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How bubbly is the New Zealand dollar?

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Abstract

This paper tests for the existence of bubbles in the value of the New Zealand
dollar. A common definition of an asset price bubble is the existence of
explosive dynamics. This paper tests for periods of explosiveness in the New
Zealand dollar measured at a monthly and quarterly frequency. To determine
whether, during any explosive changes, the exchange rate was disconnected
from changes in relative economic fundamentals, these tests are also applied
to three models of exchange rate determination. This paper finds no evidence
of episodes when either the New Zealand dollar or its fundamentals were
explosive.

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Non-technical summary

Policymakers are interested in understanding the variability of exchange rates and whether changes in exchange rates reflect developments in their theoretical drivers or whether they reflect 'bubble' behaviour. In this paper an asset price bubble is defined as a situation where an asset price exhibits explosive (i.e. exponential) dynamics.

This paper tests for explosiveness in the New Zealand dollar and assesses whether any rapid exchange rate changes have been accompanied by explosive changes in macroeconomic fundamentals. There are many exchange rate models that could be used to define the fundamental value of the exchange rate. Rather than take a stand on the determination of the value of the New Zealand dollar or its fundamental value at a given point in time, this paper applies tests for explosiveness to three commonly used models of the underlying value of the exchange rate. Based on monthly and quarterly data, there is no evidence of episodes when either the New Zealand dollar or its fundamentals were explosive.

1   Introduction

The ability of economic fundamentals to explain or even predict exchange rate dynamics remains an area of intense debate. Obstfeld and Rogoff (2000), for example, demonstrate that exchange rates appear disconnected from other economic variables. However, Engel and West (2005) argue that, when exchange rates are viewed as asset prices, it is valid to model them as a function of current and expected values of their fundamental determinants. Using a present value model of exchange rates, they show that the link between fundamentals and exchange rates will be weak if at least one of the fundamentals contains a unit root and the inter-temporal discount factor used to discount future fundamentals approaches one. In such a case, expectations of fundamentals will tend to dominate the current (or past) values of fundamentals in present value terms (and the nominal exchange rate follow a random walk). The implication from present value models is that persistent deviations from the model would be a consequence of time variation in the discount rate, the existence of speculative bubbles or explosiveness in observed or unobserved fundamentals.

Recently developed tests by Phillips et al. (2015a) and Phillips et al. (2015b) provide a methodology to date-stamp the origination and termination dates of periods where a time series is experiencing explosive dynamics. Since the volatility of the exchange rate can be high, this paper compares the results from these tests to those obtained from a wild bootstrap version of these tests that accounts for potential non-stationarity in volatility (described in detail in Steenkamp 2017).

The second contribution of this paper is to assess whether explosive periods identified in the value of the New Zealand dollar (NZD) can be explained by the fundamentals that economic theory suggest should drive changes in the value of the currency over a monthly and quarterly frequency. Test for explosiveness are applied to a range of different models of exchange rate determination, to determine whether explosive changes in fundamentals can account the emergence of any explosive dynamics in New Zealand dollar cross rates.

2   Literature review

Tests for speculative bubbles have been used in several applications, particularly in assessing stock and house prices. Many asset prices resemble

random walk processes, where the direction and magnitude of changes are near random so that predicting price changes is difficult. Rational bubbles in an asset price are typically defined as systematic departures from its fundamental price, where investors have rational expectations conditioned on all available information. An asset's underlying fundamental value cannot be directly observed, but should reflect the expected present value of future returns. Even if an asset price is above this value at a particular point in time, a rational investor may still be willing to buy the asset, provided they are confident that its price will rise and that they will be able to on-sell it. The intuition behind bubble tests is that a series should inherit explosiveness if it has a large bubble component. Assuming that the fundamental price of asset follows a random walk, an asset price will contain a bubble component if the raw series is an explosive autoregressive (AR) process. Apart from the existence of a rational bubble, explosive behaviour in an asset price could reflect a host of factors, including large changes in the discount rate, explosiveness in unobserved fundamentals themselves (see Pavlidis et al. 2015), 'irrational exuberance' (see Shiller 2005) or the possibility of 'intrinsic bubbles' (Froot and Obstfeld 1991) where fundamentals and prices are non-linearly related.[1] This paper tests whether explosiveness in measured fundamentals can account for any explosive periods in NZD cross rates.

