UNIVERSITY OF WAIKATO

Hamilton New Zealand

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

Yang Hu and Les Oxley

Department of Economics

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Corresponding Author

Les Oxley
Economics Department
Waikato Management School
University of Waikato
Private Bag 3105
Hamilton
NEW ZEALAND, 3216

Phone: +64 (0)7 856 7207

Email: loxley@waikato.ac.nz

Yang Hu
Economics Department
Waikato Management School
University of Waikato
Private Bag 3105
Hamilton
NEW ZEALAND, 3216

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 or recovery and also spurious bubbles. Whereas without an intercept in the null leads to identification of only bubbles (if they exist) and none is spurious. Bubbles are considered in the nominal exchange rate, which are then tested whether they are driven by exchange rate fundamentals (the relative price of traded or non-traded goods) or represent rational bubbles. We also test for bubbles in the exchange rate fundamentals themselves. 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 (see eg 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).

In this paper, we use two different model specifications for the null hypothesis in right-tailed unit root tests (a model without an intercept 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. We will demonstrate and compare the bubble detection results using the aforementioned model specifications. The model specification 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):

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

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

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[3]. 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.

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 [4]. 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). We therefore only discuss the bubble-detection results for these two exchange rates.

5.1.1. GBP/CHF

The left panel of Figure 1 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 1 presents the bubble detection results for s_t, $s_t - f_t^T$ and $s_t - f_t^N$ using

[3]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.

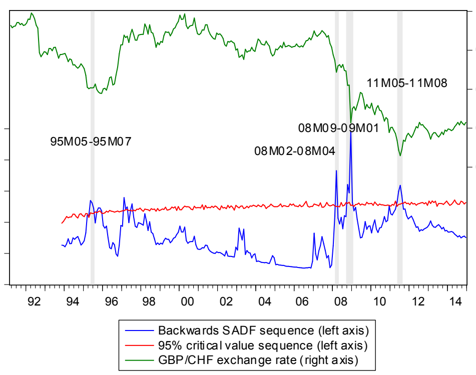
[4]The critical values for the null hypothesis with an intercept: 1.8569 (90%), 2.0977 (95%), 2.6217 (99%). The critical values for the null hypothesis without an intercept: 3.1247 (90%), 3.5343 (95%), 4.2359 (99%). When the intercept term is added, the critical values get larger.

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 1a 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.

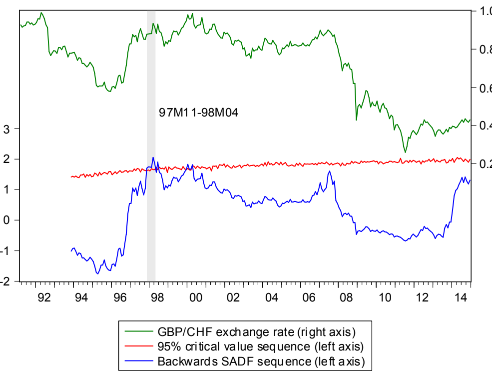
Figure 1c and Figure 1e display the backward SADF statistic sequences for the nominal exchange rate to relative prices of traded goods fundamentals $s_t - f_t^T$ and relative prices of non-traded goods fundamentals $s_t - f_t^N$, respectively. The relative prices of traded goods f_t^T have explained some explosiveness in the nominal exchange rate, while the relative prices of non-traded goods f_t^N play little role in explaining the explosiveness in the nominal exchange rate. We find a collapse and recovery episode between 2008M09 and 2009M01. Neither f_t^T or f_t^N has explained the explosiveness between 2008M09 and 2009M01, which implies the presence of rational 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.

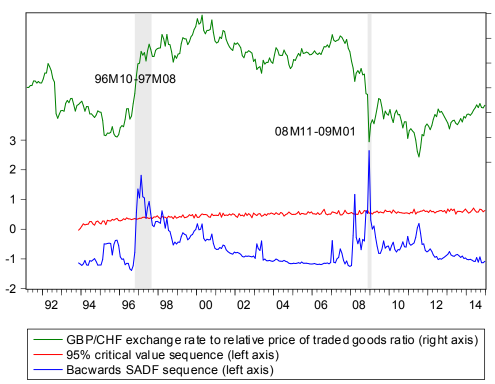
(a) GBP/CHF s_t with an intercept



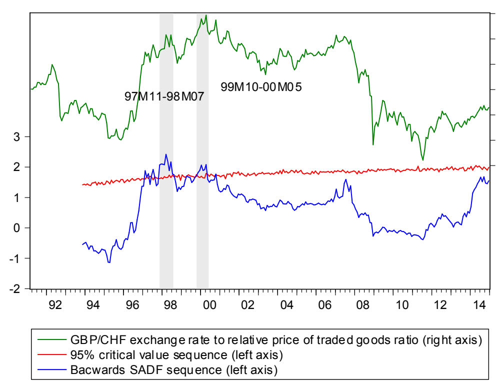
(b) GBP/CHF s_t without an intercept



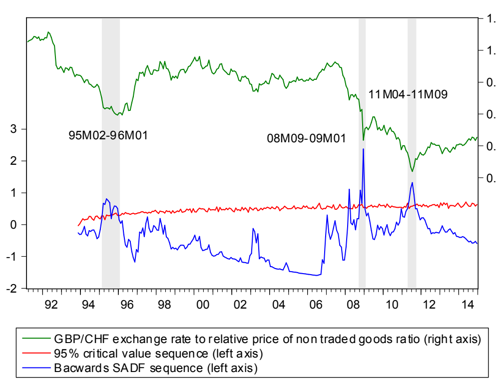
(c) GBP/CHF $s_t - f_t^T$ with an intercept



(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

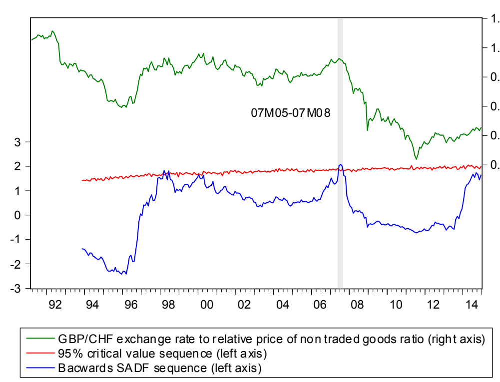


Figure 1: Dating strategy for GBP/CHF nominal exchange rate s_t, the relative ratio of the exchange rate to the traded goods fundamental $s_t - f_t^T$ and the relative ratio of the exchange rate to the non-traded goods fundamental $s_t - f_t^N$.

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	3.1743* [a]	94M07-96M10, 10M11-12M11
		10M11-12M04		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	2.6662	93M11-95M10
		08M11-09M03		
$s_t - f_t^N$	1.8988*	93M11-94M03, 95M02-95M06	3.0832	93M11-96M05, 00M08-03M05
		01M09-01M10, 08M11-09M03		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	

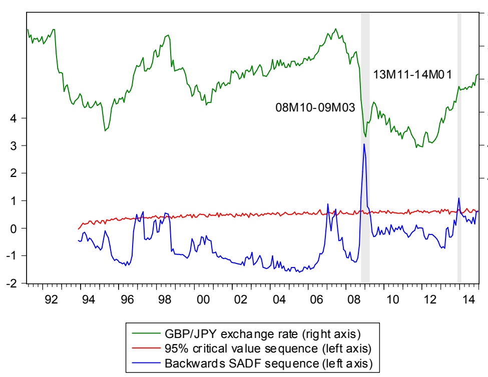
[a]* indicates significance at 10% level.
[b]*** indicates significance at 1% level.

5.1.2. GBP/JPY

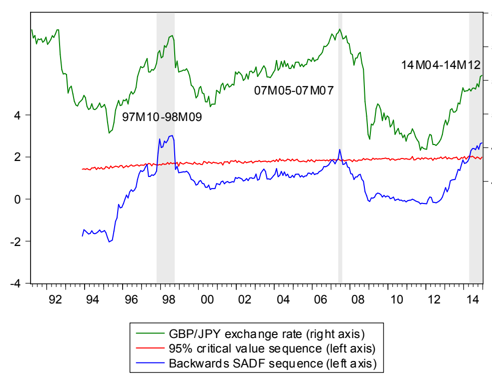
Under the null hypothesis with an intercept, Table 1 provides strong evidence of explosive behavior in the nominal exchange rate s_t for GBP/JPY at the 1% significance level. The exchange rate s_t is still explosive although both the relative prices of traded goods f_t^T and the relative prices of non-traded goods f_t^N are taken into account. Results from Figure 2c and Figure 2e suggest that both f_t^T and f_t^N do not explain the explosiveness in the Sterling-Japanese Yen exchange rate. These findings therefore indicate the presence of rational bubbles in the nominal exchange rate. As shown in Figure 2a, 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 2a, Figure 2c and Figure 2e, all three series are declining and then recovering between 2008M10 and 2009M03 and rather than growing are collapsing. We may regard this type of episode as an "inverse bubble".

By comparing the left panel of Figure 2 and right panel of Figure 2, 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 2b: 1997M10-1998M09, 2007M05-2007M07 and 2014M04-2014M12. All episodes identified from the right panel of Figure 2 correspond to a growth and collapse bubble except the 2014M04-2014M12. The nominal exchange rate series remains explosive after both traded and non-traded goods components are taken into account in Figure 2d and Figure 2f. We do not now detect the crash and recovery type of episodes between 2008M10 and 2009M03. Our findings still indicate the strong evidence of rational bubbles in the nominal exchange rate as they are not explained by exchange rate fundamentals.

