recovery' type of episodes. Moreover, the relative prices of traded goods f_t^T does not play an important role in explaining the majority of the movements in s_t.

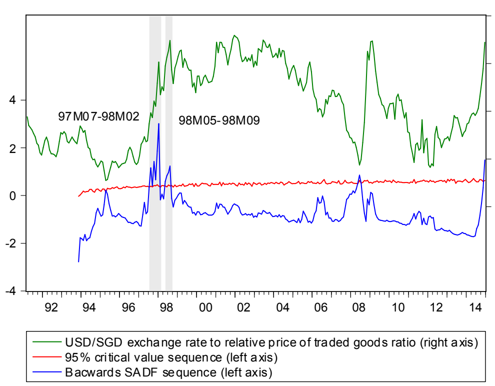
(a) USD/SGD s_t with an intercept



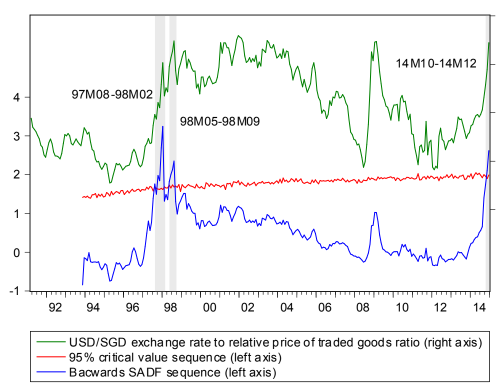
(b) USD/SGD s_t without an intercept



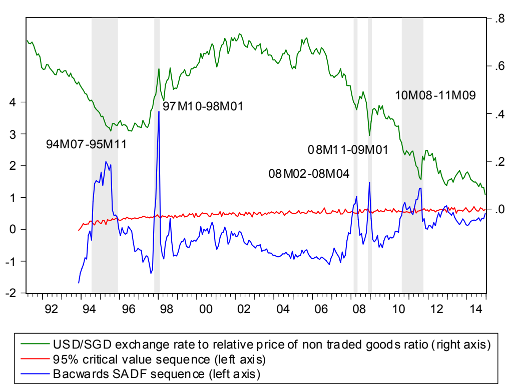
(c) USD/SGD $s_t - f_t^T$ with an intercept



(d) USD/SGD $s_t - f_t^T$ without an intercept



(e) USD/SGD $s_t - f_t^N$ with an intercept



(f) USD/SGD $s_t - f_t^N$ without an intercept

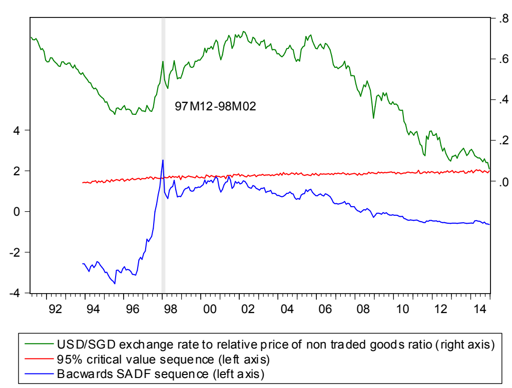


Figure 9: Dating strategy for USD/SGD nominal exchange rate s_t, the relative ratio of the exchange rate to the traded goods fundamental $s_t - f_t^T$ and the relative ratio of the exchange rate to the non-traded goods fundamental $s_t - f_t^N$.

5.3. Results for BRICS countries

We also look for evidence of explosive behavior in the exchange rate of the BRICS countries including the Brazilian Real (BRL), Indian Rupee (INR) and South African Rand (ZAR) measured against the US Dollar.[6]

5.3.1. Brazilian Real (BRL)

The Brazilian Real was pegged to 1 US Dollar when it was initially introduced in July 1994. The Real appreciated against the US Dollar in the early years, but from July 1996, the Real depreciated against the US Dollar. By the end of 1998, the Real depreciated slowly against the US Dollar at a rate of 1:1.2. The Real was allowed to fluctuate within a narrow trading band until early 1999 such that its value was closely controlled by the government (Gruben et al., 2001). The adoption of the pre-set band provides some flexibility of the exchange rate, aimed at resolving the inflation problem. The Real was floated in January 1999 as the government unable to hold the peg (Ferreira & Tullio, 2002). As a result, the Real further devalued to a rate of 1:2.

Based on Table 6, the null hypothesis of explosive behavior in the nominal US Dollar-Brazilian Real is rejected at the 5% significance level. The first bubble period between June 1997 and March 1999 in Figure 10a is associated with the devaluation of the Real. According to Ferreira & Tullio (2002), the price index for non-traded goods increased by 120 per cent, and the price index for traded goods increased by about 27 per cent between July 1994 and the end of 1998. Several short bubble episodes can be seen in Figure 10a (e.g., 2001M07-2001M10, 2002M06-2002M07, 2002M09-2002M10) along with a 'collapse' episode during 2005M08-2005M11. We then investigate whether the explosiveness in the nominal exchange rate is driven by rational bubbles or exchange rate fundamentals. According to Figure 10c, the relative ratio of the exchange rate to the traded goods fundamentals $s_t - f_t^T$ suggests no evidence of rational bubbles as the ratio is no longer explosive. Thus the relative prices of traded goods f_t^T plays a vital role in explaining the volatility of the nominal exchange rate. There appears to be no evidence of explosive episodes in $s_t - f_t^T$. The nominal exchange rate is explosive although the relative prices of non-traded goods f_t^N are considered. Thus the prices of non-traded goods f_t^N have little contributions in explaining the explosiveness.

