



Department of
Economics and Finance

Working Paper No. 2103

Economics and Finance Working Paper Series

Christina Anderl and Guglielmo Maria Caporale

Nonlinearities and Asymmetric Adjustment to PPP in
an Exchange Rate Model with Inflation Expectations

February 2021

<http://www.brunel.ac.uk/economics>

**NONLINEARITIES AND ASYMMETRIC ADJUSTMENT TO PPP
IN AN EXCHANGE RATE MODEL
WITH INFLATION EXPECTATIONS**

Christina Anderl

London South Bank University

Guglielmo Maria Caporale

Brunel University London

February 2021

Abstract

This paper estimates a model of the real exchange rate including standard fundamentals as well as two alternative measures of inflation expectations for five inflation targeting countries (UK, Canada, Australia, New Zealand, Sweden) over the period January 1993-July 2019. Both a benchmark linear ARDL model and a nonlinear ARDL (NARDL) specification are considered. The results suggest that the nonlinear framework is more appropriate to capture the behaviour of real exchange rates given the presence of asymmetries both in the long- and short-run. In particular, the speed of adjustment towards the PPP-implied long-run equilibrium is three times faster in a nonlinear framework, which provides much stronger evidence in support of PPP. Moreover, inflation expectations play an important role, with survey-based ones having a more sizable effect than market-based ones. Monetary authorities should aim to achieve a high degree of credibility to manage them and thus currency fluctuations effectively. The inflation targeting framework might be especially appropriate for this purpose.

Keywords: Nonlinearities, asymmetric adjustment, PPP, real exchange rate, inflation expectations

JEL Classification: C32, F31, G15

Corresponding author: Professor Guglielmo Maria Caporale, Department of Economics and Finance, Brunel University London, UB8 3PH, UK. Email: Guglielmo-Maria.Caporale@brunel.ac.uk

1. Introduction

The well-known PPP (Purchasing Power Parity) puzzle (Rogoff, 1996) consists in the fact that real exchange rates appear to be more volatile and to exhibit more persistence than implied by most exchange rate determination models. This has generated an extensive literature aiming to understand the reasons for the empirical failure of PPP (see Taylor, 2006 for a thorough review). Various empirical methods have been used for this purpose, including unit root and cointegration tests, and have produced mixed results (see, e.g., Chortareas and Kapetanios, 2009; Norman, 2010; Taylor et al., 2001). An important issue in this context is the possible role of the monetary policy framework adopted by central banks (Lavesson, 2011). It is noteworthy that only a few papers have carried out this type of analysis in the case of inflation targeting countries, which appear to be characterised by faster mean reversion (Ding and Kim, 2012) and lower volatility (Kim, 2014) of the real exchange rate.

The present paper aims to shed new light on these issues by estimating a model of the real exchange rate including economic fundamentals as well as inflation expectations in the case of five countries with an inflation targeting regime, namely the UK, Canada, Australia, New Zealand and Sweden, over the period from January 1993 to July 2019; in such countries the credibility of the central bank can directly affect inflation expectations and through them deviations of the real exchange rate from the PPP-implied long-run equilibrium. Various recent papers have estimated Autoregressive Distributed Lag (ARDL) models to investigate PPP (see, e.g., Ariff and Zarei, 2015), therefore we start the analysis using this type of econometric framework but, given the possible importance of nonlinearities and asymmetric adjustment to the long-run equilibrium in the case of real exchange rates (see Taylor et al., 2001), we also estimate a Nonlinear Autoregressive Distributed Lag (NARDL) model including fundamentals and two alternative measures of inflation expectations.

The layout of the paper is as follows. Section 2 briefly reviews the relevant literature; Section 3 outlines the econometric models used for the analysis; Section 4 discusses the data and the empirical results; Section 5 offers some concluding remarks.

2. Literature Review

The empirical literature on PPP is extensive. Early studies carrying Augmented Dickey-Fuller (ADF) unit root tests on the real exchange rate mostly rejected PPP (Froot and Rogoff, 1995;

Lothian and Taylor, 1996), whilst stronger evidence supporting it was found by papers using the more powerful Dickey-Fuller Generalised Least Squares (DF-GLS) test (see, e.g., Cheung and Lai, 1994). However, it is now well known that all such tests have low power in detecting mean reversion (Taylor, 2001). Therefore subsequent studies have used panel methods instead. Frankel and Rose (1996) found that deviations from PPP have half-lives of approximately four years in a panel of 150 countries, and similar results were obtained by Rogoff (1996). Coakley and Fuertes (1997) used panel unit root tests to assess mean reversion of the real exchange rate in the G10 countries and found half-lives of less than three years, whilst Wu (1996) and Papell (1997) obtained estimates of 2.0 and 2.5 years respectively. Murray and Papell (2005) applied a median-unbiased panel method that produced estimates of approximately 4 years for half-lives. Using heterogeneous unit root tests in a panel with 25 OECD countries Chortareas and Kapetanios (2009) found strong evidence of mean reversion. Ca' Zorzi et al. (2016) concluded that a half-life PPP model is able to forecast real exchange rates better than the random walk model at both short- and long-term horizons.

Some other studies allow for possible nonlinearities in the adjustment process to the long-run equilibrium implied by PPP. Taylor et al. (2001) performed multivariate unit root tests using the empirical critical values obtained by means of Monte Carlo simulations to analyse a number of real exchange rates during the Bretton-Woods period; they found faster mean reversion when these are further away from their equilibrium value. Baum et al. (2001) estimated an exponential Smooth Transition Autoregression (STAR) model based on the Johansen cointegration method and found evidence of nonlinear mean reversion with an adjustment speed which is dependent on the size of the deviation from equilibrium. Sollis et al. (2002) used a similar nonlinear STAR model to test for asymmetries in the mean reversion of the real exchange rate and reported stronger rejections of the unit root null hypothesis than when carrying out standard unit root tests. Chortareas et al. (2002) used the same STAR framework to assess whether the G7 real exchange rates follow a nonlinear stationary process. Specifically, they implemented a de-trending method suggested by Schmidt and Phillips (1992) to derive an alternative test statistic which is more powerful against linear trend-stationary processes and found evidence of nonlinear mean reversion of most real exchange rates even in cases where standard unit root tests were unable to detect linear mean reversion. These results were confirmed by Bahmani-Oskooee et al. (2008), who used the nonlinear unit root test suggested by Kapetanios et al. (2003) to assess the validity of PPP in 23 countries in a STAR framework;

they found nonlinear mean reversion and more evidence for PPP than when using the standard ADF test.

Norman (2010) estimated a STAR model to determine the empirical distribution of half-lives in response to frequent shocks. His findings provide evidence of nonlinear mean reversion with half-lives of less than the typical 3 to 5 years reported in previous studies. He concluded that half-lives of less than 5 years occur 100% of the time and half-lives of less than 3 years 30% of the time. This confirms that nonlinear mean reversion is a key feature of the real exchange rate and a potential solution to the PPP puzzle. Christopoulos and León-Ledesma (2010) developed a test for unit roots which allows for multiple endogenous breaks and for adjustments following a nonlinear exponential STAR process and applied it to 15 bilateral real exchange rates against the US Dollar during the Bretton-Woods period; they found nonlinear mean reversion of the real exchange rate to a smooth-breaking mean in almost all cases. Feenstra and Kendall (1997) reported that the pass-through behaviour of the exchange rate is able to explain at least one-third of the deviation from PPP, while interest differentials, which are mostly stationary, are unable to account for the mostly non-stationary deviations from PPP.

The extensive evidence of nonlinearities and asymmetries in real exchange behaviour discussed above motivates our estimation of a NARDL model in addition to the standard ARDL specification as discussed in the next section.

3. Empirical Framework

3.1. The ARDL Model

To investigate the issues of interest we start by following a standard ARDL approach (see Pesaran and Shin, 1998 for more details). In its general form the linear benchmark model can be expressed as follows:

$$y_t = \sum_{i=1}^p \varphi_i \Delta x_{t-i} + \sum_{j=1}^q \theta_j x_{t-j} + \varepsilon_t \quad (1)$$

where x_{t-j} are the lagged explanatory variables and Δ stands for the difference operator. We apply this framework to estimate the following model of the real exchange rate:

$$q_t = \theta_t \tilde{m}_t - \varphi_t \tilde{y}_t + \lambda_t \tilde{i}_t + \omega_t \tilde{x}_t + \varepsilon_t \quad (2)$$

where q_t is the real exchange rate, $\tilde{m}_t = m_t - m_t^*$ is the difference between domestic and foreign money supply (in nominal terms), $\tilde{y}_t = y_t - y_t^*$ is the difference between domestic and foreign output (in real terms), $\tilde{i}_t = i_t - i_t^*$ is the nominal interest rate differential and finally $\tilde{x}_t = x_t - x_t^*$ is the inflation expectation differential. This variable is included following Kamada and Nakajima (2014), who suggest that the real exchange rate should be defined as $q_t = \frac{x_t^*}{x_t} \times s_t$, namely as the difference between inflation expectations multiplied by the nominal exchange rate, which can be informative about the role of central bank credibility in the context of PPP. The chosen setup allows for the possible effects of both real and nominal shocks, since the latter can also influence the real exchange rate in the presence of sluggish price adjustment (Stockman, 1987; Clarida and Gali, 1994).