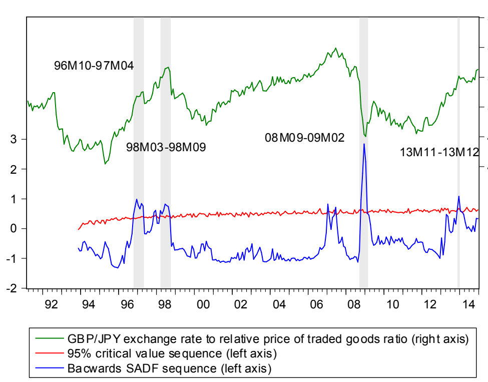
(a) GBP/JPY s_t with an intercept



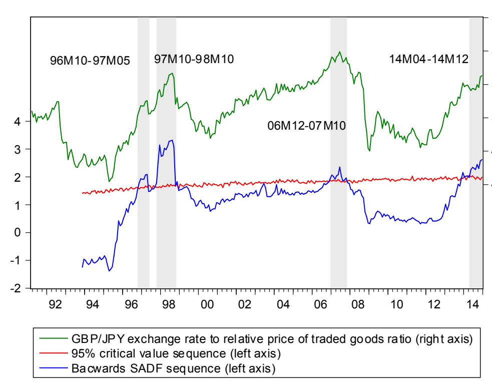
(b) GBP/JPY s_t without an intercept



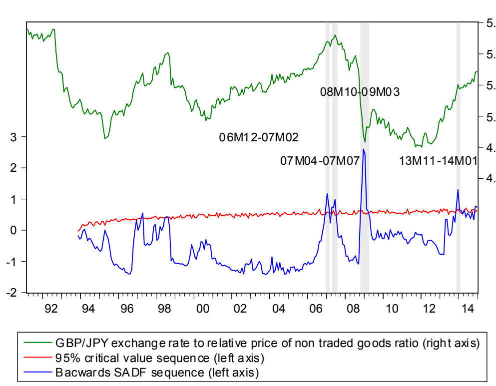
(c) GBP/JPY $s_t - f_t^T$ with an intercept



(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

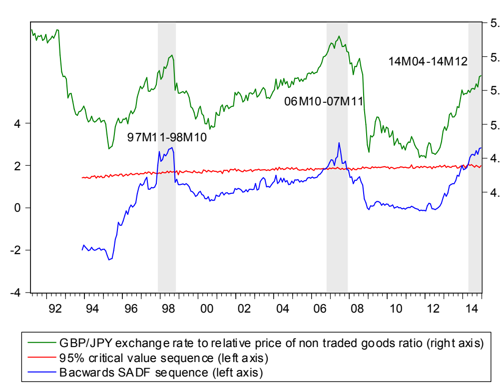


Figure 2: Dating strategy for GBP/JPY nominal exchange rate s_t, the relative ratio of the exchange rate to the traded goods fundamental $s_t - f_t^T$ and the relative ratio of the exchange rate to the non-traded goods fundamental $s_t - f_t^N$.

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 3a, there are two explosive bubbles in the nominal exchange rate (1997M07-1998M02 and 2008M01-2008M05). However, the explosiveness in 1997-1998 is driven by neither the relative prices of traded goods nor non-traded goods. Similarly, neither the relative prices of traded goods nor the relative prices of non-traded goods can explain the explosiveness in 2008. The explosiveness between 2008M01 and 2008M05 corresponds to a crash and recovery episode. In both cases, 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 3c and Figure 3e, respectively. We therefore conclude that neither the relative prices of traded goods nor non-traded goods could explain the explosiveness in the Dollar-baht exchange rate s_t, which suggest the existence of rational bubbles.

The right panel of Figure 3 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 an episode 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	2.4169	97M10-98M02
		08M01-08M05, 10M08-10M12		
USD/IDR				
s_t	9.1720***	94M08-96M08, 96M11-98M09	15.7484***	93M11-98M02, 98M05-98M08
		13M07-14M02		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	2.0424	97M10-98M01
		13M08-13M09		
USD/KRW				
s_t	9.9778***	95M03-95M08, 96M12-98M02	4.5216***	93M11-95M04, 96M05-98M02
		08M08-08M11, 09M01-09M02		
$s_t - f_t^N$	9.5177***	95M02-95M08, 97M01-98M03	2.3598	93M11-94M05, 97M02-98M02
		04M11-05M05, 05M12-06M06		
		08M08-08M11, 09M01-09M02		
$s_t - f_t$	9.9778***	95M03-95M08, 97M09-98M02	2.9672	93M11-94M11, 97M08-97M12
		08M08-08M11		08M09-08M11

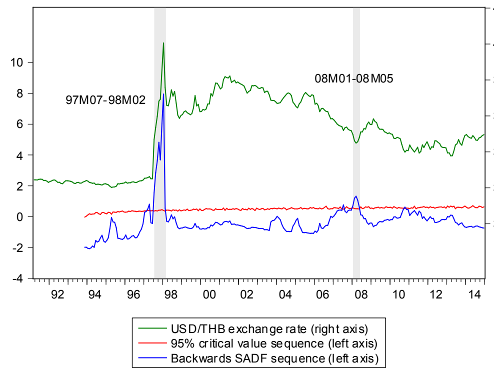
[a] *** indicates significance at 1% level.

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

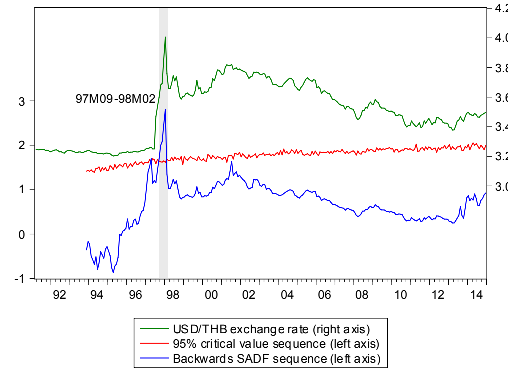
Exchange rate	Test Stat under H_0 with an intercept	Bubble Episodes	Test Stat under H_0 without an intercept	Bubble Episodes
USD/MYR				
s_t	6.8802*** [a]	97M08-98M08, 03M03-03M06	3.3746**	97M09-98M02, 98M05-98M08
		06M02-06M06, 06M11-08M08		
$s_t - f_t^N$	8.3895***	97M08-98M09	3.4557** [b]	97M09-98M02, 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.

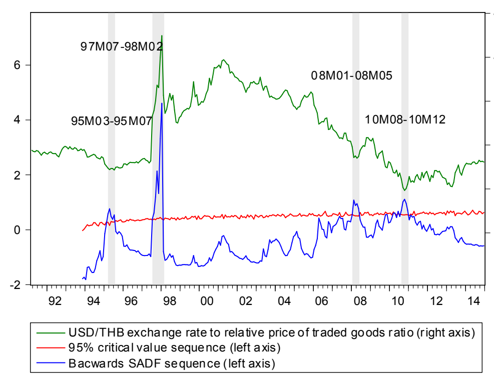
(a) USD/THB s_t with an intercept



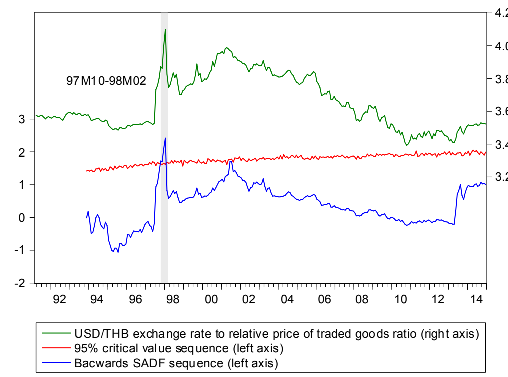
(b) USD/THB s_t without an intercept



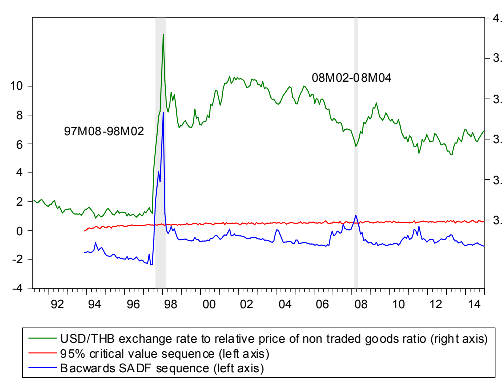
(c) USD/THB $s_t - f_t^T$ with an intercept



(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

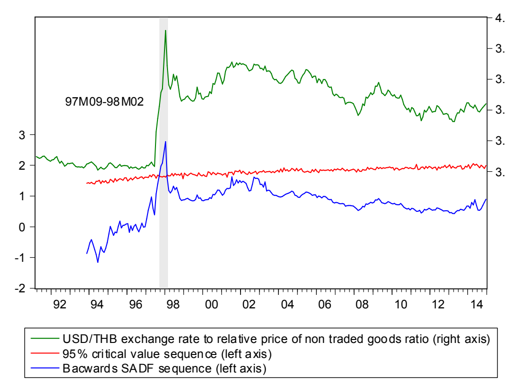


Figure 3: Dating strategy for USD/THB nominal exchange rate s_t, the relative ratio of the exchange rate to the traded goods fundamental $s_t - f_t^T$ and the relative ratio of the exchange rate to the non-traded goods fundamental $s_t - f_t^N$.

