E C O N O M I C S B U L L E T I N

Learning, Forward Premium Puzzle and Exchange Rate Fundamentals under Sticky Prices

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Abstract

Chakraborty (2007) provides a model of adaptive learning applied to a simple monetary model of exchange rate under flexible prices to generate results similar to forward premium puzzle. This paper redifines the model and empirically examines key model assumptions of structural break in the relationship between exchange rates and fundamentals and the non-stationarity of fundamentals under the alternative assumption of sticky prices. The results show that although there is stronger evidence of structural break, the fundamentals follow stationary processes.

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1 Introduction

Chakraborty (2007) introduces an adaptive learning model applied to a simple monetary model of exchange rate determination, to provide a potential explanation of forward premium puzzle, the well known empirical finding that forward premium predicts the exchange rate depreciation with an opposite sign. The results of the model crucially hinge upon two assumptions - existence of structural breaks in the relationship between exchange rates and fundamentals and a high (possibly unity) AR(1) coefficient in the stochastic process followed by the fundamentals. The structural breaks justifies the use of constant-gain (perpetual) adaptive learning and the high AR(1) coefficient complies with the range of a parameter value used in simulation that generated the strong model results. The paper also provides quite strong empirical evidence supporting both of the assumptions.

The entire analysis is performed under the assumption of flexible prices. The prices are allowed to adjust freely between two time periods so that purchasing power parity holds. The fundamentalsare constructed accordingly for empirical testing. This note alters the assumption of flexible price and addresses the issue of whether the model still produces such strong results when prices are sticky. If it does then the model will prove to be even stronger and robust to alternative model specifications.

The 'Forward Premium Puzzle' refers to a result obtained from a regression of exchange rate depreciation on corresponding forward premium (forward rate minus current spot exchange rate), which is often considered to be a test of foreign exchange market efficiency. Under 'risk neutrality' and 'rational expectations', forward rate is an unbiased predictor of the future spot exchange rate. Which implies that, the change in exchange rate from one period to the next when regressed on the forward premium in the starting period, should result in a slope coefficient of unity. In other words, if s_t is the spot exchange rate is period t, s_{t+1} is the spot exchange rate in period $t+1$ and f_t is the one period forward exchange rate set in period t then in the regression

$$(s_{t+1} - s_t) = \alpha + \beta(f_t - s_t) + u_{t+1} \tag{1}$$

$\hat{\beta}$ should be insignificantly different from unity. A large volume of literature demonstrates that $\hat{\beta} < 0$ and is significantly less than unity[1]. Researchers often view this as a reflection of foreign exchange market inefficiency. Table 1 is reproduced from Chakraborty (2007) to illustrate the puzzle showing evidence from recent data on the US dollar price of four major currencies - Australian dollar, Canadian dollar, Great Britain Pound and Japanese yen.

Chakraborty (2007) assumes away 'rational expectations', one of the key assumptions underlying forward premium regression as a test of unbiasedness of forward rate. The agents are assumed to be 'boundedly rational' in their expectation formation. The key idea is that the agents are aware of the stochastic process linking exchange rates and fundamentals, and they also know the functional form of the process. However, they do not know the actual values of the parameters of that functional form. Instead, they make effort to learn the true parameter values using econometric technique. Each period with new available information they update their knowledge about those parameters. They use econemetric regression in learning those values. Thus the agents are said to have 'bounded rationality', i.e. rationality with some constraints, as they use information efficiently but lack complete information.

The model of Chakraborty (2007), upon simulation, generates $\hat{\beta}$ values very similar to those found in literature along with other features of data. It also empirically verifies the model assumptions and finds support from data. However, both the theoretical and the empirical analyses

[1] Fama (1984), and Hodrick and Srivastava (1986) discuss and analyze the result at great length. Engel (1996) and Lewis (1995) provide comprehensive surveys on the puzzle.

are based on assumption of price flexibility. This paper alters the assumption to introduce sticky prices (deviation from purchasing power parity) and carries out the same exercise. The theoretical model seems to yield the same reduced form as Chakraborty (2007) from a slightly different set of structural equations[2], but the empirical analysis requires different treatment of the data in order to incorporate the sticky prices feature. The empirical results using sticky prices are quite different. The structural break assumption seems to have stronger support but the fundamentals processes seem to be very stationary in contrast. This, although does not necessarily undermine the model's strength[3], certainly implies that further analysis to estimate the AR(1) coefficient of the fundamental process is necessary.