The empirical specification of the model is the following:

$$\begin{aligned} \Delta q_t = \alpha + \sum_i^p \gamma_i \Delta q_{t-i} + \varphi_1 \Delta \tilde{m}_{t-1} + \varphi_2 \Delta \tilde{i}_{t-1} + \varphi_3 \Delta \tilde{y}_{t-1} + \varphi_4 \Delta \tilde{x}_{t-1} + \rho e c m_{t-1} + \\ + \theta_1 \tilde{m}_{t-1} + \theta_2 \tilde{i}_{t-1} + \theta_3 \tilde{y}_{t-1} + \theta_4 \tilde{x}_{t-1} + \varepsilon_t \end{aligned} \quad (3)$$

where the variables are defined as before.

The individual series have to be tested for their order of integration since variables whose order is higher than I(1) cannot be included in the model. For this purpose, we carry out the Dickey Fuller Generalised Least Squares (DF-GLS) test. After estimating the linear model, we assess its adequacy by carrying out a number of diagnostic tests, namely the Breusch-Pagan test for heteroscedasticity, the Breusch-Godfrey Lagrange multiplier (LM) test for serial correlation, and a Wald test of the null hypothesis that the regressors are weakly exogenous.

3.2 The NARDL (Nonlinear ARDL) Model

Given the evidence from the existing literature on possible nonlinearities in real exchange rate behaviour we then consider a Nonlinear ARDL (NARDL) specification which allows for asymmetric effects of the regression parameters. One should note that, although there is no

formal testing procedure for the presence of nonlinearities prior to the estimation of the model, parameter symmetry tests can be carried out after the estimation has been performed.

This model allows the long-run cointegrating relation between the variables as well as the short-run dynamics to be characterised by asymmetries and thus to distinguish between the impact of positive and negative changes in variables such as inflation expectations on PPP deviations and the real exchange rate adjustment to equilibrium (Arize et al., 2017). It was developed by Shin et al. (2014) and is a fairly novel addition to the class of nonlinear cointegration models. Within this framework, the regressors can be decomposed by using the partial sum of positive and negative changes, which allows to test the relationship for short- and/or long-run asymmetries or for a combination of the two (the so-called dynamic multiplier) which might arise.

The nonlinear ARDL (p, q) model can then be represented as follows:

$$y_t = \sum_{i=1}^p \varphi_j \Delta x_{t-i} + \sum_{j=0}^q (\theta_j^{+'} x_{t-j}^+ + \theta_j^{-'} x_{t-j}^-) + \varepsilon_t \quad (4)$$

where x_t is a $k \times 1$ vector of multiple regressors, which are defined such that $x_t = x_0 + x_t^+ + x_t^-$. φ_j is the autoregressive parameter and θ_j^+ and θ_j^- are the positive and negative distributed lag parameters capturing the asymmetries. The corresponding error correction specification takes the following general form:

$$\Delta y_t = \mu + \rho ec m_{t-1} + \gamma \Delta y_{t-1} + \sum_{j=1}^q (\varphi_j^{+'} \Delta x_{t-j}^+ + \varphi_j^{-'} \Delta x_{t-j}^-) + \sum_{j=1}^q (\theta_j^{+'} x_{t-j}^+ + \theta_j^{-'} x_{t-j}^-) + \varepsilon_t \quad (5)$$

and the specific model we estimate is the following:

$$\begin{aligned} \Delta q_t = & \alpha + \sum_i^p \gamma_i \Delta q_{t-i} + \varphi_1^{+'} \Delta \tilde{m}_{t-1}^+ + \varphi_1^{-'} \Delta \tilde{m}_{t-1}^- + \varphi_2^{+'} \Delta \tilde{x}_{t-1}^+ + \varphi_2^{-'} \Delta \tilde{x}_{t-1}^- + \\ & + \varphi_3^{+'} \Delta \tilde{r}_{t-1}^+ + \varphi_3^{-'} \Delta \tilde{r}_{t-1}^- + \varphi_4^{+'} \Delta \tilde{y}_{t-1}^+ + \varphi_4^{-'} \Delta \tilde{y}_{t-1}^- + \rho ec m_{t-1} + \theta_1^{+'} \tilde{m}_{t-1}^+ + \theta_1^{-'} \tilde{m}_{t-1}^- + \\ & + \theta_2^{+'} \tilde{r}_{t-1}^+ + \theta_2^{-'} \tilde{r}_{t-1}^- + \varepsilon_t \end{aligned} \quad (6)$$

where all variables are defined as before but are now entered as their partial sum decompositions. The difference between a traditional error correction model and an ARDL one is that in the latter the error correction term is replaced with the first lag of the dependent and cointegrating variables. This allows one to enter the same lagged variables in levels as in a standard error correction model, but without any restrictions on the coefficients. Therefore this model is also called a conditional or unrestricted error correction model. It is nonlinear in the variables but linear in the parameters on all short- and long-run variables (Shin et al., 2014). The null hypothesis that the positive and negative coefficients in the short- or long-run relationships are symmetric, i.e. $\left(\frac{-\theta^+}{\rho}\right)' = \left(\frac{-\theta^-}{\rho}\right)'$, can be tested by means of a Wald statistic (Ghods, 2017). The coefficient ρ on the nonlinear error correction term, ecm_{t-1} , is defined as $\rho = q_t - \beta^+ x_t^+ - \beta^- x_t^-$ where x_t^+ and x_t^- are the positive and negative partial sum components of the variables which enter the long-run cointegration relation and $\beta^+ = -\frac{\theta^+}{\rho}$ and $\beta^- = -\frac{\theta^-}{\rho}$ are the asymmetric long-run parameters. Since the model is linear in all parameters including the coefficients on the partial sum components of the regressors, it can be conveniently estimated by ordinary least squares (Pesaran and Shin, 1998).

The NARDL model is the nonlinear version of the ARDL one, which allows for the inclusion of both $I(1)$ and $I(0)$ variables but is unstable in the presence of variables with higher integration orders. It provides information about both the short-run dynamics and the long-run equilibrium in an error correction specification which also includes unrestricted lags of the regressors (Pesaran and Shin, 1998; Nkoro and Uko, 2016). An advantage of this model is that it corrects for weak endogeneity of nonstationary explanatory variables. Both the ARDL and NARDL approaches are only applicable if there is a single cointegrating vector, otherwise the Johansen and Juselius (1990) method needs to be adopted. The NARDL model can be estimated by OLS and inference allows to differentiate between various types of asymmetries.

To test for the existence of a stable long-run relationship between the variables we use the dynamic Bounds testing procedure, which is valid regardless of whether the underlying regressors are $I(0)$ or $I(1)$. The Bounds test for the existence of an asymmetric long-run relationship is an F-test for the joint null $\rho = \theta^+ = \theta^- = 0$, where ρ is the coefficient of the nonlinear error correction term in the NARDL model. The lower bound hypothesis is that all

level regressors x_t^+ and x_t^- are $I(0)$ and therefore there is no cointegrating relationship between the variables while the upper bound hypothesis is that all level regressors are $I(1)$ and a cointegrating relationship exists between the variables. The critical values for the test are provided by Pesaran et al. (2001); when the computed F-statistic exceeds the upper bound critical value then H_0 is rejected and there exists one cointegration relationship between the variables.

However, Pesaran and Shin (1998) argue that in small samples empirical critical values should be used for statistical inference. Therefore we perform a residual bootstrap to obtain empirical values and confidence intervals for the Bounds test F-statistic. These are generated by estimating an appropriate NARDL model with optimal lag length by means of OLS while excluding the coefficient values on the independent weakly exogenous variables, which imposes restrictions of the null hypothesis of no cointegration for the F-Test. This restricted model is estimated for the regressand while for the regressors an unrestricted NARDL model is estimated. The residuals of the models are saved, resampled with replacement and re-centred, which generates the bootstrap residuals (Goh et al., 2017). Afterwards, the models are estimated again using the bootstrap sample and the bootstrap t- and F-test statistics are generated. The above procedure is repeated 1000 times to compute an entire bootstrap distribution from which bootstrap critical values can be obtained according to:

$$c_{1-\alpha}^* = \min \left\{ c: \sum_{b=1}^B I(T_b^* > c) \leq \alpha \right\}$$

$$c_{\alpha}^* = \max \left\{ c: \sum_{b=1}^B I(T_b^* < c) \leq \alpha \right\}$$
(7)

where T_b^* is the bootstrap test statistic and α is the nominal level of the test (McNown et al., 2018). The null hypothesis is rejected if the F-test statistic for the restricted model is greater than $c_{1-\alpha}^*$ or the t-test statistic for the unrestricted model is less than c_{α}^* .