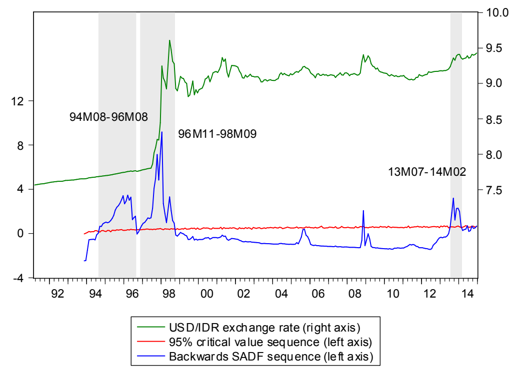
5.2.2. Indonesian Rupiah (IDR)

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).

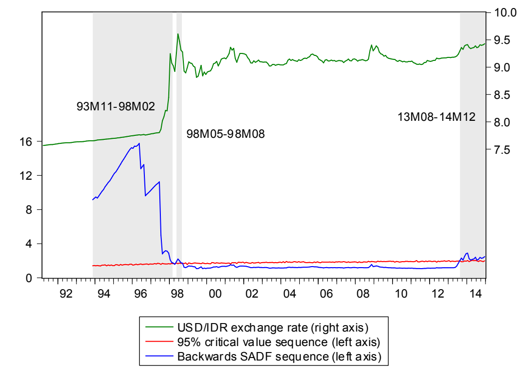
Under the model specification with an intercept, the null hypothesis of no explosive behavior in the nominal Indonesian Rupiah-Dollar exchange rate is rejected at the 1% significance level as listed in Table 4. We find the presence of multiple bubbles in the nominal exchange rate including 1994M08-1996M08, 1996M11-1998M09 and 2013M07-2014M02 from Figure 4*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.

Bubble detection results under the model specification without an intercept provide different results. Under the model specification without an intercept, 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. The $s_t - f_t^N$ series is also significant at the 1% level, which indicates strong evidence of explosive subperiods (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 4d, 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).

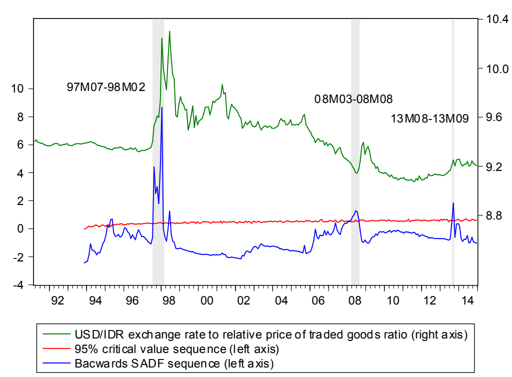
(a) USD/IDR s_t with an intercept



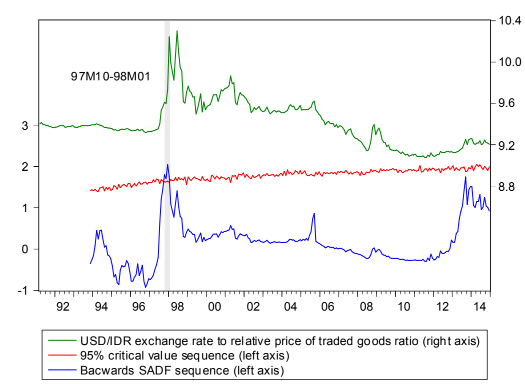
(b) USD/IDR s_t without an intercept



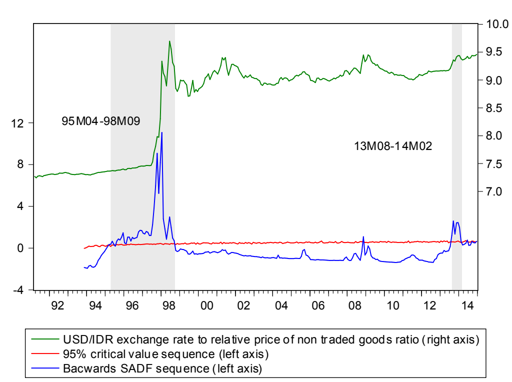
(c) USD/IDR $s_t - f_t^T$ with an intercept



(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

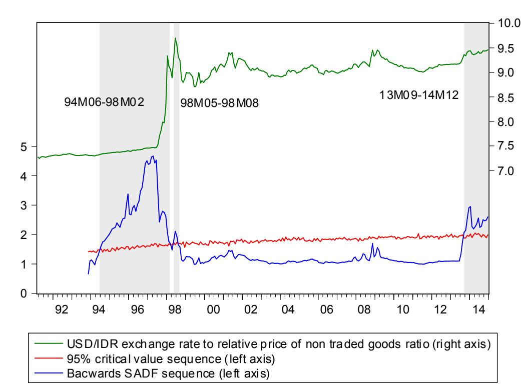


Figure 4: Dating strategy for USD/IDR nominal exchange rate s_t, the relative ratio of the exchange rate to the traded goods fundamental $s_t - f_t^T$ and the relative ratio of the exchange rate to the non-traded goods fundamental $s_t - f_t^N$.

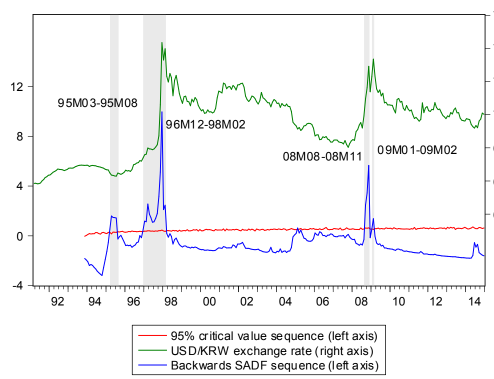
5.2.3. Korean Won (KWR)

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 results are shown in Table 4. Figure 5a, Figure 5c and Figure 5e shows the date-stamping bubbles periods in s_t, $s_t - f_t^T$ and $s_t - f_t^N$ under the model specification with an intercept, respectively. Four bubbles periods are identified from Figure 5a including 1995M03-1995M08, 1996M12-1998M02, 2008M08-2008M11 and 2009M01-2009M02.

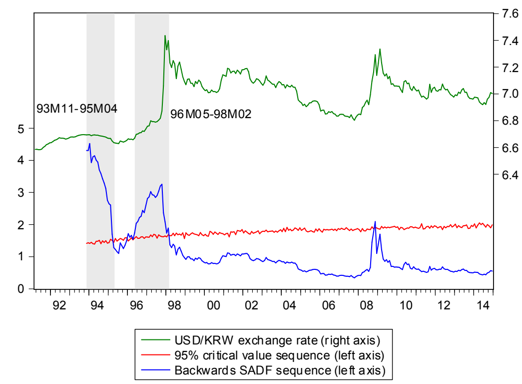
Firstly, we find the evidence of explosiveness between March 1995 and August 1995 in all three series. The exchange rate s_t remains explosive after both the relative prices of traded goods f_t^T and non-traded goods f_t^N are taken into account. Thus f_t^T and f_t^N play no role in explaining the explosive 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 bubbles periods (2008M08-2008M11 and 2009M01-2009M02) identified in the s_t series 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 contributes 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 may therefore conclude in favour of evidence of rational bubbles. 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.

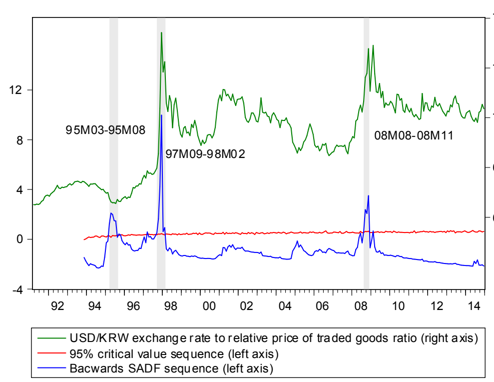
(a) USD/KRW s_t with an intercept



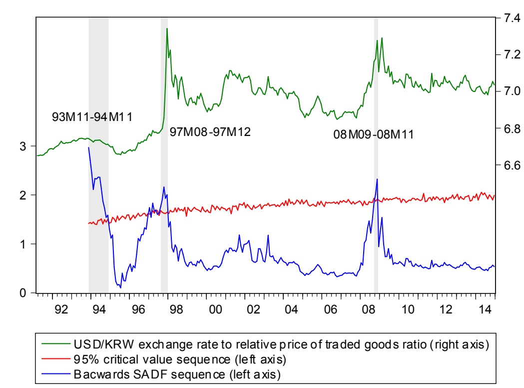
(b) USD/KRW s_t without an intercept



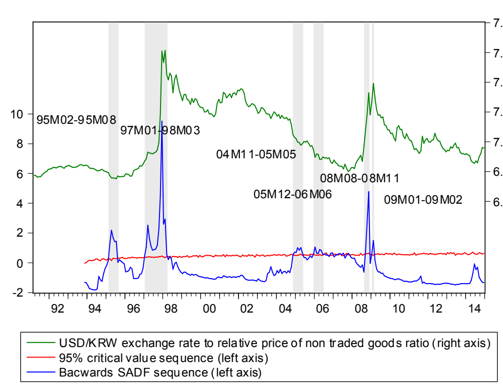
(c) USD/KRW $s_t - f_t^T$ with an intercept



(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

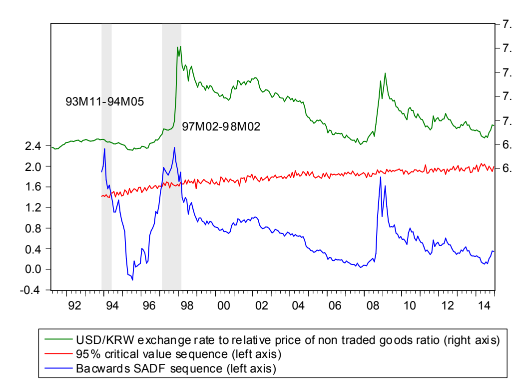


Figure 5: Dating strategy for USD/KRW nominal exchange rate s_t, the relative ratio of the exchange rate to the traded goods fundamental $s_t - f_t^T$ and the relative ratio of the exchange rate to the non-traded goods fundamental $s_t - f_t^N$.