When the intercept is not used for constructing the hypothesis, s_t and $s_t - f_t^N$ are still significant at 1% level while the null hypothesis of no explosive bubbles in $s_t - f_t^T$ cannot be rejected at 10%

[6] Due to the lack of the PPI data for Russian, we could not test for the explosive behavior in the US Dollar-Russian Ruble exchange rate fundamentals. Jiang et al. (2015) investigated the explosive behavior in the Chinese RMB-US Dollar exchange rate. We therefore only include the three remaining countries in our analysis.

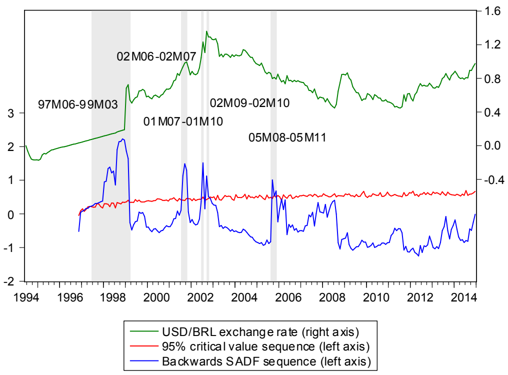
level. We find evidence of multiple bubbles in Figure 10b (e.g., 1997M12-1999M02, 2001M08-2001M11 and 2002M05-2002M10). We cannot detect those ‘collapse and recovery’ episodes any more in the right panel of Figure 10. Interestingly, there is a bubble episode between 2001M07 and 2003M03 in Figure 10f, which is not identified before. A general conclusion can be drawn that the relative prices of traded goods f_t^T have explained most movements in the exchange rate for both model formulations.

5.3.2. Indian Rupee (INR)

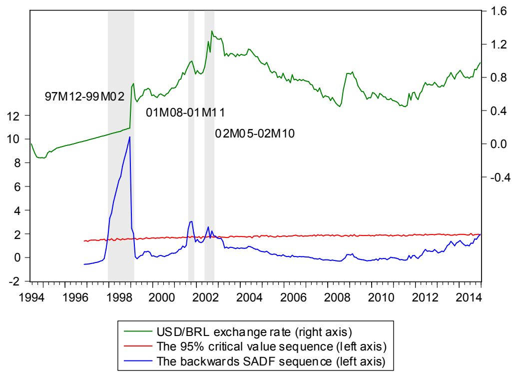
Results for the nominal US Dollar-India Rupee exchange rate are shown in Table 6. The GSADF test suggests strong evidence of bubbles in the nominal exchange rate as the null of no explosive behavior is rejected at the 1% significance level. Figure 11a shows the date-stamping results for the nominal exchange rate and displays the presence of multiple periods of explosiveness including 1995M11-1996M02, 1998M03-1999M02, 2001M09-2002M05 and 2004M01-2004M04. The nominal exchange rate s_t is no longer explosive in Figure 11c once the relative prices of traded goods $s_t - f_t^T$ are accounted for. We find no episodes in Figure 11c as the relative prices of traded goods explain the explosiveness in the nominal exchange rate. A ‘collapse and recovery’ episode between 2007M05 and 2008M04 is identified in Figure 11e.

The date-stamping results for the model specification under the assumption of no intercept is quite different as shown in Figure 11b, Figure 11d and Figure 11f. In Figure 11b, we find a spurious bubble episode in s_t from December 1993 to December 2014 and we do not expect such a long-lasting bubble. Similarly, a long-lasting episode between December 1993 and February 2007 is detected in $s_t - f_t^N$ of Figure 11f. Although the GSADF test statistic for s_t and $s_t - f_t^T$ suggest evidence of bubbles, these results are spurious and we hardly believe the existence of genuine bubbles. These results demonstrate the importance of model specification in right-tailed unit root tests. When the intercept is excluded in the model formulation for constructing the null hypothesis, we could obtain some spurious and unexpected results (i.e., a spurious long-lasting episode). Thus it is important to assess a wide range of specifications in the null.

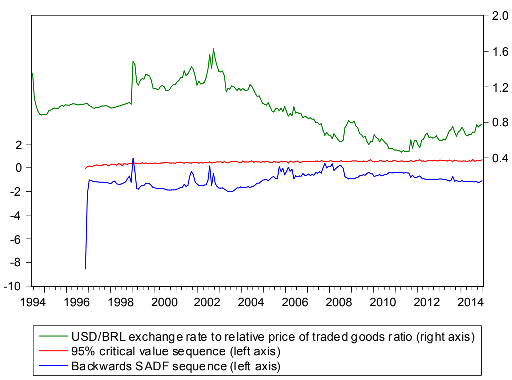
(a) USD/BRL s_t with an intercept



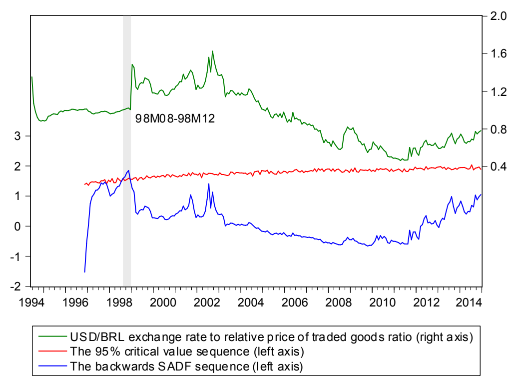
(b) USD/BRL s_t without an intercept



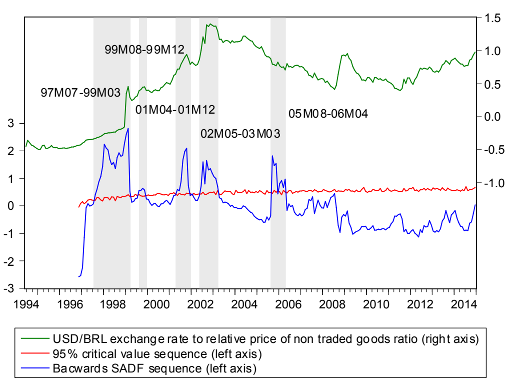
(c) USD/BRL $s_t - f_t^T$ with an intercept