The paper is organized as follows. Section 2 develops the monetary model with learning and discusses the simulation results on $\hat{\beta}$. Section 3 presents the data description and results from empirical analyses. Section 4 provides concluding remarks.

2 The Learning Model under Sticky Prices

2.1 A Sticky Prices Monetary Exchange Rate Model

We take the model as outlined in Chakraborty (2007) with the necessary modification to incorporate sticky prices. The model is similar in spirit to Evans (1986) and Mussa (1976) (the sticky prices version). The following equations describe the economy which is large and open:

$$f_t = \hat{E}_t s_{t+1} \tag{2}$$

$$m_t - p_t = k_0 + k_1 y_t - k_2 i_t \tag{3}$$

$$m_t^* - p_t^* = k_0' + k_1 y_t^* - k_2 i_t^* \tag{4}$$

$$i_t = i_t^* + \hat{E}_t s_{t+1} - s_t \tag{5}$$

$$p_t = p_t^* + s_t - q_t \tag{6}$$

Equation (2) implies that agents are risk-neutral so that current forward rate f_t is the market expectations about one period ahead future spot rate $\hat{E}_t s_{t+1}$. $\hat{E}_t s_{t+1}$ does not necessarily represent 'rational expectations'. Equations (3) and (4) represent the money market equilibria in home and foreign, respectively. Each lower case letter except the interest rate represents the natural log of the corresponding variable. m_t is the log of money supply, p_t is the log of domestic price level, y_t is log of real output in home and i_t is the domestic one period nominal interest rate. Variables with * represent the foreign counterparts. Parameters k_1 and k_2 are positive constants[4]. Equation (5) corresponds to uncovered interest parity condition. s_t is nominal exchange rate i.e. the domestic price of foreign currency. Thus equation (5) implies that the return on domestic asset is equal to expected return on foreign asset in equilibrium. Equation (6) represents the purchasing power parity condition along with a deviation term q_t. This is where our model alters the assumption in Chakraborty (2007), which assumes flexible prices and therefore, there is no deviation from purchasing power parity. In our model, however, since prices are sticky, they do not adjust readily to a change in nominal exchange rate. Thus, often there is a deviation from purchasing power parity

[2]Therefore, the simulation results from Chakraborty (2007) are not altered under sticky prices as the same reduced form is simulated under similar adaptive learning behavior.

[3]As the simulation results suggest that to get results similar to exchange rate data, the model requires a high AR(1) coefficient in fundamentals, which may not necessarily be unity.

[4]For convenience the model assumes k_1 and k_2 are same for both countries.

condition (i.e. $p_t = p_t^* + s_t$) as captured by q_t. In incorporating the price stickiness into the model through the purchasing power parity condition we follow Engel and West (2005). While, q_t could be interpreted as merely a deviation term, it is in fact the effective real exchange rate between the home and foreign. The real exchange rate becomes relevant in the construction of the fundamentals due to price stickiness.

Combining (3)-(6), yields the reduced form

$$s_t = \mu + \theta \hat{E}_t s_{t+1} + v_t \tag{7}$$

where, $\mu = (k_0' - k_0)(1+k_2)^{-1}$, $0 < \theta = k_2(1+k_2)^{-1} < 1$ and $v_t = (1+k_2)^{-1}[m_t - m_t^* - k_1(y_t - y_t^*) + q_t]$.

This reduced form equation (7) is exactly what is obtained in Chakraborty (2007), except in that model the exchange rate fundamental v_t did not have the component q_t in its definition.Therefore, after redefining v_t the simulations will follow the exact same process. Hence, we continue to assume that v_t is exogenous and follows an AR(1) process given by

$$v_t = \rho v_{t-1} + \varepsilon_t, \tag{8}$$

where $0 < \rho \leq 1$ is large (close to or equal to 1) and ε_t is white noise. Equations (7) and (8) together govern the exchange rate generating process in this economy and hold even when agents form their expectations with 'bounded rationality'.

2.2 Learning and Expectations

Chakraborty (2007) provides a detailed description of the learning dynamics - the algorithm followed by the private agents in expectations formation, the underlying intuition and compares the process with that under 'rational expectations'. Instead of going through the details, here we briefly outline the learning process followed by the agents.

Suppose that the agents believe that s_t depends on v_{t-1}, an intercept and a noise term (which is related to the white noise in v_t process), i.e., they believe that the regression equation has the following form:

$$s_t = a + b v_{t-1} + c\varepsilon_t \tag{9}$$

where, ε_t is the white noise from the v_t process.