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 6a, there is evidence of multiple bubbles in the nominal Malaysian Ringgit-Dollar 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 6a and the ratio of the exchange rate to the non-traded goods fundamental $s_t - f_t^N$ of Figure 6e 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 6c. Such bubbles correspond 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.

Our empirical results suggest that the relative prices of non-traded goods f_t^N have explained most movements in s_t based on model specification with an intercept. The exchange rate series is no longer explosive after the relative prices of non-traded goods f_t^N are taken into account except the bubble period during the 1997 Asian Financial Crisis. The relative prices of traded goods also play an important role in explaining the explosiveness in s_t as well, but the explosive behaviours during the 1997 Asian Financial Crisis and 2008 Global Financial Crisis are not driven by the relative prices of traded goods.

However, we obtain quite different results if the intercept is excluded in the model formulation. The null hypothesis of no explosive bubbles under model specification without an intercept for s_t and $s_t - f_t^N$ are rejected at the 5% significance level. We find two explosive episodes from s_t (1997M09-1998M02 and 1998M05-1998M08) and one episode from $s_t - f_t^N$ (1997M09-1998M02). 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 episode in 1997-1998, we therefore conclude the evidence of rational bubbles.

It is perhaps noteworthy to mention some interesting findings from the GSADF test using the two model specifications. First, we find a spurious bubble episode in 2003 for nominal exchange rate s_t in Figure 6a. 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 6a, there is a spurious bubble episode dated from March 2003 to June 2003 in the series. We could not explain the reason behind this explosive period. Second, we notice two crash and recovery episodes (2006M02-2006M06 and 2006M11-2008M08) in Figure 6a in the nominal exchange rate s_t. This spurious bubble episode in 2003 and two crash 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 6a and Figure 6b. 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 spurious bubble episode in 2003 and crash and recovery episodes any longer.

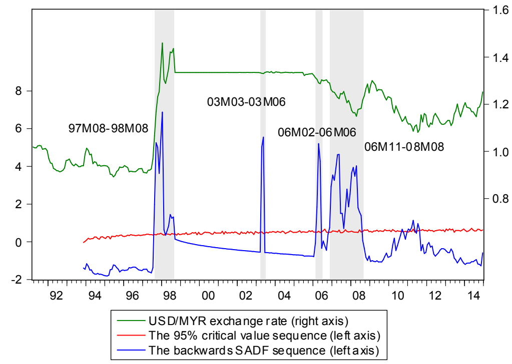
5.2.5. Philippine Peso (PHP)

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 7a, there is evidence of two bubbles in the US Dollar-Philippine Peso exchange rate s_t including 1997M08-1998M10 and 2006M12-2008M05. The first explosive episode 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.

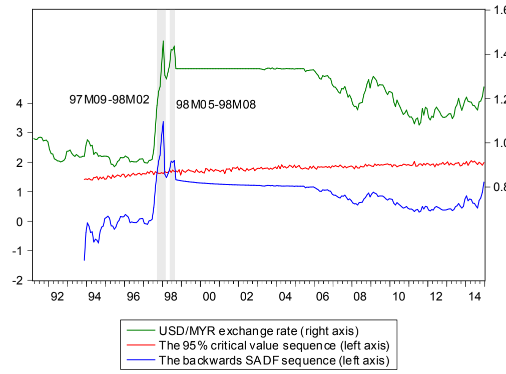
As can be seen in Figure 7c, we find no evidence of explosiveness in the $s_t - f_t^T$ series for the second explosive period in 2007-2008, which is likely associated with the 2008 Global Financial Crisis. According to Figure 7e, the exchange rate still remains explosive after the relative prices of 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 7. 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 7b and Figure 7f, respectively and these results are not expected. 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.

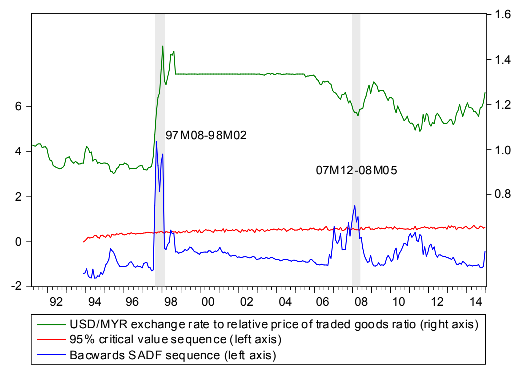
(a) USD/MYR s_t with an intercept



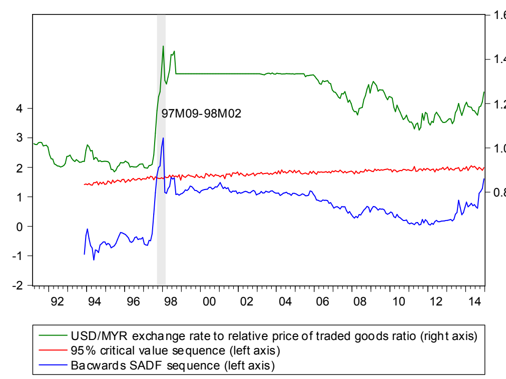
(b) USD/MYR s_t without an intercept



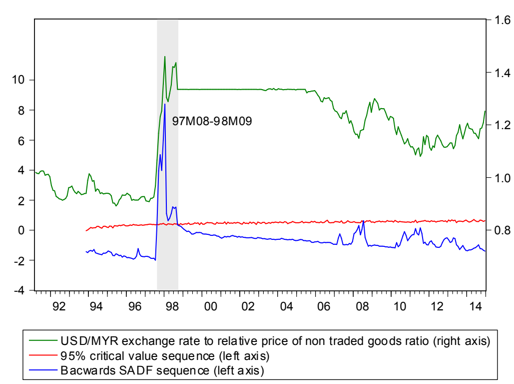
(c) USD/MYR $s_t - f_t^T$ with an intercept



(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

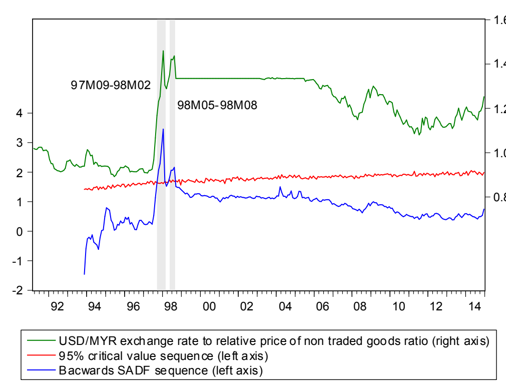
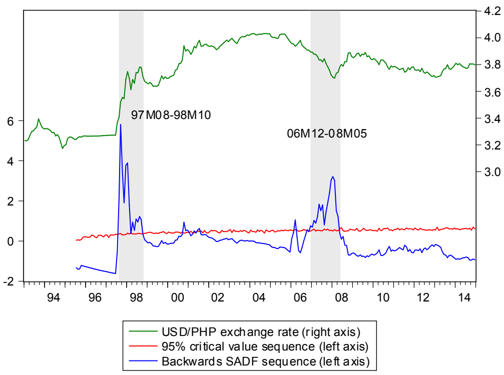
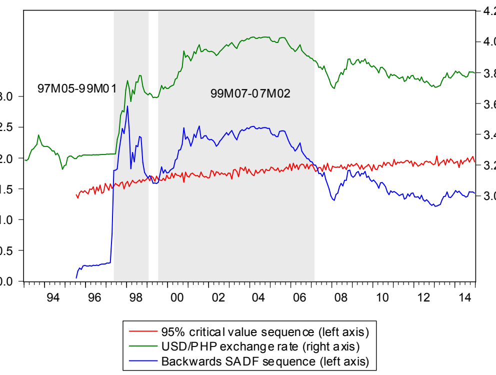


Figure 6: Dating strategy for USD/MYR nominal exchange rate s_t, the relative ratio of the exchange rate to the traded goods fundamental $s_t - f_t^T$ and the relative ratio of the exchange rate to the non-traded goods fundamental $s_t - f_t^N$.