The rational bubble literature (see Gürkaynak 2008 for a survey) demonstrates that, even with a time varying discount rate (see Phillips et al. 2011), periods of explosiveness (i.e. exponential growth) in an appropriately normalised asset price implies the existence of a 'bubble', which can be tested for econometrically.[2]

Along these lines, Diba and Grossman (1988a) note that if a bubble is an explosive autoregressive process, this implies that differincing a series containing a bubble component would not eliminate its unit root. This means that a left-tailed unit root test (testing for a root less than one) will provide evidence of bubbles if the tests show that both the levels and the differences of stock prices and their fundamentals (dividends, for example) have a unit root.

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[1] There is a substantial literature about the theoretical plausibility of rational bubbles, without a clear consensus. While many papers have asserted the theoretical inconsistency of rational bubbles, there have been many recently that show that different forms of 'irrationality', market imperfections or 'behavioural' issues that can give rise to bubbles (including asymmetric information, heterogeneous beliefs or limited arbitrage, see for example de Grauwe and Grimaldi 2006, Hong et al. 2006 or Gürkaynak 2008 for a summary).

[2] Early attempts at identifying speculative bubbles in foreign exchange markets include Evans (1986), West (1987b) or Woo (1987).

Consequently, they use unit root tests to test for cointegration between stock prices and dividends to check whether stock prices diverge from fundamentals.[3]

However, changes in persistence can cause commonly used unit root tests to loose power (affecting their ability to correctly identify bubbles). Evans (1991) demonstrates that Diba and Grossman's (1988b) approach may not correctly identify bubbles if there are boom-bust cycles, as the series may be difficult to distinguish from an I(1) series.[4]

A couple of alternative solutions have been proposed. Phillips et al. (2015a) proposes a right-tailed Dickey-Fuller unit root test to test for a root larger than one. Their 'SADF' test (Supremum Augmented-Dickey-Fuller) is applied over an expanding test window (with a fixed starting point) to prevent a period where the series has a unit root from dominating the test result. This test defines a bubble as a situation where an asset price is experiencing explosive growth over a sub-sample, but its underlying fundamentals are not.

However, in the presence of multiple bubble bursts, the SADF test might loose power in identifying bubbles. To overcome this issue, Phillips et al. (2015b) propose 'generalized SADF' (GSADF) test which uses rolling samples of variable window length when conducting unit root tests. Phillips et al. (2015b) show that their approach is good at discriminating between 'bubble' an 'no bubble' periods, even when there are multiple bubbles over the full sample.

2.1   Application to exchange rates

There is an extensive literature puzzling over the inability of fundamentals to explain exchange rate dynamics empirically (discussed in Obstfeld and Rogoff 2000 or Cheung et al. 2005). For example, Meese and Rogoff (1983) show that models based on economic variables struggle to beat a random walk forecast, challenging the validity of models linking exchange rates and fundamentals.[5] However, Engel and West (2005) argue that even if models based on measured fundamentals provide poor forecasts, they are still valid for modeling the exchange rate when exchange rates are viewed as asset

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[3] More recently, Engsted and Nielsen (2012) test for bubbles while allowing for the possibility of cointegration between fundamentals and the asset price using a co-explosive VAR approach.

[4] Evans (1991) proposes a model where there are two regimes, a bubble regime where the bubble is expected to grow, and a collapse regime where it mean reverts.

[5] Others argue that parameter instability can account for the weak link between fundamentals and exchange rates, see Rossi (2006), for example.

prices: in this case exchange rates can be modeled as a function of current and expected values of its fundamentals. Using a present value model of exchange rates, they show that the link between fundamentals and exchange rates will be weak if at least one of the fundamentals contains a unit root and the inter-temporal discount factor used to discount future fundamentals approaches one. In such a case, expectations of fundamentals will tend to dominate the current (or past) values of fundamentals in present value terms (and the nominal exchange rate follow a random walk).[6]

There has been many attempts to test whether differences between exchange rates and their theoretically consistent values may reflect speculative bubbles (see Evans 1986, West 1987b or Woo 1987). Whereas some of the early bubble tests were sensitive to mis-specification of the process governing their underlying fundamental price (Gürkaynak 2008 for a survey), the recent tests developed by Phillips et al. (2011) and Phillips et al. (2015a) are robust to model mis-specification.[7]

In the context of exchange rates, different theoretical models have been used to define the fundamental value of a currency, and different empirical tests for bubbles have been applied. Results about the presence of bubbles in exchange rates has also been mixed. West (1987a) focuses on the deutschemark-dollar exchange rate, applying a model specification test to compare the parameters obtained a monetary model determining the fundamental value of the currency against an alternative that admits stochastic bubbles, finding no