Under 'rational expectations' the agents will know the true values of a and b (the value of c is not relevant here). Under the learning mechanism the agents do not have perfect knowledge about a and b, although, they are aware of the functional form of equation (9). At the end of period $t-1$, they therefore form an estimate a_{t-1} and b_{t-1} of the coefficients by applying learning techniques using the available information, i.e. the estimated values in the past and the new information in period $t-1$. In period t they forecast the value of s_{t+1} using a_{t-1}, b_{t-1} and v_t using

$$\hat{E}_t s_{t+1} = a_{t-1} + b_{t-1} v_t \tag{10}$$

where, $\hat{E}_t s_{t+1}$ denotes the (possibly non-rational) expectation of s_{t+1} formed at time t.

At the end of period t, agents calculate the forecast error by measuring the difference between the actual s_t and its predicted value and use this information to update their estimate of the coefficients to a_t and b_t using constant-gain recursive least square learning[5]. This process is repeated every period generating a sequence of estimates (a_t, b_t). Chakraborty (2007) explains the rationale behind the use of constant-gain learning in this context and indicates that it implicitly assumes the

[5] Evans and Honkapohja (2001) provides a detailed discussion on the use and justification of constant-gain learning.

presence of irregular structural breaks in the relationship between exchange rates and fundamentals.

Under constant-gain learning, parameters are updated using the following algorithms. If we define matrices $z_t = \begin{pmatrix} 1 \\ v_t \end{pmatrix}$ and $\Phi_t = \begin{pmatrix} a_t \\ b_t \end{pmatrix}$ then the Recursive Least Square estimates of Φ_t are given by the following pair of equations[6]:

$$\Phi_t = \Phi_{t-1} + \gamma S_{t-1}^{-1} z_{t-1}(s_t - \Phi'_{t-1} z_{t-1}) \tag{11}$$

$$S_t = S_{t-1} + \gamma(z_t z'_t - S_{t-1}) \tag{12}$$

Equation (11) uses a function of the prediction error $(s_t - \Phi'_{t-1} z_{t-1})$ in period t to update last period's estimate Φ_{t-1} to Φ_t. Equation (12) uses a square matrix S_t to update the estimate of the second moments' matrix of z_t i.e. of $E(z_t z'_t)$[7]. Using this process a pair of values (a_{t-1}, b_{t-1}) are obtained at the end of $(t-1)$, which are used by agents to obtain an expected value for the exchange rate next period, i.e. $\hat{E}_t s_{t+1}$ according to equation (10), which is different from what 'rational expectations' would generate.

Thus, by applying constant-gain learning, the agents form an expectation about the future exchange rate, which is the same as the forward rate under the assumption of risk neutrality i.e. equation (2). Chakraborty (2007) demonstrates that when simulated using specific set of parameter values this model generates data that have very similar empirical properties of exchange rate data including negative $\hat{\beta}$. Since, the reduced form obtained under the assumption of sticky prices here produces exact same reduced form as Chakraborty (2007), the simulation exercise will be no different from that model. Thus, in Table 2 we present one representative simulation result from Chakraborty (2007).

2.3 Simulation Results

The simulation was run for sample size 100. Parameters μ was arbitrarily set to 1, θ was assigned two different values 0.6 and 0.9. γ was assigned three different values 0.01, 0.05 and 0.1 and ρ was assigned four different values 0.9, 0.95, 0.99 and 1.0[8]. A combination from each of those values was chosen for simulation. Thus, 24 (2 x 4 x 3) possible sets of parameter values were considered and for each combination a simulation was run 1000 times. Each simulation generated one $\hat{\beta}$. The averages of the $\hat{\beta}$, as well as their average standard errors, were calculated for the 1000 runs of each simulation. The averages of the $\hat{\alpha}$ values and corresponding standard errors and the R^2s were also calculated.

The initial values of the variables were chosen arbitrarily. s_t was initialized at 0, i.e., the exchange rate was assumed to be 1. a and b were set at their respective rational expectations values in the beginning. v_t was set to 0.

Results are presented in Table 2. To save space all values are rounded up to two decimal spaces (except for the average $\hat{\alpha}$ values which were rounded up to four decimal places because of the order of its magnitude). The most general observation is that most of the average $\hat{\beta}$ estimates are numerically less than unity and many of them are significantly so. Furthermore, many of the average $\hat{\beta}$ values are negative. Very low value of R^2 in each of the cases is observed. The average $\hat{\alpha}$ values are very low in magnitude. Each of these results seems very consistent with patterns observed in actual data.