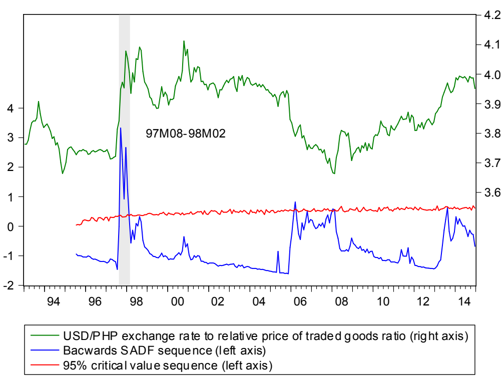
(a) USD/PHP s_t with an intercept



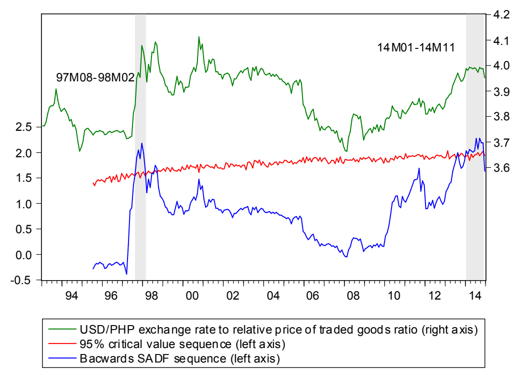
(b) USD/PHP s_t without an intercept



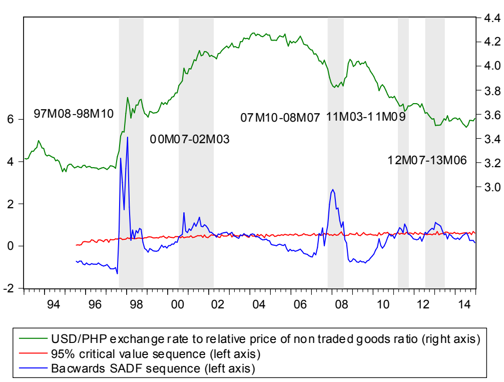
(c) USD/PHP $s_t - f_t^T$ with an intercept



(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

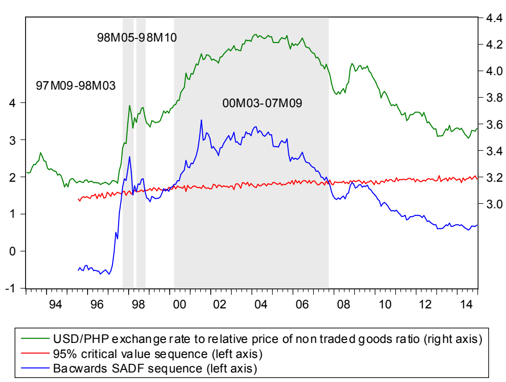


Figure 7: Dating strategy for USD/PHP nominal exchange rate s_t, the relative ratio of the exchange rate to the traded goods fundamental $s_t - f_t^T$ and the relative ratio of the exchange rate to the non-traded goods fundamental $s_t - f_t^N$.

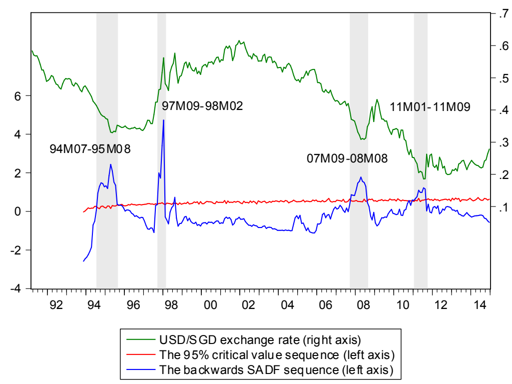
5.2.6. Singapore Dollar (SGD)

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.

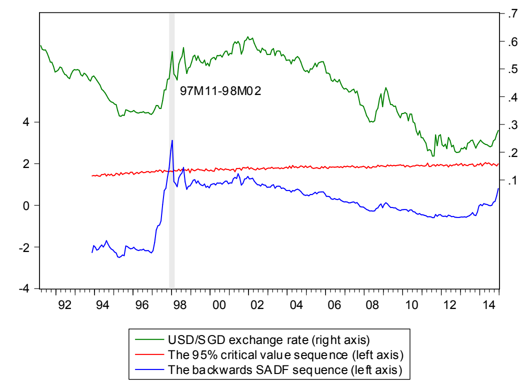
As can be seen from Table 5, we find strong evidence of explosive behaviour in the nominal exchange rate s_t, the ratio of the exchange rate to the traded goods fundamental $s_t - f_t^T$ and the ratio of the exchange rate to the non-traded goods fundamental $s_t - f_t^N$ at the 1% significance level. As shown in Figure 8a, evidence of multiple bubbles is found in the nominal exchange rate s_t (e.g., 1994M07-1995M08, 1997M09-1998M02, 2007M09-2008M08 and 2011M01-2011M09). The first episode in 1994-1995 is explained by the relative prices of traded goods. The second explosive period 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. The explosiveness in the nominal exchange rate during 2007-2008 and 2011 is explained by the relative prices of traded goods. Overall, as illustrated by Figure 8c, the relative prices of traded goods play an important role in explaining the majority of the movements in s_t as the $s_t - f_t^T$ remains explosive only during the 1997-1998. In contrast, the relative prices of non-traded goods play little role in explaining the explosiveness in s_t based on Figure 8e.

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. The episode in 1997-1998 is explosive in Figure 8b, Figure 8d and Figure 8f, which suggests the evidence of rational bubbles. We find crash and recovery type episodes in s_t in Figure 8a (e.g., 1994M07-1995M08, 2007M09-2008M08 and 2011M01-2011M09) and $s_t - f_t^N$ in Figure 8e (e.g., 1994M07-1995M11, 2008M02-2008M04 and 2010M08-2011M09) only. Once the intercept is removed, we no longer find crash 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. These results are inconsistent with early finding using the intercept for constructing the hypothesis.

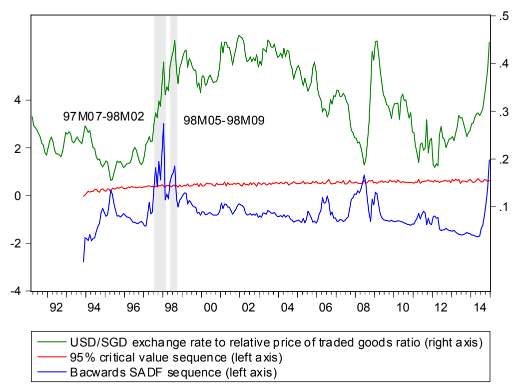
(a) USD/SGD s_t with an intercept



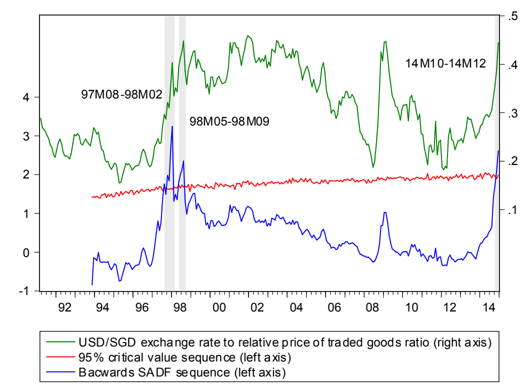
(b) USD/SGD s_t without an intercept



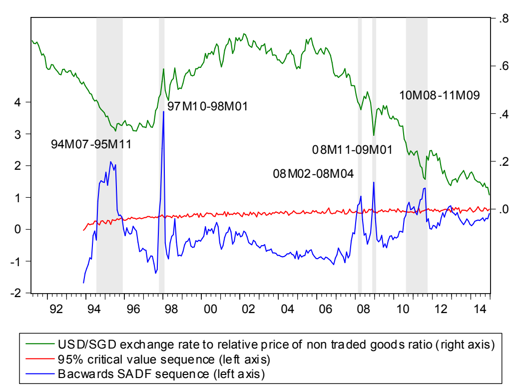
(c) USD/SGD $s_t - f_t^T$ with an intercept



(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

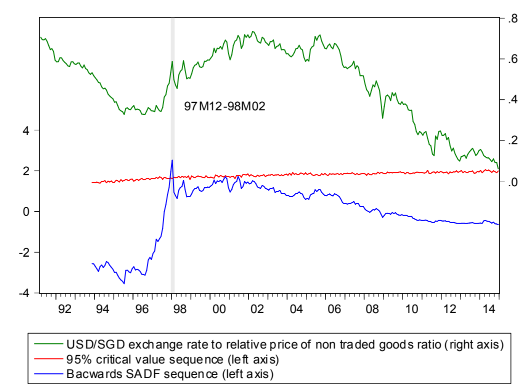


Figure 8: Dating strategy for USD/SGD nominal exchange rate s_t, the relative ratio of the exchange rate to the traded goods fundamental $s_t - f_t^T$ and the relative ratio of the exchange rate to the non-traded goods fundamental $s_t - f_t^N$.

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.[5]

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 9a 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 episodes can be seen in Figure 9a as well (e.g., 2001M07-2001M10, 2002M06-2002M07, 2002M09-2002M10 and 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 9c, 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.

[5] 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.