(d) USD/BRL $s_t - f_t^T$ without an intercept



(e) USD/BRL $s_t - f_t^N$ with an intercept



(f) USD/BRL $s_t - f_t^N$ without an intercept

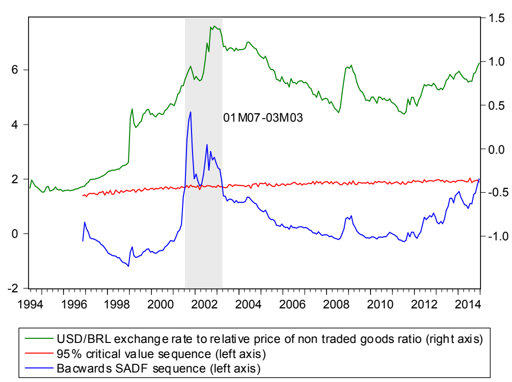


Figure 10: Dating strategy for USD/BRL nominal exchange rate s_t, the relative ratio of the exchange rate to the traded goods fundamental $s_t - f_t^T$ and the relative ratio of the exchange rate to the non-traded goods fundamental $s_t - f_t^N$.

Table 6: The GSADF test for exchange rate in emerging markets countries.

Exchange rate	Test Stat under H_0 with an intercept	Bubble Episodes	Test Stat under H_0 without an intercept	Bubble Episodes
USD/BRL				
s_t	2.2281** [a]	97M06-99M03, 01M07-01M10 02M06-02M07, 02M09-02M10 05M08-05M11	10.1813*** [b]	97M12-99M02, 01M08-01M11 02M05-02M10
$s_t - f_t^N$	2.7464***	97M07-99M03, 99M08-99M12 01M04-01M12, 02M05-03M03 05M08-06M04	4.4563***	01M07-03M03
$s_t - f_t$	0.8156		1.8511	98M08-98M12
USD/INR				
s_t	2.7861***	95M11-96M02, 98M03-99M02 01M09-02M05, 04M01-04M04	4.0151**	93M12-14M12
$s_t - f_t^N$	1.3143	98M04-98M07, 07M05-08M04	3.1064	93M12-07M02
$s_t - f_t$	0.7890		1.9111	
USD/ZAR				
s_t	3.7159***	94M01-94M08, 96M03-97M01 98M04-98M10, 98M12-99M04 00M08-02M09	4.8427***	93M11-03M09
$s_t - f_t^N$	4.9297***	94M02-94M08, 96M03-97M02 97M09-99M08, 00M08-02M11	5.0760***	93M11-03M09
$s_t - f_t$	2.1865**	98M06-98M08, 00M10-01M04 01M09-02M03	2.8881	96M03-96M12, 98M05-98M09 00M04-02M04

[a] ** indicates significance at 5% level.

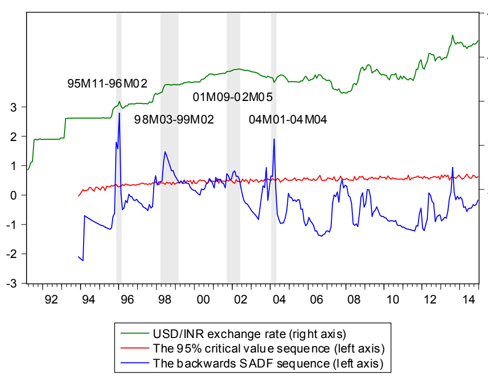
[b] *** indicates significance at 1% level.

Table 7: The GSADF test for exchange rate in emerging markets countries.

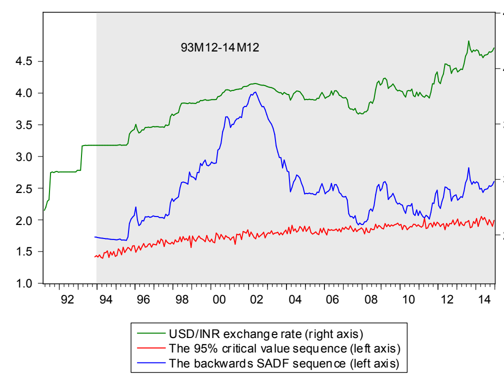
Exchange rate	Test Stat under H_0 with an intercept	Bubble Episodes	Test Stat under H_0 without an intercept	Bubble Episodes
USD/COP				
s_t	2.1757** [a]	97M09-01M10, 02M07-03M04	5.4578*** [b]	94M08-14M12
$s_t - f_t^N$	2.7464***	97M09-03M11, 05M11-06M03	4.9002***	95M06-08M02, 08M09-09M05
		07M04-07M07, 08M01-08M08		
$s_t - f_t$	0.7397	94M08-94M12	2.1901	00M08-01M05, 02M07-03M04
USD/MXN				
s_t	3.5056***	94M02-94M04, 94M12-95M04	2.5653	98M08-98M11, 03M01-03M03
$s_t - f_t^N$	3.3521***	94M02-94M04, 94M11-95M03	2.6254	98M08-99M03, 02M12-03M02
		98M08-98M11, 08M04-08M08		04M04-04M10
$s_t - f_t$	1.8151	94M11-95M03	1.9643	

[a] ** indicates significance at 5% level.
[b] *** indicates significance at 1% level.