To assess model adequacy, we perform various diagnostic tests (Shin et al., 2014), specifically Wald tests for the symmetry of the short- and long-run parameters, LM tests for serial correlation, and ARCH tests. We also compare the in-sample and out-of-sample performance of the linear and the nonlinear ARDL models. In particular, we run rolling regressions with a 120-month window, using data over the period January 1993-December 2002, and use the remaining 187 observations data to produce out-of-sample forecasts. We then compute the

mean squared prediction errors (MSPEs) of a 120-month rolling window 1-month ahead forecast with real-time data obtained for both specifications, where a lower MSPE indicates a better forecasting performance (see Clark and West, 2007).

4. Data and Empirical Results

4.1 Data Description

We consider five inflation targeting countries, namely the UK, Canada, Australia, New Zealand and Sweden. The series used for the analysis are monthly and span the period from January 1993 to July 2019. The nominal short-term interest rates are the monthly averages of the overnight lending rates charged by each central bank, more precisely for the UK the base rate published by the Bank of England, for Canada the Bank of Canada Overnight Repo Rate, for Australia the Reserve Bank of Australia Official Cash Rate, for New Zealand the Reserve Bank of New Zealand Official Cash Rate, and for Sweden the Swedish market rate published by the Riksbank. The sources for the nominal broad money supply M3 series are the statistics database of each central bank, and for real GDP (output approach) the OECD National Accounts database. The real effective CPI-based exchange rates series have been obtained from the BIS (Bank for International Settlements) Statistics Warehouse. As for inflation expectations, we use both market and survey data. Specifically, the yield curve data used to construct the market-based inflation expectations measure have been obtained from Bloomberg. For the UK and Canada the original sources are respectively the Inflation Attitudes Survey and the Canadian Survey of Consumer Expectations. For Australia we use a survey measure of consumer expectations about increases in final prices for the 3-month ahead period published by the Reserve Bank of Australia. For New Zealand the series comes from the Reserve Bank's monetary conditions survey. Finally, for Sweden this series was obtained from the Riksbank's survey of inflation expectations.

As already mentioned, the market-based measure of inflation expectations is derived from the yield curve. Specifically, we take the difference between nominal and inflation-indexed 10-year bond yields (the latter representing real forward interest rates), which is essentially the compensation demanded by investors to offset expected future inflation and any associated risks (Sack, 2000). Low volatility of this measure suggests that the inflation-targeting framework has been successful in anchoring long-run inflation expectations. The second measure we use is based on quantitative rather than qualitative survey data. More precisely, we

compute the monthly 12-months ahead mean inflation forecast. Unlike financial instrument-based measures, survey measures do not necessarily represent expectations on which agents are willing to act but have the advantage of being a more direct estimate of inflation expectations.

As a first step, we test for the order of integration of all series using the DF-GLS test since, as already explained, variables of order higher than $I(1)$ cannot be included in an ARDL model. The results in Table 1 imply that real exchange rates, money supply and interest rate differentials are $I(1)$ while GDP and both inflation expectations measures are $I(0)$; therefore all variables can enter the model.

Table 1. DF-GLS Test Results for individual series

| | Level series | Differenced series | Level series | Differenced series |
|-----------------------|---|--------------------|---|--------------------|
| | Real Exchange Rate | | Interest Rate Differential | |
| UK-Canada | -2.409633 | -16.14660*** | -2.906923 | -12.95680*** |
| UK-Australia | -1.806277 | -14.15482*** | -1.606476 | -7.266742*** |
| UK-New Zealand | -2.244035 | -15.27184*** | -2.404156 | -8.202538*** |
| UK-Sweden | -2.335293 | -14.01395*** | -3.412704 | -8.718320*** |
| Canada-Australia | -3.127759 | -15.17735*** | -1.482159 | -8.561225*** |
| Canada-New Zealand | -2.457177 | -15.36612*** | -1.956365 | -9.431650*** |
| Canada-Sweden | -2.767811 | -13.68189*** | -1.818217 | -8.998787*** |
| Australia-New Zealand | -3.083718 | -15.01991*** | -2.614297 | -13.06459*** |
| Australia-Sweden | -2.611152 | -13.51788*** | -0.128862 | -7.785444*** |
| New Zealand-Sweden | -2.405530 | -12.82593*** | -0.279920 | -7.981418*** |
| | Money Supply Differential | | Output Differential | |
| UK-Canada | 0.726967 | -11.16236*** | -5.745060*** | -13.50751*** |
| UK-Australia | -1.248922 | -4.529805*** | -5.538494*** | -13.37257*** |
| UK-New Zealand | -0.178168 | -4.623221*** | -3.617988** | -3.617988** |
| UK-Sweden | -1.576314 | -6.571804*** | -5.576428*** | -13.86241*** |
| Canada-Australia | 0.680567 | -14.49548*** | -3.454509** | -14.72166*** |
| Canada-New Zealand | -3.002544 | -15.50797*** | -4.728182*** | -13.73744*** |
| Canada-Sweden | -1.040547 | -13.08886*** | -5.921135*** | -14.70774*** |
| Australia-New Zealand | -0.218186 | -4.131359*** | -7.719430*** | -14.73735*** |
| Australia-Sweden | -1.987129 | -4.893552*** | -6.255319*** | -14.92583*** |
| New Zealand-Sweden | -1.390497 | -5.578336*** | -6.600979*** | -14.78302*** |
| | Market-based Inflation Expectations Differential | | Survey-based Inflation Expectations Differential | |
| UK-Canada | -2.093259** | -24.39729*** | -3.007652*** | -18.85474*** |
| UK-Australia | -2.102593** | -24.18133*** | -2.773300*** | -21.39735*** |
| UK-New Zealand | -2.102116** | -24.28768*** | -2.866010*** | -23.71241*** |
| UK-Sweden | -2.078134** | -24.53556*** | -2.717170*** | -17.82799*** |
| Canada-Australia | -3.759669** | -11.45993*** | -6.102653*** | -13.07812*** |
| Canada-New Zealand | -3.741017** | -8.341847*** | -5.371546*** | -24.24426*** |
| Canada-Sweden | -3.547323** | -18.69621*** | -5.801584*** | -14.46930*** |

| | | | | |
|-----------------------|--------------|--------------|--------------|--------------|
| Australia-New Zealand | -4.135290*** | -18.07779*** | -5.967459*** | -14.55439*** |
| Australia-Sweden | -2.705271*** | -21.04204*** | -6.845524*** | -14.19519*** |
| New Zealand-Sweden | -2.112474** | -19.96549*** | -5.669287*** | -13.44838*** |

DF-GLS Test hypothesis: H_0 : series contains a unit root; H_1 : series is stationary; Case II: constant and linear trend.

4.2 Results for the ARDL Model

The results for the linear ARDL model are reported in Tables 2a and 2b below. It can be seen that the error correction coefficient is not always significant, which implies that only in some cases there exists a long-run relationship between the real exchange rate and fundamentals. The speed of adjustment is low and ranges between 1% and 6%. In the short run, positive changes in the money supply differential lead to a real exchange rate appreciation in the majority of cases. However, the real exchange rate depreciates in response to increases in the interest rate differential. Likewise, expectations of higher inflation rates cause the real exchange rate to depreciate, but this effect is not significant. The output differential is only significant in a few cases, when a higher differential leads to a depreciation of the real exchange rate. In the long run, most of the standard fundamentals and the inflation expectation variable are insignificant, which implies that there is no long-run relationship linking the real exchange rate to fundamentals.