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[6] They test whether exchange rates can predict fundamentals and show that the dollar exchange rate against other G7 currencies actually Granger-causes (precede) fundamentals, and not the other way around. Likewise, Chen et al. (2010) show that for commodity exporters, exchange rates may be useful for forecasting fundamentals. In a two-country model for the US and Canada, Kano (2015) finds a low discount rate, which suggests that open economy models cannot jointly explain the existence of a random walk process for the nominal exchange rate and I(1) fundamentals as conjectured by Engel and West (2005). Pavlidis et al. (2015) show that it is important to separately consider the bubble component and the possibility of explosive fundamentals or time-varying discount rate, with the latter capable of explaining rapid increases in house prices.

[7] Deviations from fundamental prices could reflect mis-specification of the model used to approximate fundamental values. Early approaches for separately testing for a lack of a bubble and for correct model specification include West (1987a) which defines bubbles as situations where different models of how fundamentals determine prices provide significantly different estimates. His approach involves estimating a model where the asset price is determined only by fundamentals as well as another model that admits a bubble component in the asset prices and then using a Hausmann specification test to check whether the estimates from the two models differ. Later approaches, such as those by Phillips et al. (2011) or Phillips et al. (2015a) provide test statistics that are invariant to incorrect specification of the bubble component or the distribution of asset price model residuals.

evidence of bubbles. Meese (1986) and Evans (1986) use monetary models of the exchange rate, with Meese (1986) finding mixed evidence of bubbles for the deutschemark-dollar and sterling-dollar exchange rates for the period 1973-1982, and Evans finding bubbles in Sterling-dollar exchange rate between 1981 and 1984. Wu (1995) also uses a monetary model, estimated for the sterling-dollar and yen-dollar and deutsche mark-dollar cross rates for 1974-1988. He distinguishes between an observed fundamental component of the exchange rate and an unobserved (bubble) component consistent with the model and applies a Kalman filter to estimate the unobserved component. He finds no evidence of bubbles. More recently, Bettendorf and Chen (2013) and Jiang et al. (2015) apply the tests from Phillips et al. (2011) and Phillips et al. (2015b) to monthly data and suggest that explosive relative tradeable prices can account for nominal exchange rate explosiveness in GBP:USD and CNY:USD, respectively. On the other hand, Hu and Oxley (2017, *forthcoming*) apply the same approach and fail to find evidence of explosiveness in G10 currency pairs.

3 Tests for explosiveness

This paper applies a variant of the tests of Phillips et al. (2015b) and Phillips et al. (2015a) (known as the PSY approach) to gauge whether whether specific bouts of explosiveness in an exchange rate are accompanied by explosive changes in relative fundamentals from specific models.[8] The test is a right-tailed ADF test, applied over recursive sub-samples:

$$\Delta y_t = \alpha_{r_1,r_2} + \beta_{r_1,r_2} y_{t-1} + \sum_{j=1}^{p} \delta_{r_1,r_2}^j \Delta y_{t-j} + \varepsilon_t \qquad (1)$$

where Δ is the difference operator, p is the number of lags, ε_t represents the error term and r_1 and r_2 denote the start and end points of the estimation range. The null is that the series y_t being test has a unit root (i.e. $\beta = 1$) and the alternative is that the series is explosive (i.e. $\beta > 1$). For inference, the critical values need to be simulated since null of the test statistic is non-standard (Phillips et al. 2015b). To test whether a series contains at

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[8] These tests are not, however, useful for assessing the magnitude of exchange rate misalignment relative to fundamentals, identifying the drivers of specific periods of rapid exchange rate change, predicting when these may reverse, or assessing the macroeconomic impact of periods of explosive exchange rate dynamics.

least one episode of explosiveness during the sample, the GSADF statistic is calculated, where the starting point r_1 moves within the range $[0, r_2 - r_0]$ and the end point of the regression r_2 moves from r_0 to 1:

$$GSADF(r_0) = sup_{r_2 \in [r_0, 1], r_1 \in [0, r_2 - r_0]} ADF_{r_1}^{r_2} \tag{2}$$