[6] This representation is nothing but discounted least square equation written recursively. Hence, the name is recursive least square. See Evans and Honkapohja (2001) for more on 'Recursive Least Square' learning.

[7] See Chakraborty (2007) for details of the intuition.

[8] Chakraborty (2007) describes how the parameters are calibrated for simulations.

3 Data and Empirical Results

As noted by Chakraborty (2007) the simulations that generate negative $\hat{\beta}$ assign high (near unity or unity) values to the AR(1) coefficient ρ. Also, application of constant-gain learning requires the assumption of structural breaks in the relationship between exchange rates and fundamentals. Thus, Augmented Dickey-Fuller and KPSS unit root tests are performed on fundamentals and several structural break tests are performed on the regression of exchange rates on fundamentals. The empirical results from Chakraborty (2007) seem to support both the assumptions. However, the fundamentals in those tests are constructed under the assumption of flexible prices. We perform the same set of tests using fundamentals that are constructed based on sticky prices assumption.

3.1 Data

The data are quarterly series on four exchange rates – the US dollar prices of the Australian dollar, Canadian dollar, British pound and Japanese Yen. Quarterly data for the period 1988-Q4 to 2005-Q3 on spot exchange rate and three month forward rate are taken from Bloomberg. All raw exchange rate data are closing mid-prices for which the value-date is the last business day of the quarter. The future spot rate for a given period is constructed by observing the spot rate for which the value-date is the last business day one quarter ahead. Thus end-points are adjusted properly. Logarithmic transformation is made on each series.

Data on fundamentals are collected from International Financial Statistics, published by the International Monetary Fund, for the period of 1988.Q4 through 2005.Q3. They are quarterly series on money supply ($M0$ for Great Britain and $M1$ for the other four countries), real GDP for the five countries: US, Australia, Canada, Great Britain and Japan and real exchange rate data between USA and the other four countries. Effective real exchange rate for each country are taken and then real exchange rate between USA and a foreign country is calculated as

$q_t = (\textit{Effective real exchange rate of USA} - \textit{Effective real exchange rate of the foreign country})$.

Money supply and real GDP series are adjusted for seasonal variation by adding three lagged values of the variable and then dividing by four. Logarithmic transformation is made on each series. The fundamental for each exchange rate is constructed following the model as:

$v_t = [log(\textit{US Money Supply}) - log(\textit{Foreign Money Supply})] - [log(\textit{US Real GDP}) - log(\textit{Foreign Real GDP})] + q_t$

This measure follows directly from equation (7) and the corresponding definition of v_t. However, to construct the fundamental k_1 is set to 1. This assumption appears reasonable since k_1 is the income elasticity of money demand and Stock and Watson (1993) demonstrated that this elasticity is not significantly different from 1 for most countries.

3.2 Test for Structural Break

Following Chakraborty (2007) two alternative versions of exchange rate-fundamental models are used for structural break tests. These are chosen following the methodology used by Rossi (2006). The models are an AR(1) and an AR(2) specifications, each augmented with lagged v_t as exogenous variables (as do the agents in our framework), where the exchange rate depends on fundamentals in the previous period and previous two periods, respectively. Also, both exchange rates and fundamentals are first-differenced to generate stationary series to use in the regressions. In other words, the two specifications are

$$\Delta s_t = \phi_0 + \phi_1 \Delta s_{t-1} + \phi_2 \Delta v_{t-1} + \eta_t \tag{13}$$

$$\Delta s_t = \phi'_0 + \phi'_1 \Delta s_{t-1} + \phi'_2 \Delta s_{t-2} + \phi'_3 \Delta v_{t-1} + \phi'_4 \Delta v_{t-2} + \varphi_t \quad (14)$$

where, Δs_t is first difference of spot exchange rate in period t and Δv_t is that of fundamental in period t. η_t and φ_t are white noise error terms. Lagged values of the dependent variable are added to the regressors in order to deal with possible serial correlations in error terms. Tests are performed to check stability of the ϕ_i and ϕ'_i parameters.

Three structural break tests are used - Andrews-Quandt test, Andrews-Ploberger test and Hansen's test. All the three tests use p-values computed using Hansen's approximation. Since constant gain-learning is motivated by a concern that there are periodic breaks, the Bai-Perron multiple break test is also performed to check specifically for the possibility of more than one break (a comparison between tests involving one break, two breaks and three breaks).