Table 2a. Linear Autoregressive Distributed Lag Model Results with Market Expectations

| | GBPCAD | GBPAUD | GBPNZD | GBPSEK | CADAUD |
|-------------------------|---------------|---------------|---------------|---------------|---------------|
| α | 0.0042 | 0.0067 | 0.0045 | -0.0005 | -0.0010 |
| ecm_{t-1} | -0.0110 | -0.0242* | -0.0306** | -0.0450*** | -0.0475*** |
| $\Delta\tilde{m}_{t-1}$ | -0.3343** | -0.3279* | -0.1452 | -0.1924** | -0.1213 |
| $\Delta\tilde{x}_{t-1}$ | 0.0041 | 0.0108* | 0.0054 | -0.0005 | 0.0001 |
| $\Delta\tilde{i}_{t-1}$ | 0.0797*** | 0.1908*** | 0.1057*** | 0.0234*** | 0.0439*** |
| $\Delta\tilde{y}_{t-1}$ | 0.0044 | 0.0172 | 0.0321** | 0.0230 | 0.0134 |
| \tilde{m}_{t-1} | -0.0163 | 0.0080 | 0.0055 | -0.0103 | -0.0046 |
| \tilde{x}_{t-1} | -0.0004 | -0.0007 | -0.0008 | 0.0001 | 0.0030 |
| \tilde{i}_{t-1} | 0.0019 | 0.0054 | 0.0056* | 0.0076*** | 0.0041 |
| \tilde{y}_{t-1} | 0.0097 | -0.0067 | 0.0364** | 0.0610** | 0.0063 |

| | CADNZD | CADSEK | AUDNZD | AUDSEK | NZDSEK |
|-------------------------|---------------|---------------|---------------|---------------|---------------|
| α | -0.0021 | -0.0037 | -0.0062** | -0.0062 | 0.0018 |
| ecm_{t-1} | -0.0194* | -0.0133 | -0.0505*** | -0.0637*** | -0.0585*** |
| $\Delta\tilde{m}_{t-1}$ | -0.0357 | -0.2634*** | 0.0251 | -0.2119* | -0.0499 |

| | | | | | |
|-------------------------|-----------|----------|-----------|---------|-----------|
| $\Delta\tilde{x}_{t-1}$ | -0.0092 | -0.0031 | 0.0527 | -0.0034 | -0.0042 |
| $\Delta\tilde{i}_{t-1}$ | 0.0305** | 0.0044 | 0.1407*** | 0.0127* | 0.0104* |
| $\Delta\tilde{y}_{t-1}$ | 0.0325*** | -0.0018 | 0.0135 | 0.0108 | 0.0236* |
| \tilde{m}_{t-1} | -0.0139 | -0.0121 | -0.0073 | 0.0154 | 0.0402** |
| \tilde{x}_{t-1} | 0.00005 | -0.00007 | 0.0042 | 0.0007 | 0.0004 |
| \tilde{i}_{t-1} | 0.0028 | 0.0020 | 0.0184 | 0.0037 | 0.0037* |
| \tilde{y}_{t-1} | 0.0424*** | 0.0141 | 0.0010 | 0.0067 | 0.0609*** |

* significant at 10% level, ** significant at 5% level, *** significant at 1% level. Standard errors in parentheses.

Table 2b. Linear Autoregressive Distributed Lag Model Results with Survey Expectations

| | GBPCAD | GBPAUD | GBPNZD | GBPSEK | CADAUD |
|-------------------------|---------------|---------------|---------------|---------------|---------------|
| α | 0.0065* | 0.0095 | 0.0050 | 0.0006 | 0.0020 |
| ecm_{t-1} | -0.0174 | -0.0355** | -0.0327** | -0.0508*** | -0.0423** |
| $\Delta\tilde{m}_{t-1}$ | -0.3237** | -0.3102* | -0.1667 | -0.1966** | -0.1896 |
| $\Delta\tilde{x}_{t-1}$ | -0.0015 | 0.0012 | 0.0049** | -0.0010 | -0.0011 |
| $\Delta\tilde{i}_{t-1}$ | 0.0804*** | 0.1956*** | 0.0922*** | 0.0225*** | 0.0457*** |
| $\Delta\tilde{y}_{t-1}$ | 0.0061 | 0.0152 | 0.0335** | 0.0226 | 0.0176* |
| \tilde{m}_{t-1} | 0.0175* | 0.0123 | -0.0021 | -0.0110 | -0.0123 |
| \tilde{x}_{t-1} | -0.0017 | -0.0054* | 0.0002 | -0.0021 | -0.0008 |
| \tilde{i}_{t-1} | 0.0040 | 0.0066* | 0.0059* | 0.0076*** | 0.0046 |
| \tilde{y}_{t-1} | 0.0139 | -0.0058 | 0.0419** | 0.0606*** | 0.0143 |

| | CADNZD | CADSEK | AUDNZD | AUDSEK | NZDSEK |
|-------------------------|---------------|---------------|---------------|---------------|---------------|
| α | -0.0038 | -0.0032 | -0.0105*** | -0.0065 | 0.0006 |
| ecm_{t-1} | -0.0232** | -0.0118 | -0.0520*** | -0.0636*** | -0.0563*** |
| $\Delta\tilde{m}_{t-1}$ | -0.0299 | -0.2546*** | -0.0587 | -0.2154* | -0.0333 |
| $\Delta\tilde{x}_{t-1}$ | 0.0001 | -0.0001 | -0.0032 | 0.0000 | 0.0053 |
| $\Delta\tilde{i}_{t-1}$ | 0.0320** | 0.0057 | 0.0947*** | 0.0148** | 0.0115** |
| $\Delta\tilde{y}_{t-1}$ | 0.0312*** | -0.0024 | 0.0076 | 0.0095 | 0.0260** |
| \tilde{m}_{t-1} | 0.0103 | -0.0124 | -0.0136 | 0.0150 | 0.0406** |
| \tilde{x}_{t-1} | -0.0003 | 0.0015 | -0.0079** | 0.0000 | 0.0052 |
| \tilde{i}_{t-1} | 0.0022 | 0.0014 | 0.0164** | 0.0034 | 0.0031 |
| \tilde{y}_{t-1} | 0.0407*** | 0.0129 | -0.0076 | 0.0037 | 0.0687*** |

* significant at 10% level, ** significant at 5% level, *** significant at 1% level. Standard errors in parentheses.

Table 3 reports some diagnostic tests. The presence of serial correlation cast doubts on the data congruence of the model and motivated the estimation of the nonlinear model.

Table 3. ARDL Model Specification Tests

| | Breusch-Pagan Test | Breusch-Godfrey Test | Wald Test | Breusch-Pagan Test | Breusch-Godfrey Test | Wald Test |
|--------|---|----------------------|-----------|---|----------------------|-----------|
| | Model using Market-based Inflation Expectations | | | Model using Survey-based Inflation Expectations | | |
| GBPCAD | 0.2107 | 0.0040*** | 0.9902 | 0.4271 | 0.0039*** | 0.9723 |
| GBPAUD | 0.4510 | 0.0082*** | 0.9612 | 0.3168 | 0.0087*** | 0.7643 |
| GBPNZD | 0.0176** | 0.0093*** | 0.6906 | 0.0166** | 0.0051*** | 0.4522 |
| GBPSEK | 0.0154** | 0.0073*** | 0.1395 | 0.0707* | 0.0064*** | 0.1078 |
| CADAUD | 0.1102 | 0.0002*** | 0.6089 | 0.1285 | 0.0007*** | 0.7237 |
| CADNZD | 0.0029*** | 0.0002*** | 0.4685 | 0.0551* | 0.0010*** | 0.4391 |
| CADSEK | 0.0348** | 0.0002*** | 0.9831 | 0.0543* | 0.0003*** | 0.9666 |
| AUDNZD | 0.0312** | 0.0000*** | 0.7201 | 0.0330** | 0.0000*** | 0.2306 |
| AUDSEK | 0.0850* | 0.0000*** | 0.4218 | 0.5451 | 0.0000*** | 0.4217 |
| NZDSEK | 0.0132** | 0.0000*** | 0.0210** | 0.0166** | 0.0000*** | 0.0187** |

* significant at 10% level, ** significant at 5% level, *** significant at 1% level. P-values reported for all.

Breusch-Pagan Test for

Heteroscedasticity:

H_0 : homoscedastic errors

H_1 : heteroscedastic errors

Breusch-Godfrey LM Test for serial

correlation:

H_0 : no serial correlation

H_1 : serial correlation

Wald F-Test for weak exogeneity:

H_0 : no endogeneity

H_1 : weak endogeneity

4.3 Results for the NARDL (Nonlinear ARDL) Model

The estimates of the NARDL specifications including market- and survey-based inflation expectations in turn are reported in Tables 4a and 4b respectively. It appears that, when nonlinearities are taken into account, evidence can be obtained of mean reversion to a long-run relationship between the real exchange rate and key fundamentals as implied by the negative and significant coefficient on the adjustment term ecm_{t-1} . As for the short-run dynamics, in those cases when the estimated coefficients are significant they indicate that both positive and negative money supply and output changes lead to a real exchange rate appreciation, while both positive and negative interest rate changes lead to an exchange rate depreciation. This finding confirms the presence of short-run asymmetric effects of these variables.