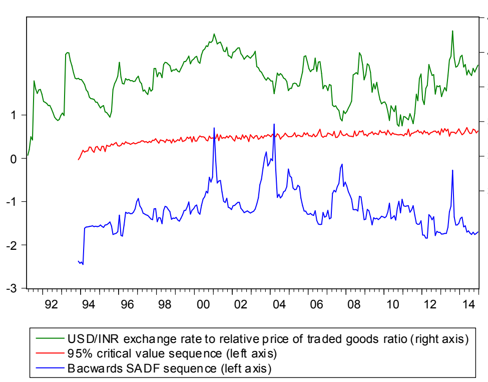
(a) USD/INR s_t with an intercept



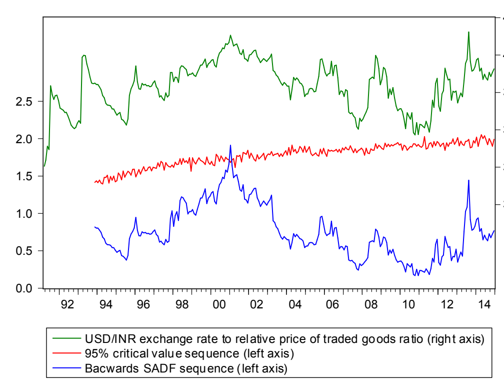
(b) USD/INR s_t without an intercept



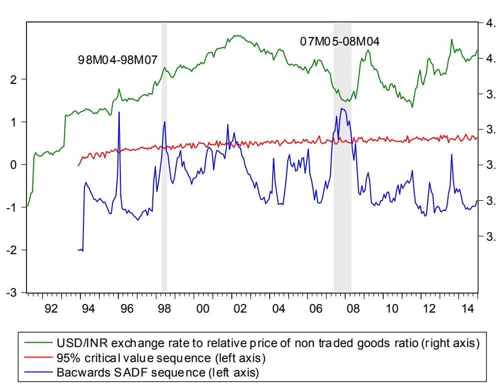
(c) USD/INR $s_t - f_t^T$ with an intercept



(d) USD/INR $s_t - f_t^T$ without an intercept



(e) USD/INR $s_t - f_t^N$ with an intercept



(f) USD/INR $s_t - f_t^N$ without an intercept

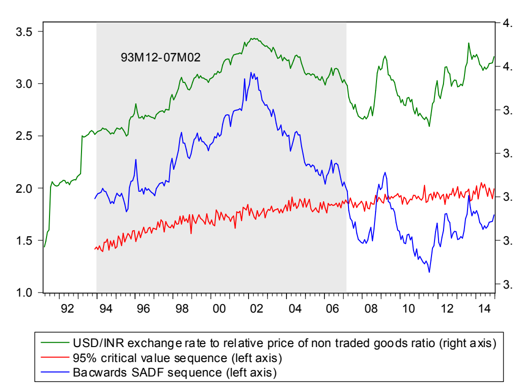


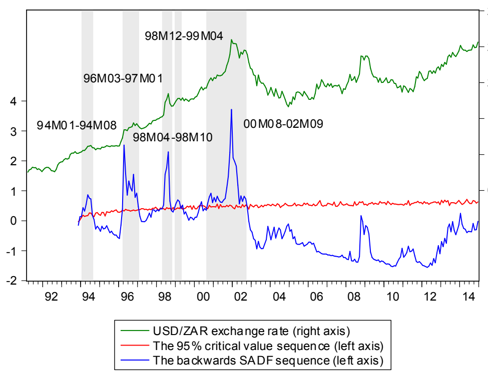
Figure 11: Dating strategy for USD/INR nominal exchange rate s_t, the relative ratio of the exchange rate to the traded goods fundamental $s_t - f_t^T$ and the relative ratio of the exchange rate to the non-traded goods fundamental $s_t - f_t^N$.

5.3.3. South African Rand (ZAR)

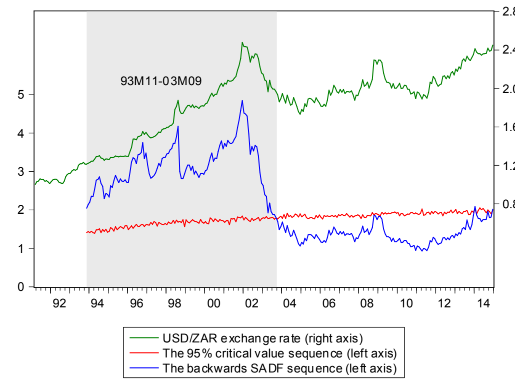
We find strong evidence of bubbles from the nominal US Dollar-South African Rand exchange rate as shown in Table 6 as the null of no bubbles is rejected at the 1% significance level. Multiple bubbles periods are found in Figure 12a including 1994M01-1994M08, 1996M03-1997M01, 1998M04-1998M10, 1998M12-1999M04 and 2000M08-2002M09. According to Figure 12c and Figure 12e, the relative prices of traded goods f_t^T have explained the majority of the movements in the nominal exchange rate. As both the relative prices of traded goods fundamentals and non-traded goods fundamentals cannot explain all the explosiveness in the nominal exchange rate, we therefore conclude the evidence of rational bubbles.