Results of the Andrews-Quandt test, Andrews-Ploberger test and Hansen's test are presented in Table 3. The evidence is very mixed, as previously found by Rossi (2006) and Chakraborty (2007). However, compared to Chakraborty (2007) there is more evidence of structural breaks as indicated by much lower p-values (in parentheses). Even for currencies with quite high p-values the magnitudes seem to have diminished in the present model (specially evident in CAD and GBP). The Bai-Perron test results using Bayesian Information Criteria (BIC) are reported in Table 4. The same features are observed i.e. there is stronger evidence of structural break as in more cases the BIC suggests more than one breaks. Overall, the evidence suggests that a sticky prices model strengthens the assumption of structural break. This even more strongly justifies the use of constant-gain learning dynamics in expectation formation in foreign exchange market.

3.3 Unit Root Test

The simulation results show that when ρ is equal to or very close to unity, regardless of the other parameter values, the $\hat{\beta}$ obtained in simulations is negative, but for a low value of ρ often the negative sign of $\hat{\beta}$ was lost. Thus, Chakraborty (2007) tests the assumption of $\rho = 1$ (or ρ close to one). This is done by testing for unit root in the fundamentals. Augmented Dickey-Fuller test and KPSS test are applied on the four fundamentals assuming both the presence and the absence of a trend. The results from both the tests clearly indicate $\rho = 1$[9].

In our model, however, when fundamentals are constructed under the assumption of sticky prices, they cease to be non-stationary. From the results of ADF test and KPSS test as presented in Tables 5 and 6, respectively, it is evident that both the tests strongly reject unit root in fundamentals for all the exchange rates. The results are so strong that a null hypothesis of unit root is rejected even at 1% level for ADF test and that of no unit root can not be rejected even at 5% level for KPSS test. This however does not refute the model, since, it is possible to have stationary fundamentals and yet quite high values of the AR(1) coefficients. The simulation results suggest that even in that case the model may generate data similar to exchange rate data and thus the model may still pass the validity tests.

4 Conclusions

The objective of this paper was to test the model of Chakraborty (2007) under the alternative assumption of sticky prices. For that purpose the same set of structural equations are used with a modification in purchasing power parity condition to accommodate the assumption of sticky prices. Under the same reduced form and learning dynamics the simulation of the model remains

[9]See Chakraborty (2007) for justifications for all the empirical tests used and detailed discussion of the tests and results.

unaltered. However, the empirical properties of the data needs verification when the fundamentals are transformed to comply with sticky prices. Therefore, the same set of empirical tests are performed.

The results strengthen the evidence for the existence of structural break in the link between exchange rates and fundamentals thereby making a stronger case for the use of constant-gain learning. However, the non-stationarity of sticky prices fundamentals is rejected by the tests which suggests $\rho = 1$ is inappropriate for simulations. This, although does not render the model erroneous, certainly warrants reestimation of the AR(1) coefficient ρ in fundamentals and further analyses of the model outcomes.

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Table 1: Regressions of Quarterly Depreciation on 3-Month Forward Premium
$(s_{t+1} - s_t) = \alpha + \beta(f_t - s_t) + u_{t+1}$

	USD/AUD	USD/CAD	USD/GBP	USD/JPY
$\hat{\alpha}_{OLS}$	-0.0089	-0.0009	0.0023	0.0148
	(0.0086)	(0.0039)	(0.0086)	(0.0111)
$\hat{\beta}_{OLS}$	-1.2267^{*}	-0.5990^{*}	0.4487	-1.9371^{*}
	(1.0185)	(0.7834)	(1.0587)	(1.1826)
R^2	0.0218	0.0089	0.0028	0.0396

Note: Standard errors are in parentheses. * represents 5% level of significance for $H_0 : \beta = 1$

Table 2: Results from 1000 simulations of the model for sample size 100.