Table 4a. Nonlinear Autoregressive Distributed Lag Model Results with Market Expectations

| | GBPCAD | GBPAUD | GBPNZD | GBPSEK | CADAUD |
|----------------------------|---------------|---------------|---------------|---------------|---------------|
| α | 0.0535*** | 0.0421** | 0.0712** | 0.0385*** | 0.0448** |
| ecm_{t-1} | -0.0495*** | -0.0323** | -0.0320** | -0.0964*** | -0.0812*** |
| Δq_{t-1} | 0.1209** | 0.1036* | 0.1566*** | 0.0590 | 0.2128*** |
| $\Delta \tilde{m}_{t-1}^+$ | -0.3480** | -0.3823** | 0.0736 | -0.3515* | 0.1158 |
| $\Delta \tilde{m}_{t-1}^-$ | -0.5562 | -5.0506*** | -0.0221 | -0.2752 | -1.1064 |
| $\Delta \tilde{x}_{t-1}^+$ | -0.0140* | -0.0249** | -0.0007** | -0.0041 | 0.0235*** |
| $\Delta \tilde{x}_{t-1}^-$ | 0.0040 | 0.0159* | 0.0000 | 0.0067 | -0.0027 |
| $\Delta \tilde{i}_{t-1}^+$ | 0.0298 | 0.1516*** | 0.0116 | -0.0120* | 0.0169 |
| $\Delta \tilde{i}_{t-1}^-$ | 0.0131 | 0.0250 | 0.0429* | 0.0646*** | 0.0151 |
| $\Delta \tilde{y}_{t-1}^+$ | -0.0002 | -0.0148 | -0.0310 | 0.0172 | -0.0119 |
| $\Delta \tilde{y}_{t-1}^-$ | -0.0016 | 0.0292 | 0.0086 | 0.0061 | -0.0528* |
| \tilde{m}_{t-1}^+ | -0.0767*** | -0.0303 | -0.0398 | -0.0907** | -0.0810** |
| \tilde{m}_{t-1}^- | 0.2276*** | 1.1015 | 0.0377* | 0.0677* | 0.2629 |
| \tilde{x}_{t-1}^+ | -0.0020 | -0.0061 | -0.0004** | 0.0002 | -0.0005 |
| \tilde{x}_{t-1}^- | 0.0002 | -0.0039 | 0.0000 | 0.0017 | 0.0125 |
| \tilde{i}_{t-1}^+ | -0.0020 | 0.0084 | -0.0131 | 0.0039 | 0.0041 |
| \tilde{i}_{t-1}^- | -0.0003 | 0.0036 | 0.0059 | 0.0155* | 0.0097 |
| \tilde{y}_{t-1}^+ | -0.0119 | -0.0213 | 0.0369 | -0.0146 | -0.0119 |
| \tilde{y}_{t-1}^- | 0.0975 | 0.0314 | 0.0028 | 0.0689 | 0.0571 |

| | CADNZD | CADSEK | AUDNZD | AUDSEK | NZDSEK |
|----------------------------|---------------|---------------|---------------|---------------|---------------|
| α | -0.0047 | -0.0087** | 0.0231** | -0.0260*** | -0.0016 |
| ecm_{t-1} | -0.0220* | -0.0219** | -0.1404*** | -0.0751*** | -0.0772*** |
| Δq_{t-1} | 0.2022*** | 0.1597*** | 0.2957*** | 0.2370*** | 0.2639*** |
| $\Delta \tilde{m}_{t-1}^+$ | 0.1896 | -0.9054** | -0.2036 | -0.0050 | -0.1541 |
| $\Delta \tilde{m}_{t-1}^-$ | -0.8428 | -0.1397 | 0.2285 | 0.0004 | -0.0114 |
| $\Delta \tilde{x}_{t-1}^+$ | 0.0161 | 0.0077 | 0.1314*** | -0.0052 | 0.0099 |
| $\Delta \tilde{x}_{t-1}^-$ | 0.0171 | 0.0141 | -0.0272 | 0.0138*** | -0.0006 |
| $\Delta \tilde{i}_{t-1}^+$ | -0.0498 | -0.0086 | -0.0485 | -0.0011 | -0.0015 |
| $\Delta \tilde{i}_{t-1}^-$ | -0.0064 | 0.0060 | 0.0270 | 0.1252*** | 0.0767*** |
| $\Delta \tilde{y}_{t-1}^+$ | -0.0088 | 0.0036 | -0.0118 | -0.0427 | 0.0022 |
| $\Delta \tilde{y}_{t-1}^-$ | -0.0169 | 0.0060 | 0.0198 | 0.0124 | -0.0236 |
| \tilde{m}_{t-1}^+ | -0.0048 | 1.3986*** | 0.1098 | 0.0000 | -0.1236 |
| \tilde{m}_{t-1}^- | 0.0916 | -0.0229 | 0.0693*** | -0.0004 | 0.0325* |
| \tilde{x}_{t-1}^+ | -0.0005 | -0.0065 | -0.0279* | 0.0024 | -0.0003 |
| \tilde{x}_{t-1}^- | -0.0004 | -0.0078 | -0.0193 | -0.0011 | -0.0008 |
| \tilde{i}_{t-1}^+ | 0.0267 | -0.0016 | 0.0096 | 0.0026 | 0.0007 |
| \tilde{i}_{t-1}^- | -0.0009 | 0.0077 | -0.0068 | -0.0095 | 0.0014 |
| \tilde{y}_{t-1}^+ | 0.0295 | 0.0155 | 0.0269 | 0.0355 | -0.0064 |
| \tilde{y}_{t-1}^- | 0.0029 | 0.0253 | -0.0384** | 0.0194 | 0.0991*** |

* significant at 10% level, ** significant at 5% level, *** significant at 1% level. Standard errors in parentheses.

Table 4b. Nonlinear Autoregressive Distributed Lag Model Results with Survey Expectations

| | GBPCAD | GBPAUD | GBPNZD | GBPSEK | CADAUD |
|----------------------------|---------------|---------------|---------------|---------------|---------------|
| α | 0.0506*** | -0.0013 | 0.0232* | 0.0270** | 0.0448** |
| ecm_{t-1} | -0.0569*** | -0.0684*** | -0.0642*** | -0.0743*** | -0.0812*** |
| Δq_{t-1} | 0.1016* | 0.1600*** | 0.1450** | 0.0582 | 0.2128*** |
| $\Delta \tilde{m}_{t-1}^+$ | -0.3580** | -0.0017 | -0.1666 | -0.3763* | 0.1158 |
| $\Delta \tilde{m}_{t-1}^-$ | -0.7340** | -1.3426* | -0.8949* | -0.2473 | -1.1064 |
| $\Delta \tilde{x}_{t-1}^+$ | 0.0045 | 0.0032 | 0.0007 | 0.0014 | 0.0235*** |
| $\Delta \tilde{x}_{t-1}^-$ | 0.0007 | 0.0022 | 0.0014 | 0.0005 | -0.0027 |
| $\tilde{\Delta i}_{t-1}^+$ | 0.0271 | -0.0211 | 0.0126 | -0.0123* | 0.0169 |
| $\tilde{\Delta i}_{t-1}^-$ | 0.0098 | 0.0857** | 0.0421* | 0.0685*** | 0.0151 |
| $\Delta \tilde{y}_{t-1}^+$ | 0.0021 | -0.0144 | -0.0183 | 0.0172 | -0.0119 |
| $\Delta \tilde{y}_{t-1}^-$ | -0.0038 | 0.0282 | 0.0212 | 0.0088 | -0.0528* |
| \tilde{m}_{t-1}^+ | -0.0716*** | 0.0497** | -0.0605** | -0.0797 | -0.0810** |
| \tilde{m}_{t-1}^- | 0.2415*** | 0.3199 | 0.1381 | 0.0348 | 0.2629 |
| \tilde{x}_{t-1}^+ | -0.0041** | -0.0087* | 0.0034* | -0.0019 | -0.0005 |
| \tilde{x}_{t-1}^- | -0.0034* | -0.0141** | -0.0048 | -0.0015 | 0.0125 |
| \tilde{i}_{t-1}^+ | -0.0009 | 0.0175** | -0.0056 | 0.0032 | 0.0041 |
| \tilde{i}_{t-1}^- | 0.0011 | 0.0120** | 0.0059 | 0.0091 | 0.0097** |
| \tilde{y}_{t-1}^+ | -0.0176 | -0.0233 | 0.0041** | -0.0151 | -0.0119 |
| \tilde{y}_{t-1}^- | 0.1005* | 0.0311 | 0.0021* | 0.0663 | 0.0571 |