Comparing the left panel and right panel of Figure 12, we obtain very different date-stamping results. Both the s_t and $s_t - f_t^N$ series remain explosive at the 1% significance level. However, $s_t - f_t^T$ is no longer explosive as f_t^T could explain some explosiveness in s_t. More importantly, we find a long-lasting bubble episode from 1993M11 to 2003M09 in both s_t and $s_t - f_t^N$ series and this episode is spurious. This indicates that the intercept term has greatly affected the asymptotic theory and the date-stamping strategy of the PSY approach. As discussed before, without considering the intercept in the null, the PSY approach no longer identifies 'collapse' episodes and 'collapse and recovery' episodes but this example shows that it could lead to spurious bubbles.

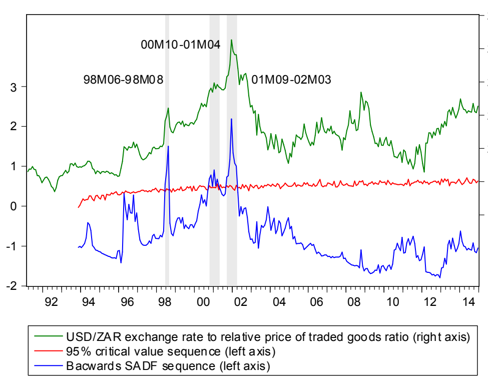
(a) USD/ZAR s_t with an intercept



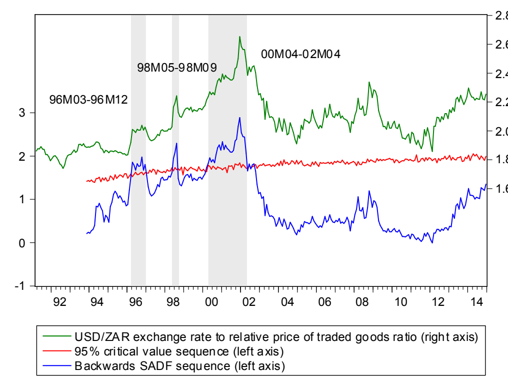
(b) USD/ZAR s_t without an intercept



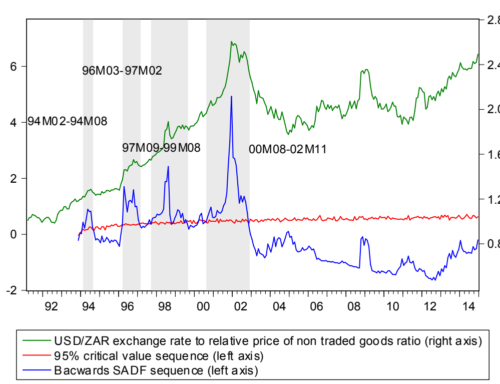
(c) USD/ZAR $s_t - f_t^T$ with an intercept



(d) USD/ZAR $s_t - f_t^T$ without an intercept



(e) USD/ZAR $s_t - f_t^N$ with an intercept



(f) USD/ZAR $s_t - f_t^N$ without an intercept

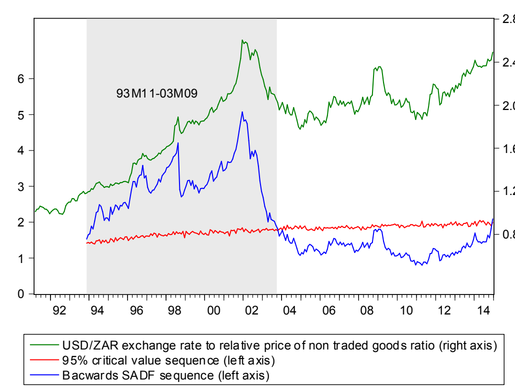


Figure 12: Dating strategy for USD/ZAR nominal exchange rate s_t, the relative ratio of the exchange rate to the traded goods fundamental $s_t - f_t^T$ and the relative ratio of the exchange rate to the non-traded goods fundamental $s_t - f_t^N$.

5.4. Results for Other Emerging Markets Countries

In this section, we test for the existence of exchange rate bubbles in the US Dollar against Colombian Peso and Mexican Peso and the bubble detection results are provided in Table 7.

5.4.1. Colombian Peso (COP)

As shown in Table 7, the null hypothesis of no bubbles in the nominal US Dollar-Colombian peso exchange rate s_t is rejected at the 10% significance level [7]. Figure 13a illustrates two episodes (1997M09-2001M10 and 2002M07-2003M04). The first episode is likely related with the Colombian Banking Crisis between late 1990s and early 2000s.

The nominal exchange rate s_t is no longer explosive as the relative price of traded goods fundamentals explain the explosiveness in Figure 13c, which is consistent with the theory of Engel (1999) and Betts & Kehoe (2005). On the contrary, the relative prices of non-traded goods fundamentals play little role in explaining the explosiveness of exchange rates as the exchange rate series remain explosive after the relative prices of non-traded goods f_t^N are considered. Comparing Figure 13e and Figure 13a shows that the backward SADF statistic sequences for the exchange rate to the non-traded goods fundamental ratio behaves similarly to those of the nominal exchange rate s_t. In addition, we spot another two 'collapse' episodes in Figure 13e (e.g., 2007M04-2007M07 and 2008M01-2008M08).