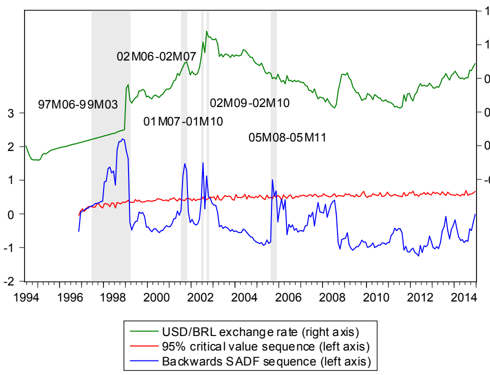
When the intercept is not used for constructing the hypothesis, s_t and $s_t - f_t^N$ are still significant at 1% level while the null hypothesis of no explosive bubbles in $s_t - f_t^T$ cannot be rejected at 10% level. There are two crash and recovery episodes in Figure 9a (2005M08-2005M11) and Figure 9e (2005M08-2006M04). We cannot detect these crash and recovery episodes any more in the right panel of Figure 9. 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)

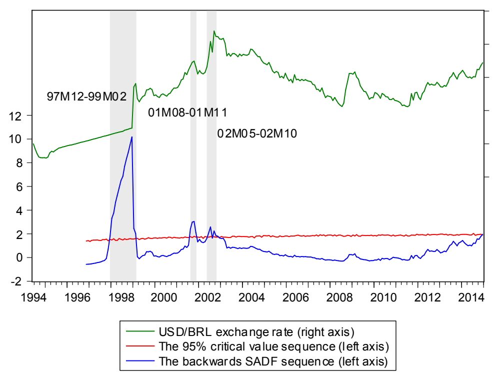
Results for the nominal US Dollar-India Rupee exchange rate are shown in Table 6. The GSADF test suggests strong evidence of bubbles in the nominal exchange rate as the null of no explosive behavior is rejected at the 1% significance level. Figure 10a shows the date-stamping results for the nominal exchange 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 10c once the relative prices of traded goods $s_t - f_t^T$ are accounted for.

The date-stamping results for the model specification under the assumption of no intercept is quite different as shown in Figure 10b, Figure 10d and Figure 10f. In Figure 10b, 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 10f. 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.

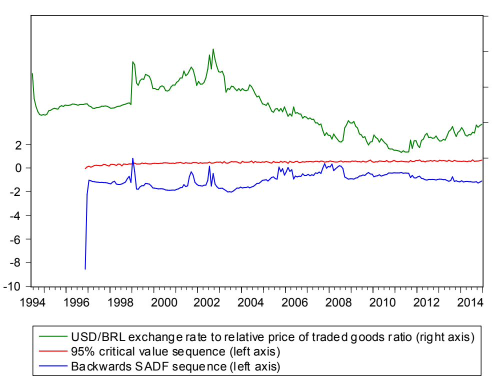
(a) USD/BRL s_t with an intercept



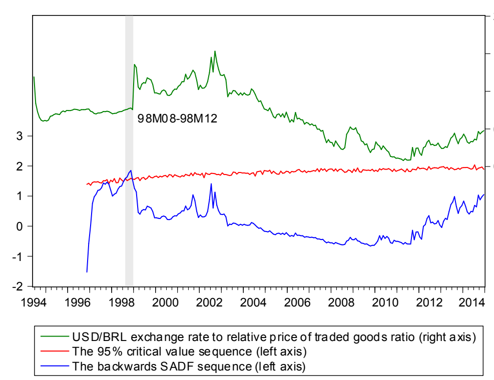
(b) USD/BRL s_t without an intercept



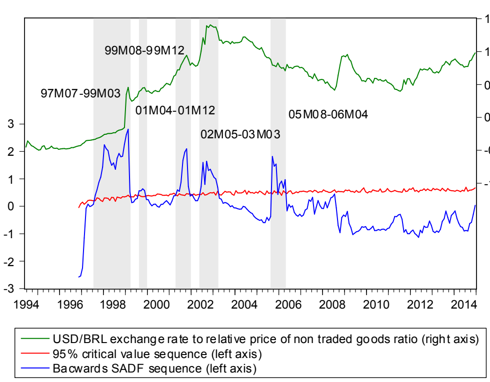
(c) USD/BRL $s_t - f_t^T$ with an intercept



(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

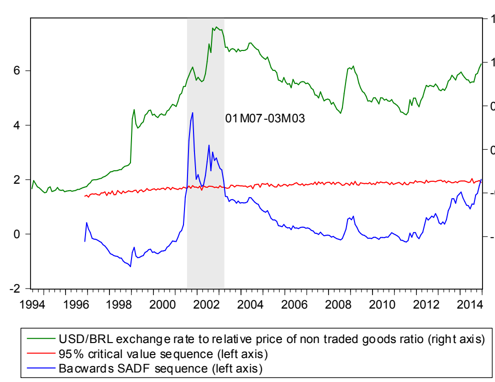


Figure 9: Dating strategy for USD/BRL nominal exchange rate s_t, the relative ratio of the exchange rate to the traded goods fundamental $s_t - f_t^T$ and the relative ratio of the exchange rate to the non-traded goods fundamental $s_t - f_t^N$.

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	10.1813*** [b]	97M12-99M02, 01M08-01M11
		02M06-02M07, 02M09-02M10		02M05-02M10
		05M08-05M11		
$s_t - f_t^N$	2.7464***	97M07-99M03, 99M08-99M12	4.4563***	01M07-03M03
		01M04-01M12, 02M05-03M03		
		05M08-06M04		
$s_t - f_t$	0.8156		1.8511	98M08-98M12
USD/INR				
s_t	2.7861***	95M11-96M02, 98M03-99M02	4.0151**	93M12-14M12
		01M09-02M05, 04M01-04M04		
$s_t - f_t^N$	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	4.8427***	93M11-03M09
		98M04-98M10, 98M12-99M04		
		00M08-02M09		
$s_t - f_t^N$	4.9297***	94M02-94M08, 96M03-97M02	5.0760***	93M11-03M09
		97M09-99M08, 00M08-02M11		
$s_t - f_t$	2.1865**	98M06-98M08, 00M10-01M04	2.8881	96M03-96M12, 98M05-98M09
		01M09-02M03		00M04-02M04

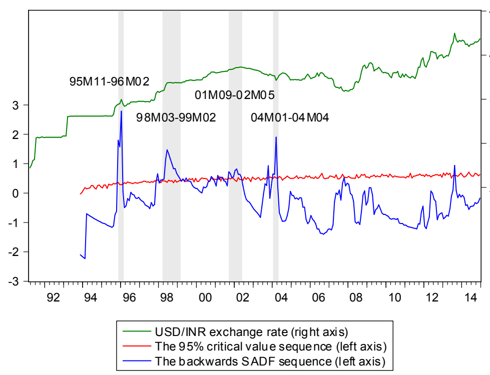
[a]** indicates significance at 5% level.
[b]*** indicates significance at 1% level.

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

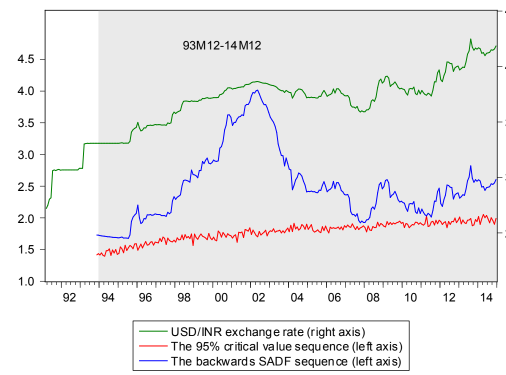
Exchange rate	Test Stat under H_0 with an intercept	Bubble Episodes	Test Stat under H_0 without an intercept	Bubble Episodes
USD/COP				
s_t	2.1757** [a]	97M09-01M10, 02M07-03M04	5.4578*** [b]	94M08-14M12
$s_t - f_t^N$	2.7464***	97M09-03M11, 05M11-06M03	4.9002***	95M06-08M02, 08M09-09M05
		07M04-07M07, 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.

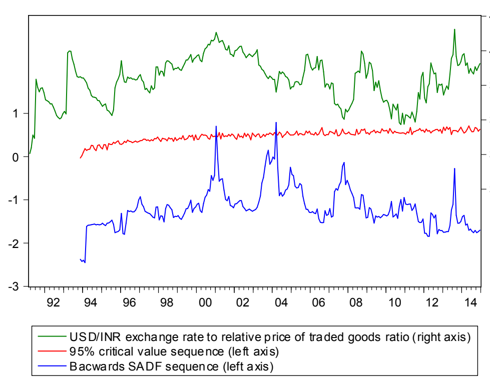
(a) USD/INR s_t with an intercept



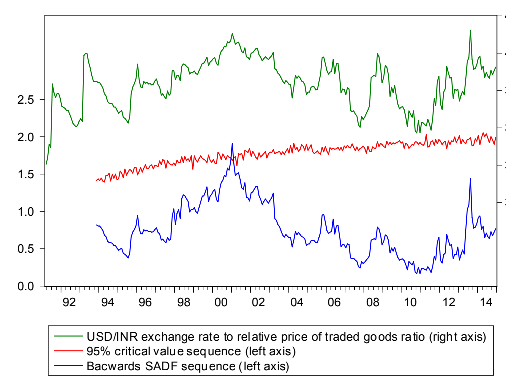
(b) USD/INR s_t without an intercept



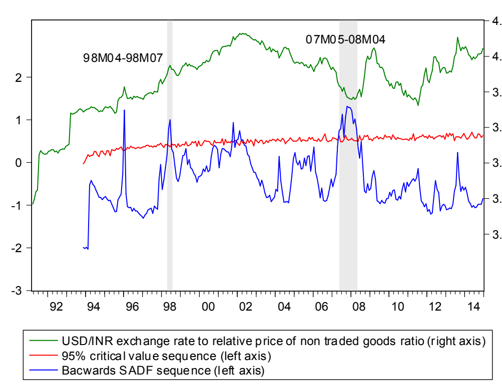
(c) USD/INR $s_t - f_t^T$ with an intercept



(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

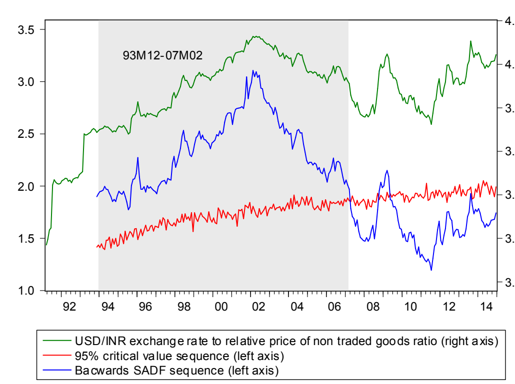


Figure 10: Dating strategy for USD/INR nominal exchange rate s_t, the relative ratio of the exchange rate to the traded goods fundamental $s_t - f_t^T$ and the relative ratio of the exchange rate to the non-traded goods fundamental $s_t - f_t^N$.