| | CADNZD | CADSEK | AUDNZD | AUDSEK | NZDSEK |
|----------------------------|---------------|---------------|---------------|---------------|---------------|
| α | -0.0054 | -0.0111** | 0.0251** | -0.0254*** | -0.0225*** |
| ecm_{t-1} | -0.0276** | -0.0312** | -0.1362*** | -0.0801*** | -0.1300*** |
| Δq_{t-1} | 0.1898*** | 0.1740*** | 0.2859*** | 0.2213*** | 0.2256*** |
| $\Delta \tilde{m}_{t-1}^+$ | 0.1353 | -0.8615** | -0.1658 | -0.0040 | -0.2111 |
| $\Delta \tilde{m}_{t-1}^-$ | -0.8081 | -0.1420* | 0.2398 | 0.0002 | 0.1811 |
| $\Delta \tilde{x}_{t-1}^+$ | 0.0010 | 0.0012 | 0.0095** | 0.0013 | 0.0004 |
| $\Delta \tilde{x}_{t-1}^-$ | 0.0031 | 0.0052** | -0.0038 | -0.0015 | 0.0116* |
| $\tilde{\Delta i}_{t-1}^+$ | -0.0589 | -0.0097* | -0.1012** | -0.0042 | -0.0076 |
| $\tilde{\Delta i}_{t-1}^-$ | 0.0064 | 0.0087 | -0.0081 | 0.1337*** | -0.0050 |
| $\Delta \tilde{y}_{t-1}^+$ | -0.0154 | 0.0007 | -0.0159 | -0.0376 | -0.0303 |
| $\Delta \tilde{y}_{t-1}^-$ | -0.0254 | 0.0075 | 0.0248* | 0.00709 | -0.0010 |
| \tilde{m}_{t-1}^+ | -0.0006 | 1.2173*** | 0.1048 | 0.0000 | 0.1102*** |
| \tilde{m}_{t-1}^- | 0.1446 | -0.0203 | 0.0885*** | -0.0003 | -0.0119 |
| \tilde{x}_{t-1}^+ | -0.0018 | -0.0023 | -0.0086** | -0.0036 | -0.0010 |
| \tilde{x}_{t-1}^- | -0.0018 | -0.0024 | -0.0078** | -0.0012 | -0.0016 |
| \tilde{i}_{t-1}^+ | 0.0287 | -0.0008 | 0.0241* | 0.0041* | 0.0069** |
| \tilde{i}_{t-1}^- | 0.0016 | 0.0092 | 0.0109 | -0.0109 | 0.0039 |
| \tilde{y}_{t-1}^+ | 0.0382 | 0.0219 | 0.0469 | -0.0337 | 0.0591 |
| \tilde{y}_{t-1}^- | 0.0108 | 0.0224 | -0.0489** | -0.0140 | 0.0511 |

* significant at 10% level, ** significant at 5% level, *** significant at 1% level. Standard errors in parentheses.

Unlike in the linear ARDL, the inflation expectation differential now also plays a role and has an asymmetric effect; more precisely, only positive inflation expectation changes are significant and cause an appreciation of the real exchange rate. In other words, deviations from PPP occur only when the market expects inflation to be higher than the target rate in the future, i.e. when the central bank lacks credibility. A positive (negative) sign for the coefficient on the negative partial sum component means that convergence (divergence) between expected future inflation between the two countries will lead to a depreciation (appreciation) of the real exchange rate. For most exchange rates, changes in inflation expectations lead to an appreciation, regardless of whether inflation expectations converge or not. Further, only one of the partial sum components has a significant short-run effect. Finally, the adjustment speed ranges between 2% and 14% and is therefore up to three times faster than in the linear ARDL models, and slightly faster in the model including survey-based expectations.

Table 5 reports the long-run asymmetric coefficients associated with positive and negative changes in the independent variables. It can be seen that positive (negative) money supply shocks have a negative (positive) impact, with the positive multipliers being greater than the negative ones. Both positive and negative interest rate shocks have a positive effect. Also, both types of inflation expectation shocks cause an exchange rate appreciation, while the effect of positive and negative output shocks on the real exchange rate varies. Finally, negative shocks to fundamentals or inflation expectations have a greater impact than positive ones, which is consistent with the evidence reported by other studies on the presence of asymmetries (Holmes and Wang, 2006). On the whole, money supply and output shocks have the largest long-run effects, but interest rate and inflation expectation shocks also have a significant impact on real exchange rate deviations from PPP and the adjustment process to the PPP equilibrium. In addition, changes in survey-based expectations have a more sizable impact than those in market-based ones.

Table 5. Long Run Asymmetries

| Market Expectations | | | | | |
|---------------------|------------|------------|------------|------------|------------|
| | GBPCAD | GBPAUD | GBPNZD | GBPSEK | CADAUD |
| $L\tilde{m}^+$ | -1.5509*** | -0.9359*** | -1.2431** | -0.9409*** | -0.9980*** |
| $L\tilde{m}^-$ | 4.6012*** | 34.0792*** | 1.1780** | 0.7026*** | 3.2375*** |
| $L\tilde{i}^+$ | -0.0410*** | 0.2606*** | -0.4094** | 0.0407*** | 0.0504*** |
| $L\tilde{i}^-$ | -0.0053*** | 0.1116*** | 0.1840** | 0.1606*** | 0.1201*** |
| $L\tilde{x}^+$ | -0.0405*** | -0.1890*** | -0.0130** | 0.0019*** | -0.0057*** |
| $L\tilde{x}^-$ | 0.0042*** | -0.1198*** | -0.0024** | 0.0175*** | 0.1536*** |
| $L\tilde{y}^+$ | -0.2412*** | -0.6591*** | 1.1541** | -0.1515*** | -0.1465*** |
| $L\tilde{y}^-$ | 1.9712*** | 0.9730*** | 0.0860** | 0.7143*** | 0.7028*** |
| Survey Expectations | | | | | |
| | GBPCAD | GBPAUD | GBPNZD | GBPSEK | CADAUD |
| $L\tilde{m}^+$ | -0.2172* | 63.9348** | 0.7820*** | -0.0001** | -1.6019*** |
| $L\tilde{m}^-$ | 4.1573* | -1.0472** | 0.4933*** | -0.0047*** | 0.4210*** |
| $L\tilde{i}^+$ | 1.2105* | -0.0721** | 0.0687*** | 0.0348*** | 0.0094*** |
| $L\tilde{i}^-$ | -0.0424* | 0.3497** | -0.0487*** | -0.1267*** | 0.0186*** |
| $L\tilde{x}^+$ | -0.0215* | -0.2949** | -0.1991*** | 0.0323*** | -0.0035*** |
| $L\tilde{x}^-$ | -0.0182* | -0.3545** | -0.1373*** | -0.0140*** | -0.0098*** |
| $L\tilde{y}^+$ | 1.3395* | 0.7086** | 0.1915*** | 0.4726*** | -0.0830*** |
| $L\tilde{y}^-$ | 0.1305* | 1.1570** | -0.2732*** | -0.2587*** | 1.2847*** |
| | GBPCAD | GBPAUD | GBPNZD | GBPSEK | CADAUD |
| $L\tilde{m}^+$ | -1.2573*** | 0.7271*** | -0.9426*** | -1.0727*** | -0.9980*** |
| $L\tilde{m}^-$ | 4.2404*** | 4.6771*** | 2.1513*** | 0.4684*** | 3.2375*** |
| $L\tilde{i}^+$ | -0.0161*** | 0.2564*** | -0.0874*** | 0.0430*** | 0.0504*** |
| $L\tilde{i}^-$ | 0.0198*** | 0.1747*** | 0.0917*** | 0.1223*** | 0.1201*** |
| $L\tilde{x}^+$ | -0.0711*** | -0.1274*** | 0.0534*** | -0.0261*** | -0.0057*** |
| $L\tilde{x}^-$ | -0.0594*** | -0.2061*** | -0.0751*** | -0.0203*** | 0.1536*** |
| $L\tilde{y}^+$ | -0.3098*** | -0.3400*** | 0.0641*** | -0.2033*** | -0.1465*** |
| $L\tilde{y}^-$ | 1.7651*** | 0.3242*** | 0.0324*** | 0.8929*** | 0.7028*** |
| | CADNZD | CADSEK | AUDNZD | AUDSEK | NZDSEK |
| $L\tilde{m}^+$ | -0.0225** | 38.9586*** | 0.7693*** | -0.0001*** | 0.8473*** |
| $L\tilde{m}^-$ | 5.2368** | -0.6481*** | 0.6501*** | -0.0041*** | -0.0917*** |
| $L\tilde{i}^+$ | 1.0408** | -0.0240*** | 0.1773*** | 0.0507*** | 0.05271*** |
| $L\tilde{i}^-$ | 0.0584** | 0.2948*** | 0.0803*** | -0.1358*** | 0.0297*** |
| $L\tilde{x}^+$ | -0.0642** | -0.0741*** | -0.0633*** | -0.0445*** | -0.0076*** |
| $L\tilde{x}^-$ | -0.0657** | -0.0783*** | -0.0574*** | 0.0154*** | -0.0121*** |
| $L\tilde{y}^+$ | 1.3815** | 0.7014*** | 0.3448*** | 0.4206*** | 0.4548*** |
| $L\tilde{y}^-$ | 0.3920** | 0.7155*** | -0.3593*** | -0.1750*** | 0.3929*** |

* significant at 10% level, ** significant at 5% level, *** significant at 1% level. Standard errors in parentheses.