Model formulation in the null hypothesis seems to have an impact on the PSY approach as detailed in Figure 13b, Figure 13d and Figure 13f. The PSY approach detects two long-lasting episodes in Figure 13b (1994M08-2014M12) and Figure 13f (1995M06-2008M02) and these results are not expected and spurious. Thus the rejection of no bubbles in the null hypothesis under the assumption 'without an intercept' in the PSY could lead to false positive identification. Even if the GSADF test statistic for s_t and $s_t - f_t^N$ indicate evidence of bubbles, we hardly believe the presence of genuine bubbles on a close inspection of the actual exchange rate series.

5.4.2. Mexican Peso (MXN)

The Mexican Peso was pegged to the US Dollar and the Peso was allowed to appreciate or depreciate against the US Dollar within a narrow target band. The Mexican central bank maintained the peg by frequently intervening in the exchange rate markets (Whitt Jr, 1996). As can be seen from Table 7, we find evidence of explosive behavior in the nominal Dollar-Mexican Peso exchange rate s_t under

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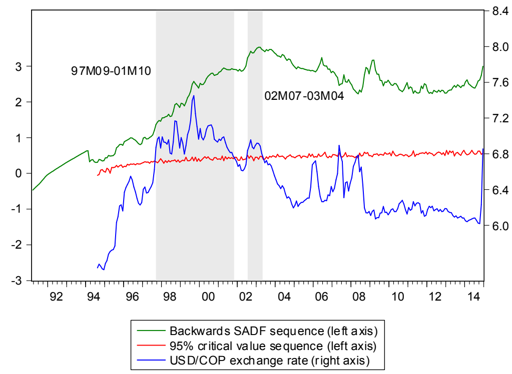
[7] We let r_0=0.15 for the following analysis. If we let $r_0 = 0.01 + 1.8/\sqrt{T}$ and T is 286, r_0 is approximately to 12%. We find that r_0 is not larger enough for initial estimation and therefore consider a larger r_0.

the assumption of the intercept[8]. The null hypothesis of no bubbles in s_t can be rejected at the 1% significance level and can observe two episodes from Figure 14a (i.e., 1994M02-1994M04, 1994M12-1995M04).

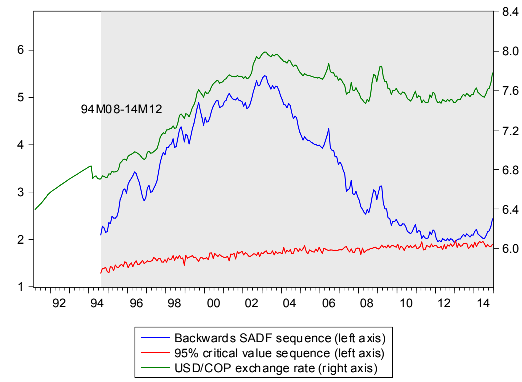
Importantly, our results support the finding of explosiveness in the nominal exchange rate between 1994 and 1995. The episode between 1994M12 and 1995M04 cannot be explained by the two exchange rate fundamentals, which indicates the presence of rational bubbles. The 1994 Mexican currency crisis is one of the most well-known exchange rate crises in the literature. The North American Free Trade Agreement (NAFTA) came into force at the beginning of 1994 and was signed by Canada, Mexico and the US. The agreement aimed at encouraging foreign investors to take advantage of Mexican's access to the US market and lowering trade barriers between two countries (Whitt Jr, 1996). However, in fewer than 12 months, the crisis exploded in December 1994, when the Mexican government suddenly devalued the Peso by 15%. Devaluation of the Peso led to a deep crisis in Mexico's financial services sector (Wilson et al., 2000). Thus the USD/MXN crisis of 1994-1995 is a bubble, which is of particular interest. However, when the intercept is removed from model formulation under the null hypothesis, all three series (s_t, $s_t - f_t^N$ and $s_t - f_t^T$) are not explosive. The null hypothesis of no bubbles cannot be rejected at the 10% level, suggesting no significant evidence of bubbles in the exchange rate. Although there are short-lived episodes in Figure 14b and Figure 14f during 1994-1995, we couldn't conclude that the crisis of 1994-1995 is a bubble when the intercept term is excluded in the null.

[8] We let r_0=0.05 for the following analysis. This is due to the fact that the sample data starts from January 1993 and we would like to test for the evidence of exchange rate bubbles during Mexican currency crisis in 1994-1995. We also carry out an analysis by letting $r_0 = 0.01 + 1.8/\sqrt{T}$ and do not find significant evidence of bubbles.