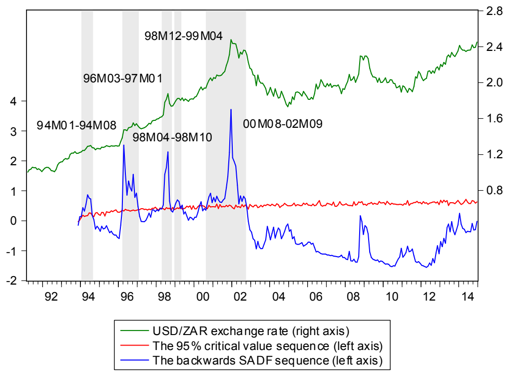
5.3.3. South African Rand (ZAR)

We find strong evidence of bubbles from the nominal US Dollar-South African Rand exchange rate as shown on the third row in Table 6 as the null of no bubbles is rejected at the 1% significance level. Multiple bubbles periods are found in Figure 11a including 1994M01-1994M08, 1996M03-1997M01, 1998M04-1998M10, 1998M12-1999M04 and 2000M08-2002M09.

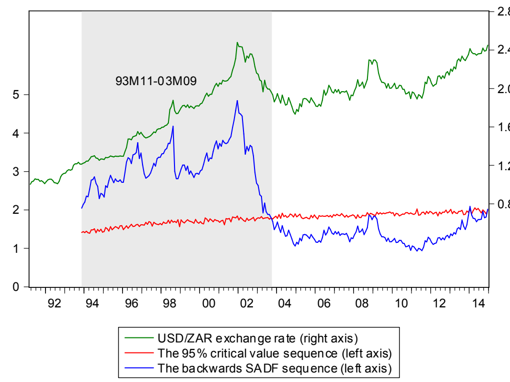
According to Figure 11c and Figure 11e, the relative prices of traded goods f_t^T have explained the majority of the movements in the nominal exchange rate. As both the relative prices of traded goods fundamentals and non-traded goods fundamentals cannot explain all the explosiveness in the nominal exchange rate, we therefore conclude the evidence of rational bubbles.

Comparing the left panel and right panel of Figure 11, 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. This indicates that the intercept term has greatly affected the asymptotic theory and the date-stamping strategy of the PSY approach. This finding does not conform with our previous results for the model specification under the assumption of the inclusion intercept.

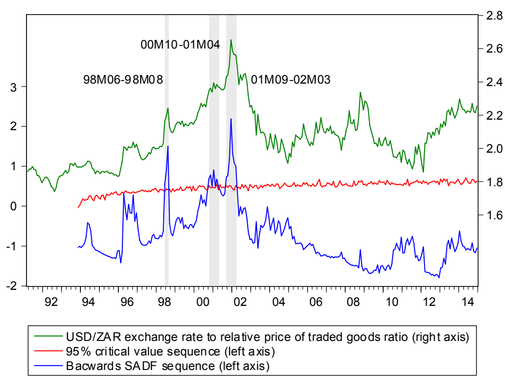
(a) USD/ZAR s_t with an intercept



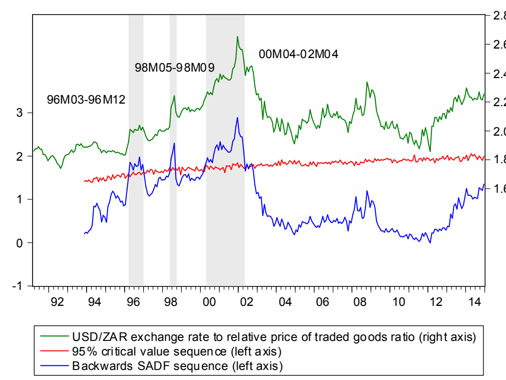
(b) USD/ZAR s_t without an intercept



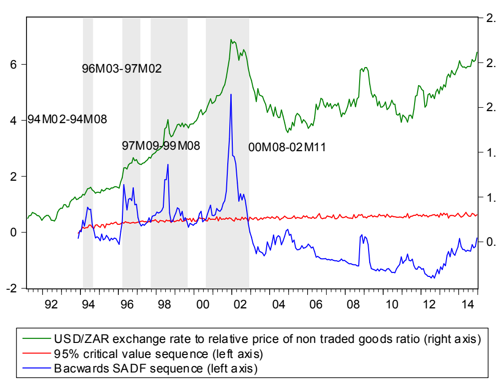
(c) USD/ZAR $s_t - f_t^T$ with an intercept



(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

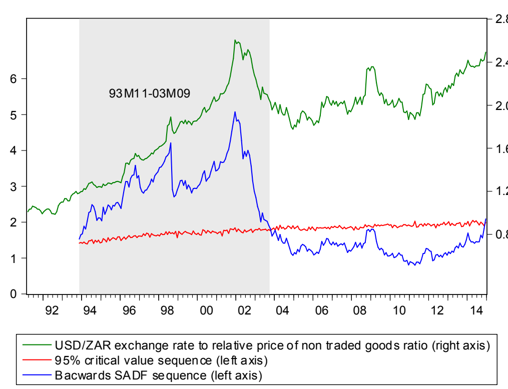


Figure 11: Dating strategy for USD/ZAR nominal exchange rate s_t, the relative ratio of the exchange rate to the traded goods fundamental $s_t - f_t^T$ and the relative ratio of the exchange rate to the non-traded goods fundamental $s_t - f_t^N$.

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.

5.4.1. Colombian Peso (COP)

As shown in Table 6, the null hypothesis of no bubbles in the nominal US Dollar-Colombian peso exchange rate s_t is rejected at the 10% significance level[6]. Figure 12a 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 12c, 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 12e and Figure 12a 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 three episodes in Figure 12e.

Model formulation in the null hypothesis seems to have an impact on the PSY approach as detailed in Figure 12b, Figure 12d and Figure 12f. The PSY approach detects two long-lasting episodes in Figure 12b (1994M08-2014M12) and Figure 12f (1995M06-2008M02) and these results are not expected.

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 6, we find evidence of explosive behavior in the nominal Dollar-Mexican Peso exchange rate s_t under the assumption of the intercept[7]. The null hypothesis of no bubbles in s_t can be rejected at the 1%

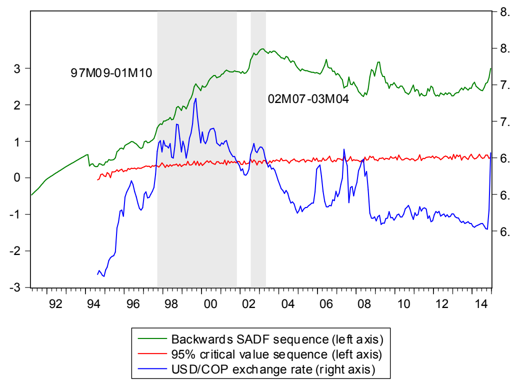
[6] We let r_0=0.15 for the following analysis. If we let $r_0 = 0.01 + 1.8/\sqrt{T}$ and T is 286, r_0 is approximately to 12%. We find that r_0 is not larger enough for initial estimation and therefore consider a larger r_0.

[7] 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.

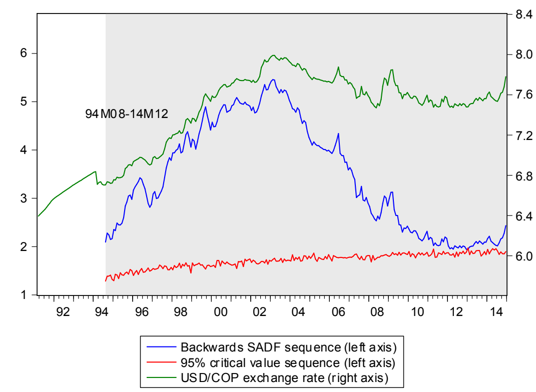
significance level and can observe two episodes from Figure 13a (i.e., 1994M02-1994M04, 1994M12-1995M04).

Importantly, however, our results support the finding of explosiveness in the nominal exchange rate between 1994 and 1995. The episode between 1994M11 and 1995M03 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). However, when the intercept is removed from model formulation under the null hypothesis, we no longer find evidence of bubbles in 1994-95. All three series (s_t, $s_t - f_t^N$ and $s_t - f_t^T$) are not explosive as the null hypothesis cannot be rejected at the 10% level.