L^+ and L^- denote the positive and negative long run coefficients, which are defined by $\beta^+ = -\frac{\theta^+}{\rho}$ and $\beta^- = -\frac{\theta^-}{\rho}$

The results of the Wald tests for symmetry of both the short- and long-run parameters (required as part of the NARDL procedure) are reported in Table 6 and imply a rejection of the null of parameter symmetry, which confirms the presence of nonlinearities. As noted earlier, there are

three types of possible asymmetries in the NARDL model. The first is reaction asymmetry, namely asymmetry of the long-run coefficients, i.e. $\beta^+ \neq \beta^-$, for which we find plenty of evidence. Of particular interest is the result that negative inflation expectation shocks have a more pronounced effect than positive ones, which suggests that central banks are perceived as more credible when aiming to reduce (rather than increase) inflation. The second type is impact asymmetry of the short-run coefficients on the first differences of the independent variables, i.e. $\Delta x^+ \neq \Delta x^-$. Our results are less supportive of the existence of such asymmetries. The third type is dynamic adjustment asymmetry combining reaction and impact asymmetries in the error correction coefficient. Its estimated values are larger than those yielded by the linear model, and therefore allowing for nonlinearities provides evidence of faster adjustment to the long-run equilibrium value implied by PPP.

Table 6. Wald Test of Parameter Symmetry

| | Market Expectations | | Survey Expectations | |
|--------|---------------------------------|----------------------------------|---------------------------------|----------------------------------|
| | Wald Test for long run symmetry | Wald Test for short run symmetry | Wald Test for long run symmetry | Wald Test for short run symmetry |
| GBPCAD | 0.0000*** | 0.0002*** | 0.0000*** | 0.0000*** |
| GBPAUD | 0.0018*** | 0.3750 | 0.0651* | 0.0000*** |
| GBPNZD | 0.0280** | 0.0069*** | 0.0358** | 0.0003*** |
| GBPSEK | 0.0021*** | 0.0031*** | 0.0126** | 0.0148** |
| CADAUD | 0.0278*** | 0.0000*** | 0.0278** | 0.0000*** |
| CADNZD | 0.8779 | 0.0360** | 0.7392 | 0.0729* |
| CADSEK | 0.0324** | 0.0000*** | 0.0489** | 0.0000*** |
| AUDNZD | 0.0000*** | 0.0000*** | 0.0000*** | 0.0000*** |
| AUDSEK | 0.0081*** | 0.0000*** | 0.0117** | 0.0000*** |
| NZDSEK | 0.7883 | 0.0117** | 0.0005*** | 0.0000*** |

Wald test of the null hypothesis of parameter symmetry.

4.4 NARDL Model Performance and Mis-Specification Tests

To check the adequacy of the NARDL specification we conduct various tests. Table 7 reports the F-tests statistics of the Bounds test using both the asymptotic and bootstrapped critical values; the null hypothesis of no cointegration cannot be rejected in either case with the single exception of the CADNZD model.

Table 7. Bounds Test Results using asymptotic and bootstrap critical values

| | F-statistic for NARDL model (1) using market-based inflation expectations | F-statistic for NARDL model (2) using survey-based inflation expectations |
|--------|---|---|
| GBPCAD | 14.6989*** | 22.8373*** |
| GBPAUD | 0.7892 | 3.4263** |
| GBPNZD | 4.8728*** | 4.4447*** |
| GBPSEK | 9.6628*** | 6.3136*** |
| CADAUD | 4.8838*** | 4.8838*** |
| CADNZD | 0.0236 | 0.1111 |
| CADSEK | 4.6149*** | 3.9070** |
| AUDNZD | 19.7235*** | 17.9692*** |
| AUDSEK | 7.0785*** | 6.4219*** |
| NZDSEK | 0.0722 | 12.3972*** |

Asymptotic critical values: 10%: 3.09, 5%: 3.49, 1%: 4.37

Bootstrap critical values: 10%: 2.85, 5%: 3.15, 1%: 3.77

** indicates significance at bootstrap critical value of 5%

Table 8 shows lag selection and other diagnostic tests for serial correlation and ARCH effects; these confirm data congruency; in particular, unlike in the linear case, there is no evidence of serial correlation, which supports the choice of a nonlinear model.

Table 8. NARDL model lag selection and diagnostic tests

| | Selected Lag | Model using Market-based Inflation Expectations | | Model using Survey-based Inflation Expectations | |
|--------|--------------|---|---------|---|---------|
| | | ARCH Effects | LM Test | ARCH Effects | LM Test |
| GBPCAD | 1 | 0.0633 | 0.5490 | 0.1689 | 0.3520 |
| GBPAUD | 1 | 0.2594 | 0.2193 | 0.2616 | 0.1652 |
| GBPNZD | 1 | 0.8188 | 0.2955 | 0.2004 | 0.2689 |
| GBPSEK | 1 | 0.0874 | 0.8898 | 0.0866 | 0.7452 |
| CADAUD | 1 | 0.0658 | 0.2394 | 0.0658 | 0.2394 |
| CADNZD | 1 | 0.3472 | 0.6370 | 0.1660 | 0.9497 |
| CADSEK | 1 | 0.3201 | 0.3554 | 0.4116 | 0.4125 |
| AUDNZD | 1 | 0.1189 | 0.7916 | 0.0967 | 0.7057 |
| AUDSEK | 1 | 0.7500 | 0.4914 | 0.3815 | 0.3978 |
| NZDSEK | 1 | 0.9090 | 0.9965 | 0.4234 | 0.4723 |

LM Test for ARCH Effects:

H_0 : no ARCH effects

H_1 : ARCH effects

LM Test for serial correlation:

H_0 : no serial correlation

H_1 : serial correlation

As a final step, we compare both the in-sample and out-of-sample performance of the previously estimated linear and nonlinear specifications. Table 9 reports the computed Clark and West statistics for all models; as can be seen, these indicate that the nonlinear model outperforms the linear one in all cases.

Table 9. Clark and West t-test statistics for comparing in-sample and out-of-sample forecasting performance of the linear and nonlinear models

| | CW Statistic for models using market-based inflation expectations | | CW Statistic for models using survey-based inflation expectations | |
|--------|---|---------------------------|---|---------------------------|
| | In-sample Performance | Out-of-sample Performance | In-sample Performance | Out-of-sample Performance |
| GBPCAD | 3.03387487** | 3.39208724** | 4.58454583** | 3.38925156** |
| GBPAUD | 10.6863519** | 3.49883333** | 10.5228289** | 9.98319246** |
| GBPNZD | 11.6279898** | 12.2931721** | 2.81195405** | 11.4778461** |
| GBPSEK | 4.13871062** | 16.3711914** | 3.8333045** | 13.0607168** |
| CADAUD | 2.44888098** | 15.4383316** | 3.39201903** | 21.2617149** |
| CADNZD | 2.90834757** | 5.36748511** | 2.71442531** | 5.88069641** |
| CADSEK | 5.50953645** | 2.63149382** | 5.44269445** | 1.79559331** |
| AUDNZD | 42.7264363** | 48.4560815** | 3.48202603** | 35.0526318** |
| AUDSEK | 2.49953189** | 4.98907343** | 2.49985165** | 5.45426571** |
| NZDSEK | 4.04552116** | 26.2182514** | 3.99499817** | 31.502991** |

** indicates significance at normal critical value of 5%: 1.645

CW = Clark and West test statistic for comparing the MSPE of the NARDL model with the MSPE of the linear ARDL model.

t-Test hypotheses:

$$H_0: MSPE_{ARDL} = MSPE_{NARDL}$$

$$H_1: MSPE_{ARDL} > MSPE_{NARDL}$$

5. Conclusions

The aim of this paper was to shed new light on the PPP puzzle by estimating a model of the real exchange rates including standard fundamentals as well as two alternative measures of inflation expectations in the specific case of five countries that have adopted inflation targeting (UK, Canada, Australia, New Zealand, Sweden). In particular, both a benchmark linear ARDL model and a nonlinear (NARDL) specification are estimated.