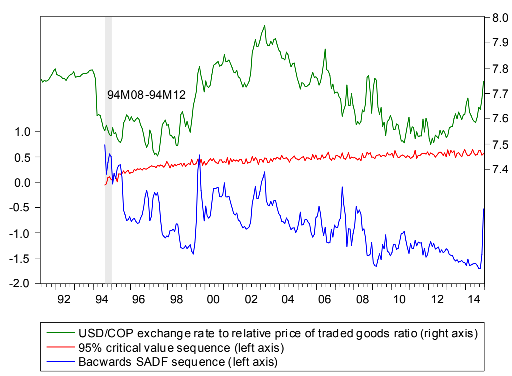
(a) USD/COP s_t with an intercept



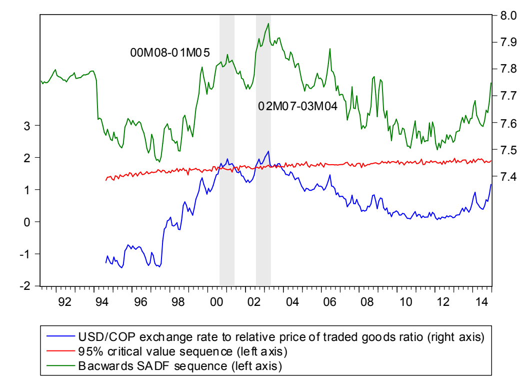
(b) USD/COP s_t without an intercept



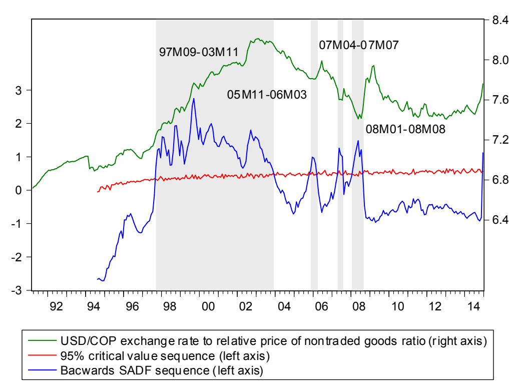
(c) USD/COP $s_t - f_t^T$ with an intercept



(d) USD/COP $s_t - f_t^T$ without an intercept



(e) USD/COP $s_t - f_t^N$ with an intercept



(f) USD/COP $s_t - f_t^N$ without an intercept

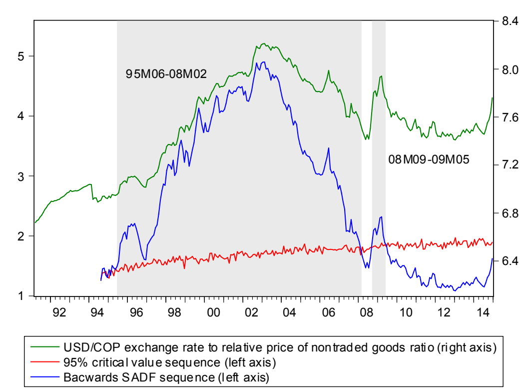
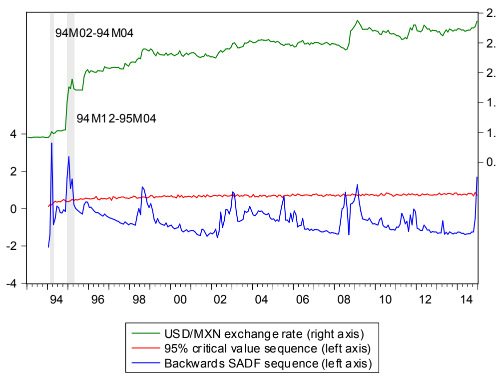
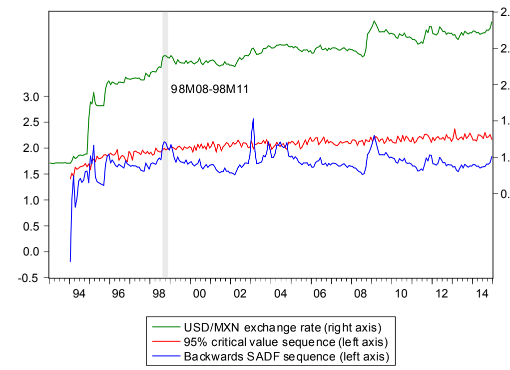


Figure 13: Dating strategy for USD/COP nominal exchange rate s_t, the relative ratio of the exchange rate to the traded goods fundamental $s_t - f_t^T$ and the relative ratio of the exchange rate to the non-traded goods fundamental $s_t - f_t^N$.

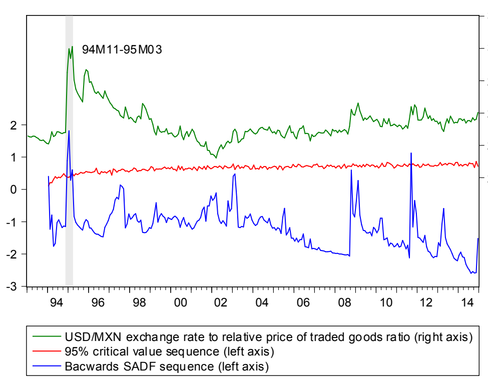
(a) USD/MXN s_t with an intercept



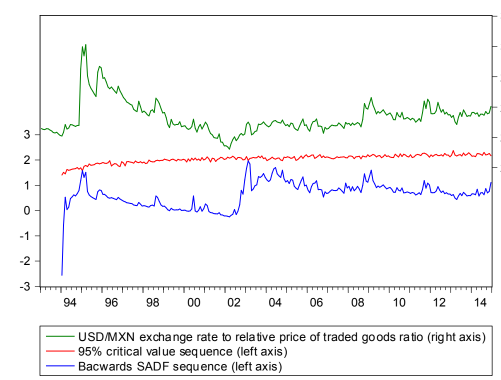
(b) USD/MXN s_t without an intercept



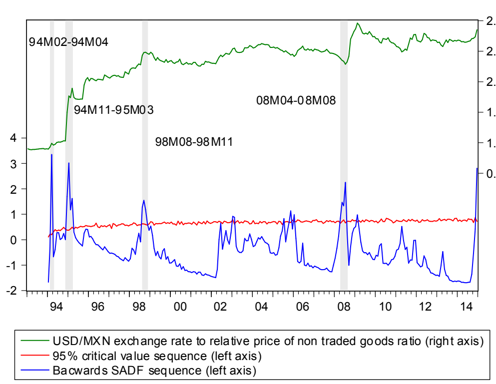
(c) USD/MXN $s_t - f_t^T$ with an intercept