θ	ρ	γ	*Avg.* $\hat{\alpha}$	*Avg* $SE(\hat{\alpha})$	*Avg.* $\hat{\beta}$	*Avg* $SE(\hat{\beta})$	*S.D. of* $\hat{\beta}$	*Avg.* R^2
0.6	0.9	0.01	0.0013	0.23	1.17	0.53	0.42	0.05
		0.05	−0.0072	0.22	0.50	0.56	0.63	0.02
		0.1	0.0002	0.22	−0.19	0.50	0.80	0.02
	0.95	0.01	0.0017	0.26	1.07	0.97	1.15	0.03
		0.05	0.0072	0.24	−0.25	0.82	1.13	0.02
		0.1	0.0088	0.23	−0.57	0.56	0.77	0.02
	0.99	0.01	−0.0034	0.29	−1.02	1.79	2.55	0.02
		0.05	−0.0075	0.27	−0.95	0.87	1.17	0.02
		0.1	−0.0251	0.25	−0.69	0.55	0.73	0.02
	1.0	0.01	−0.0227	0.31	−1.51	1.71	2.32	0.02
		0.05	−0.0135	0.29	−0.97	0.83	1.11	0.02
		0.1	−0.0151	0.26	−0.75	0.53	0.71	0.02
0.9	0.9	0.01	0.0261	0.58	1.28	0.52	0.46	0.06
		0.05	−0.0052	0.57	0.97	0.54	0.35	0.04
		0.1	−0.0074	0.57	0.51	0.60	0.62	0.02
	0.95	0.01	0.0525	0.82	1.71	0.88	0.85	0.04
		0.05	0.0002	0.81	0.63	1.10	1.82	0.02
		0.1	−0.0441	0.80	−0.57	1.07	2.18	0.02
	0.99	0.01	−0.0567	1.24	−0.65	4.24	8.07	0.02
		0.05	0.1570	1.20	−2.99	2.40	4.58	0.03
		0.1	−0.0067	1.13	−2.21	1.42	2.67	0.03
	1.0	0.01	0.1155	1.38	−5.49	5.38	9.40	0.03
		0.05	−0.0133	1.41	−3.23	2.16	4.27	0.03
		0.1	0.1195	1.35	−2.34	1.32	2.46	0.04

Note: The S.D. of $\hat{\beta}$ is across 1000 simulations

Table 3: Andrews-Quandt, Andrews-Ploberger and Hansen structural break test results for the four exchange rates

	Andrews-Quandt test		Andrews-Ploberger test		Hansen test	
	AR(1)	AR(2)	AR(1)	AR(2)	AR(1)	AR(2)
USD/AUD	11.22	11.47	3.66	4.38	1.37	1.59
	(0.14)	(0.39)	(0.09)	(0.19)	(0.03)	(0.07)
USD/CAD	23.78	27.47	8.87	10.71	1.77	2.10
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.01)
USD/GBP	6.47	16.26	1.41	5.08	0.96	1.07
	(0.60)	(0.09)	(0.62)	(0.11)	(0.16)	(1.00)
USD/JPY	6.37	6.13	1.76	2.04	0.31	0.69
	(0.61)	(0.94)	(0.47)	(0.79)	(1.00)	(1.00)

Table 4: Bai-Perron multiple structural break test results for the four exchange rates

	AR(1)			AR(2)		
No. of breaks	1	2	3	1	2	3
USD/AUD	−5.79	−5.88	−5.98	−5.63	−5.59	−5.52
USD/CAD	−7.25	−7.23	−7.23	−7.11	−7.17	−7.08
USD/GBP	−5.91	−6.00	−6.18	−5.99	−6.16	−6.12
USD/JPY	−5.35	−5.36	−5.36	−5.15	−5.05	−5.08

Table 5: Augmented Dicky-Fuller unit-root test results for the fundamentals of the four exchange rates

	Australian dollar	Canadian dollar	British pound	Japanese yen
Without trend				
t-stat	−7.94	−7.70	−6.05	−8.19
1% critical value	−3.51	−3.51	−3.51	−3.51
5% critical value	−2.89	−2.89	−2.89	−2.89
With trend				
t-stat	−7.88	−7.63	−6.00	−8.12
1% critical value	−4.04	−4.04	−4.04	−4.04
5% critical value	−3.45	−3.45	−3.45	−3.45

Note: The critical values are ADF critical values

Table 6: KPSS unit-root test results for the fundamentals of the four exchange rates

	Australian dollar	Canadian dollar	British pound	Japanese yen
Without trend				
KPSS-stat	0.06	0.07	0.12	0.07
1% critical value	0.74	0.74	0.74	0.74
5% critical value	0.46	0.46	0.46	0.46
With trend				
KPSS-stat	0.06	0.07	0.12	0.07
1% critical value	0.22	0.22	0.22	0.22
5% critical value	0.15	0.15	0.15	0.15

Note: The critical values are asymptotic critical values for KPSS test