The analysis yields two key findings. First, consistently with other studies (e.g., Taylor et al., 2001; Baum et al., 2001; Sollis et al., 2002), it suggests that a nonlinear framework is more appropriate to capture the behaviour of real exchange rates given the presence of asymmetries both in the long- and short-run. The speed of adjustment towards the PPP-implied long-run equilibrium is three times faster in a nonlinear framework, which provides much stronger evidence in support of PPP. Second, it highlights the role of inflation expectations, which is often overlooked in models including only standard fundamentals. In particular, survey-based ones appear to have a more sizable effect than market-based ones and to be more informative about the degree of credibility of a central bank and the possible impact of monetary policy on the real exchange rate. Since they can cause deviations from PPP and affect the adjustment

process it is clearly crucial that monetary authorities achieve a high degree of credibility and adopt appropriate policies to manage them and thus currency fluctuations effectively (Baharumshah et al., 2017). The inflation targeting framework has proven to be generally successful and therefore is also well placed in this respect.

References

- Ariff, M. and Zarei, A., 2015. Parity theorems revisited: an ARDL bounds test with non-parity factors. *Asian Academy of Management Journal of Accounting & Finance*, 11(1).
- Arize, A.C., Malindretos, J. and Igwe, E.U., 2017. Do exchange rate changes improve the trade balance: An asymmetric nonlinear cointegration approach. *International Review of Economics & Finance*, 49, pp.313-326.
- Baharumshah, A.Z., Soon, S.V. and Wohar, M.E., 2017. Markov-switching analysis of exchange rate pass-through: Perspective from Asian countries. *International Review of Economics & Finance*, 51, pp.245-257.
- Bahmani-Oskooee, M., Kutan, A.M. and Zhou, S., 2008. Do real exchange rates follow a nonlinear mean reverting process in developing countries?. *Southern Economic Journal*, pp.1049-1062.
- Baum, C.F., Barkoulas, J.T. and Caglayan, M., 2001. Nonlinear adjustment to purchasing power parity in the post-Bretton Woods era. *Journal of International Money and Finance*, 20(3), pp.379-399.
- Ca'Zorzi, M., Muck, J. and Rubaszek, M., 2016. Real exchange rate forecasting and PPP: This time the random walk loses. *Open Economies Review*, 27(3), pp.585-609.
- Cheung, Y.W. and Lai, K.S., 1994. Mean reversion in real exchange rates. *Economics Letters*, 46(3), pp.251-256.
- Chortareas, G. and Kapetanios, G., 2009. Getting PPP right: identifying mean-reverting real exchange rates in panels. *Journal of Banking & Finance*, 33(2), pp.390-404.
- Chortareas, G.E., Kapetanios, G. and Shin, Y., 2002. Nonlinear mean reversion in real exchange rates. *Economics Letters*, 77(3), pp.411-417.
- Christopoulos, D.K. and León-Ledesma, M.A., 2010. Smooth breaks and non-linear mean reversion: Post-Bretton Woods real exchange rates. *Journal of International Money and Finance*, 29(6), pp.1076-1093.
- Clarida, R. and Gali, J., 1994. Sources of real exchange-rate fluctuations: How important are nominal shocks?. In *Carnegie-Rochester conference series on public policy* (Vol. 41, pp. 1-56). North-Holland.
- Clark, T.E. and West, K.D., 2007. Approximately normal tests for equal predictive accuracy in nested models. *Journal of econometrics*, 138(1), pp.291-311.
- Coakley, J. and Fuertes, A.M., 1997. New panel unit root tests of PPP. *Economics Letters*, 57(1), pp.17-22.

- Ding, H. and Kim, J., 2012. Does inflation targeting matter for PPP? An empirical investigation. *Applied Economics Letters*, 19(18), pp.1777-1780.
- Feenstra, R.C. and Kendall, J.D., 1997. Pass-through of exchange rates and purchasing power parity. *Journal of International Economics*, 43(1-2), pp.237-261.
- Frankel, J.A. and Rose, A.K., 1996. A panel project on purchasing power parity: mean reversion within and between countries. *Journal of International Economics*, 40(1-2), pp.209-224.
- Froot, K.A. and Rogoff, K., 1995. Perspectives on PPP and long-run real exchange rates. *Handbook of international economics*, 3, pp.1647-1688.
- Ghodsi, S.H., 2017. Nonlinear ARDL Approach and the Housing Market in the US.
- Goh, S.K., Sam, C.Y. and McNown, R., 2017. Re-examining foreign direct investment, exports, and economic growth in asian economies using a bootstrap ARDL test for cointegration. *Journal of Asian Economics*, 51, pp.12-22.
- Holmes, M.J. and Wang, P., 2006. Asymmetric adjustment towards long-run PPP: Some new evidence for Asian economies. *International Economic Journal*, 20(2), pp.161-177.
- Johansen, S. and Juselius, K., 1990. Maximum likelihood estimation and inference on cointegration—with applications to the demand for money. *Oxford Bulletin of Economics and statistics*, 52(2), pp.169-210.
- Kamada, K. and Nakajima, J., 2014. On the reliability of Japanese inflation expectations using purchasing power parity. *Economic Analysis and Policy*, 44(3), pp.259-265.
- Kapetanios, G., Shin, Y. and Snell, A., 2003. Testing for a unit root in the nonlinear STAR framework. *Journal of econometrics*, 112(2), pp.359-379.
- Kim, J., 2014. Inflation targeting and real exchange rates: A bias correction approach. *Economics Letters*, 125(2), pp.253-256.
- Lavesson, N. 2011. *Is inflation mean-reverting?* Department of economics, Lund University.
- Lothian, J.R. and Taylor, M.P., 1996. Real exchange rate behavior: the recent float from the perspective of the past two centuries. *Journal of political economy*, 104(3), pp.488-509.
- McNown, R., Sam, C.Y. and Goh, S.K., 2018. Bootstrapping the autoregressive distributed lag test for cointegration. *Applied Economics*, 50(13), pp.1509-1521.
- Murray, C.J. and Papell, D.H., 2005. The purchasing power parity puzzle is worse than you think. *Empirical Economics*, 30(3), pp.783-790.
- Nkoro, E. and Uko, A.K., 2016. Autoregressive Distributed Lag (ARDL) cointegration technique: application and interpretation. *Journal of Statistical and Econometric Methods*, 5(4), pp.63-91.

- Norman, S., 2010. How well does nonlinear mean reversion solve the PPP puzzle?. *Journal of International Money and Finance*, 29(5), pp.919-937.
- Papell, D.H., 1997. Searching for stationarity: Purchasing power parity under the current float. *Journal of international Economics*, 43(3-4), pp.313-332.
- Pesaran, M.H. and Shin, Y., 1998. An autoregressive distributed-lag modelling approach to cointegration analysis. *Econometric Society Monographs*, 31, pp.371-413.
- Pesaran, M.H., Shin, Y. and Smith, R.J., 2001. Bounds testing approaches to the analysis of level relationships. *Journal of applied econometrics*, 16(3), pp.289-326.
- Rogoff, K., 1996. The purchasing power parity puzzle. *Journal of Economic literature*, 34(2), pp.647-668.
- Sack, B., 2000. Deriving inflation expectations from nominal and inflation-indexed Treasury yields. *The Journal of Fixed Income*, 10(2), pp.6-17.
- Schmidt, P. and Phillips, P.C., 1992. LM tests for a unit root in the presence of deterministic trends. *Oxford Bulletin of Economics and Statistics*, 54(3), pp.257-287.
- Shin, Y., Yu, B. and Greenwood-Nimmo, M., 2014. Modelling asymmetric cointegration and dynamic multipliers in a nonlinear ARDL framework. In *Festschrift in honor of Peter Schmidt* (pp. 281-314). Springer, New York, NY.
- Sollis, R., Leybourne, S. and Newbold, P., 2002. Tests for symmetric and asymmetric nonlinear mean reversion in real exchange rates. *Journal of Money, Credit and Banking*, pp.686-700.
- Stockman, A.C., 1987. The equilibrium approach to exchange rates. *FRB Richmond Economic Review*, 73(2), pp.12-30.
- Taylor, J.B., 2001. The role of the exchange rate in monetary-policy rules. *American Economic Review*, 91(2), pp.263-267.
- Taylor, M.P., 2006. Real exchange rates and purchasing power parity: mean-reversion in economic thought. *Applied Financial Economics*, 16(1-2), pp.1-17.
- Taylor, M.P., Peel, D.A. and Sarno, L., 2001. Nonlinear mean-reversion in real exchange rates: toward a solution to the purchasing power parity puzzles. *International economic review*, 42(4), pp.1015-1042.
- Wu, Y., 1996. Are real exchange rates nonstationary? Evidence from a panel-data test. *Journal of Money, Credit and Banking*, 28(1), pp.54-63.