(d) USD/MXN $s_t - f_t^T$ without an intercept



(e) USD/MXN $s_t - f_t^N$ with an intercept



(f) USD/MXN $s_t - f_t^N$ without an intercept

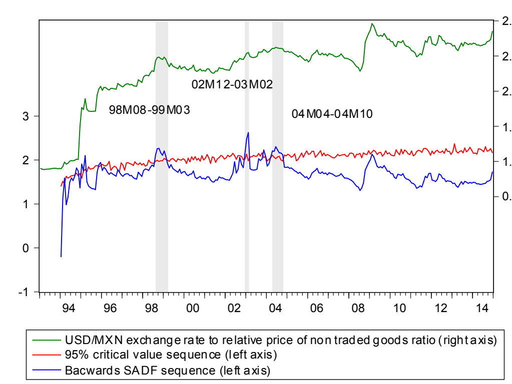


Figure 14: Dating strategy for USD/MXN nominal exchange rate s_t, the relative ratio of the exchange rate to the traded goods fundamental $s_t - f_t^T$ and the relative ratio of the exchange rate to the non-traded goods fundamental $s_t - f_t^N$.

6. Conclusion

In this paper, we test for the explosiveness in the nominal exchange rate and if it is identified, investigate the cause of the explosiveness. We then explore whether the explosiveness in the nominal exchange rate is driven by rational bubbles or exchange rate fundamentals. We concur with Bettendorf & Chen (2013), that explosiveness in the asset price does not, on its own, imply the existence of rational bubbles, where it is necessary to consider the role played by economic fundamentals in asset prices. Following the recent work of Bettendorf & Chen (2013) and Jiang et al. (2015), we use the GSADF test of Phillips, Shi & Yu (2015b, PSY) to investigate the evidence of exchange rate bubbles for both G10 and emerging markets countries (including some Asian and BRICS countries). The results can be summarized as follows.

Results for some G10 cross rates as presented in Table 1, Table 2 and Table 3 suggest, no evidence of bubbles in most exchange rate pairs with only a few exceptions. Under the assumption 'with an intercept', the GSADF test statistic for the Sterling-Swiss Franc and Sterling-Japanese Yen seems to suggest evidence of bubbles as the test statistic is significant at 1% or 5% level in Table 1. In fact, the PSY identifies several 'collapse' episodes rather than bubbles as it cannot distinguish between 'collapse' episodes and bubbles if the intercept term is included in the null. Hence, we find little evidence of bubbles in these two exchange rate pairs.

Some interesting results are obtained from the Asian currencies. Firstly, in line with the theory of Engel (1999) and Betts & Kehoe (2005), the relative prices of traded goods play an important role in explaining the majority of the movements in the US Dollar-Philippine Peso, US Dollar-Indonesian Rupiah and US Dollar-Singapore Dollar (under the model specification 'with an intercept') exchange rates. Secondly, our results indicate that the exchange rate movements between Korea, Malaysia, Thailand and the US cannot be explained by the theory of Engel (1999) and Betts & Kehoe (2005), who find that the relative prices of traded goods explain most of the movements in exchange rates. We conclude that neither the relative prices of traded goods nor the relative prices of non-traded goods explain the explosiveness in the US Dollar-Thai Baht and US Dollar-Korean Won exchange rates, which confirm the presence of rational bubbles. Unlike existing studies, our empirical results also suggest that the relative prices of traded goods don't explain most movements in the US Dollar-Malaysian Ringgit exchange rate under two model specifications. Lastly, we find evidence of bubbles or rational bubbles in several Asian currencies during the 1997 Asian Financial Crisis and also identify several 'collapse' episodes and 'collapse and recovery' episodes.

Our results from the three BRICS countries (e.g., Brazil, India and South African) suggest that the relative prices of traded goods account for the majority of the movements in the exchange rate, which confirms Engel (1999) and Betts & Kehoe (2005). Overall, we find evidence of bubbles for these currencies but some evidence obtained from the model specification 'without an intercept' is spurious (e.g., Indian Rupee and South African Rand).

We also find evidence of explosive behavior in the US Dollar-Colombian Peso exchange rate but the evidence obtained from the model specification 'without an intercept' is spurious. The explosiveness in the US Dollar-Colombian Peso seems to be explained by the relative prices of traded goods. Moreover, we find significant evidence of explosive behavior in the US Dollar-Mexican Peso exchange rate as well. Our results also support the hypothesis that there is a bubble in the US Dollar-Mexican Peso exchange rate during the 1994-1995 Mexican currency crisis and this finding should be of some considerable interest.

Overall, we obtain quite different results when using a model specification 'without an intercept' in the null hypothesis. First, the null hypothesis of no explosive bubbles is frequently not rejected as the critical values become larger under the model specification without an intercept. Second, when the intercept term is included in the model formulation for constructing the null hypothesis, we will identify both 'collapse' episodes, 'collapse and recovery' episodes and potential bubbles as the PSY cannot distinguish between the 'collapse' type of episodes and bubbles. Third, if the null hypothesis involves no intercept, the 'collapse' type of episodes will not be identified by the PSY approach but some episodes may be spurious (e.g., Philippine Peso, Indian Rupee, South African Rand and Colombian Peso). In short, the intercept term affects the asymptotic theory and date-stamping strategy of the PSY approach. The inclusion of the intercept demonstrates the practical importance in right-tailed unit root tests. It is of great importance to assess a wide range of specifications in the null and make a suitable choice.

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