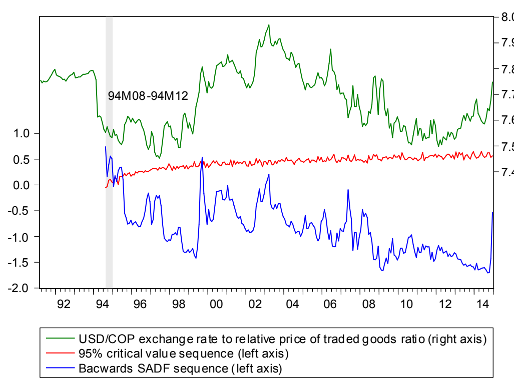
(a) USD/COP s_t with an intercept



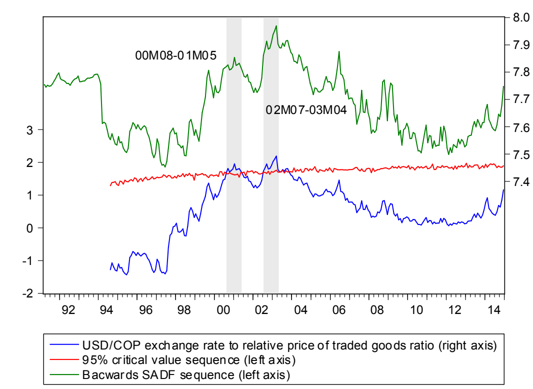
(b) USD/COP s_t without an intercept



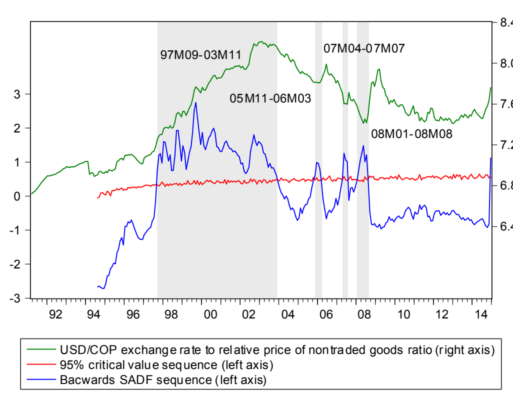
(c) USD/COP $s_t - f_t^T$ with an intercept



(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

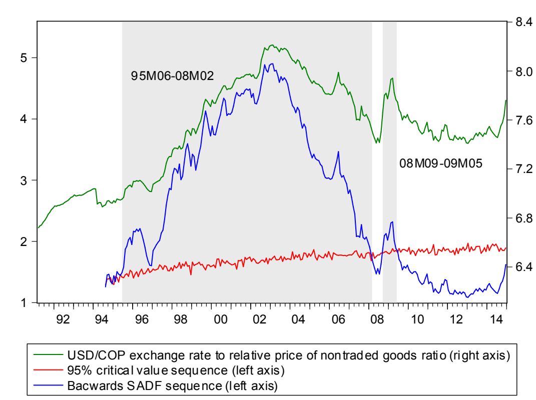
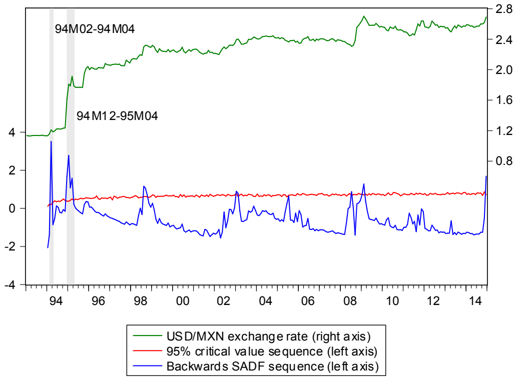
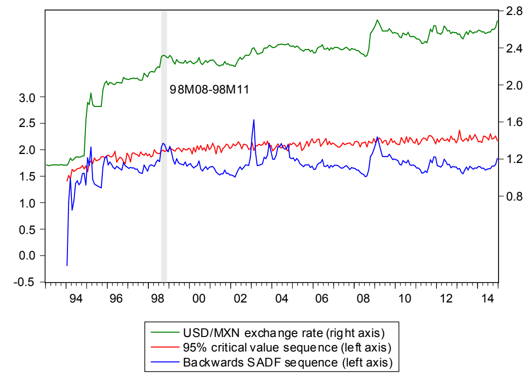


Figure 12: Dating strategy for USD/COP nominal exchange rate s_t, the relative ratio of the exchange rate to the traded goods fundamental $s_t - f_t^T$ and the relative ratio of the exchange rate to the non-traded goods fundamental $s_t - f_t^N$.

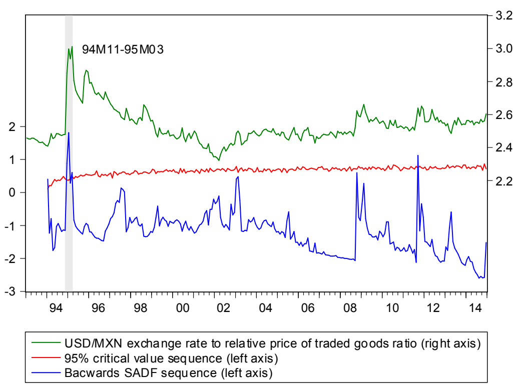
(a) USD/MXN s_t with an intercept



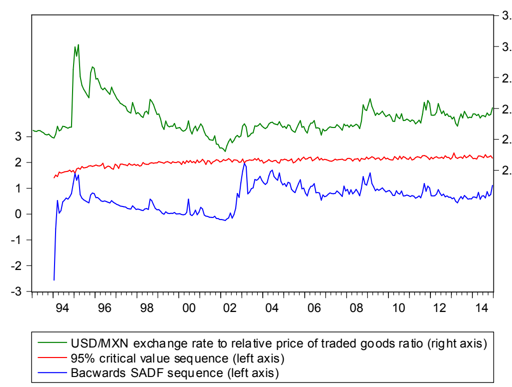
(b) USD/MXN s_t without an intercept



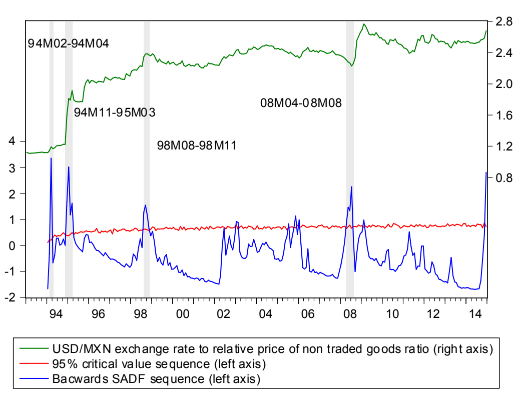
(c) USD/MXN $s_t - f_t^T$ with an intercept



(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

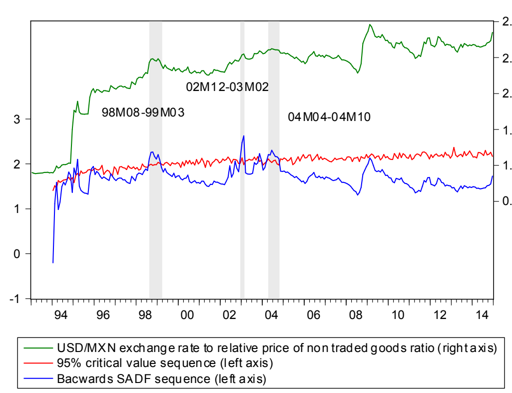


Figure 13: Dating strategy for USD/MXN nominal exchange rate s_t, the relative ratio of the exchange rate to the traded goods fundamental $s_t - f_t^T$ and the relative ratio of the exchange rate to the non-traded goods fundamental $s_t - f_t^N$.

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 including the Sterling-Swiss Franc and Sterling-Japanese Yen. Not only do we find evidence of explosiveness in the nominal Sterling-Swiss Franc exchange rate, but also evidence of rational bubbles. For the Sterling-Japanese Yen exchange rate, we also find significant evidence of rational bubbles as the exchange rate fundamentals cannot explain the explosiveness in the nominal exchange rate.

Some interesting results are obtained from the Asian currencies. In general, we provide evidence of bubbles in several Asian currencies during the 1997 Asian Financial Crisis. 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 exchange rates. Secondly, 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 suggest that the relative prices of non-traded goods have explained most movements in the US Dollar-Malaysian Ringgit exchange rate. Our results therefore 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. More importantly, we also detect a spurious bubble for the nominal Dollar-Malaysian Ringgit exchange rate. This spurious episode in 2003 arises due to the inclusion of the intercept in the null hypothesis.

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), Betts & Kehoe (2005), Bettendorf & Chen (2013) and Jiang et al. (2015). The bubble detection results from Brazil and India suggest the non-existence of rational bubbles while the results from South Africa provide some evidence of rational bubbles.

We find evidence of explosive behavior in the US Dollar-Colombian Peso exchange rate. 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 for several currencies (e.g., Philippine Peso, Indian Rupee, South African Rand and Colombian Peso). 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 the collapse and recovery type of episodes. However, if the null hypothesis involves no intercept, the collapse and recovery episodes will not be identified by the PSY approach. 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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