The null is rejected if the GSADF statistic exceeds the $100(1 - \kappa)\%$ critical values for significance level κ. The start and end dates of a period of explosiveness is determined using a 'Backward Sup ADF' (BSADF) test statistic, calculated by expanding the sample backwards from the end of the sample and varying the starting points of each sample. The BSADF statistic is the sup value over the moving intervals:

$$BSADF_{r_2}(r_0) = sup_{r_1 \in [0, r_2 - r_0]} ADF_{r_1}^{r_2} \tag{3}$$

with the sequence of BSADF statistics again compared to the corresponding simulated critical values. These tests assume that volatility of the series being tested is stationary. If this assumption does not hold, these tests may not provide accurate inference. Since exchange rates often exhibit heteroscedasticity, wild bootstrap versions of the critical values will be compared to those from the standard tests. The approach used to for the wild bootstrap procedure is discussed in Steenkamp (2017).[9]

4   Models of exchange rate determination

Using the framework of Engel and West (2005), the current value of the log nominal exchange rate may be written as a linear combination of current and expected fundamentals and spot rates:

$$s_t = (1 - \gamma) \sum_{j=0}^{k} \gamma^j E_t[f_{t+j}] + \gamma^{k+1} E_t[s_{t+j+1}] \tag{4}$$

where s is the the nominal exchange rate, f_{t+j} denotes economic fundamentals at time $t + j$ and γ is the discount factor that will depend on the model being used or assumptions about long run returns. Under the law of iterated

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[9] Cavaliere and Taylor (2008) show that a wild bootstrap of the test statistics mimics any heteroscedasticity present in the series and that it ensures accurate inference.

expectations, $E_t[s_{t+j+1}]$ will tend to zero in the limit (since no change in the exchange rate would be predictable at any horizon). That is, the exchange rate will only be determined by an infinite sum of expected future fundamentals, with the elements of f_{t+j} discounted by γ.[10] However, if the terminal condition for exchange rate expectations does not hold (i.e. $E_t[s_{t+j+1}] \neq 0$), then the exchange rate will include both a fundamental component (s_t^f) and bubble component ($bubble_t$):

$$s_t = s_t^f + bubble_t \tag{5}$$

where

$$bubble_t = \frac{1}{1-\gamma} bubble_{t-1} + \varepsilon_t \tag{6}$$

The bubble component resembles an AR(1) process for $\frac{1}{1-\gamma} < 1$. On the other hand, the bubble would be on expectation explosive when $\frac{1}{1-\gamma} > 1$.[11] An asset price containing a bubble component will be an explosive process, even if fundamentals are not. Likewise, the exchange rate will be at most I(1) when fundamentals are I(1), unless fundamentals are also explosive.

This paper also gauges whether specific instances of explosive exchange rate changes have been accompanied by explosive movements in economic fundamentals. There are several broad classes of structural models of exchange rates that could be used to define the underlying equilibrium value of the exchange rate.

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[10] If γ is less than 1, a forward solution for the conditional expectation of the exchange rate exists (see discussion in Pavlidis et al. 2015).

[11] A rational bubble exists if $E_t(bubble_{t+1}) = 1 + \gamma bubble_t$ where $\gamma > 0$. As a result, $bubble_t$ is mildly explosive (submartingale). This is a random process where the expectation based on current information is that the next value in the sequence will be larger than the current value, i.e. it has an AR coefficient equal to $1 + \frac{c}{T^{0<\gamma<1}}$ where $c > 0$ and $\rho > 1$. While ever-expanding bubbles may be unlikely in reality, there may be rational bubbles that display such behaviour over some sub-samples. On the other hand, if $\frac{1}{1-\gamma} < 1$, then the bubble component will shrink towards zero over time.

4.1 Accounting for exchange rate fundamentals at monthly and quarterly frequencies

Different economic theories suggest different economic variables to consider as the fundamental determinants of exchange rates. Instead of taking a stand on exchange rate determination in this paper, three standard models of the exchange rate are to account for developments in economic factors and used to empirically assess the explosiveness of the normalised exchange rate.[12] This analysis does not prohibit the possibility that other drivers of bubbles, such as speculation, were associated with periods of currency explosiveness.[13]

4.2 Model 1: Purchasing Power Parity

The first approach used in this paper is to use cross-country inflation differentials as a benchmark to compare explosiveness in the exchange rate against, following the approach used by Bettendorf and Chen (2013) and Jiang et al. (2015). The real exchange rate is normalised to relative prices,

$$s_t^f = p_t - p_t^* \tag{7}$$

where exchange rates are defined as the foreign currency price of one unit of home currency and relative prices are written as the difference between p_t (denoting CPI in the home country) and the foreign equivalent p_t^*. Decomposing the aggregate CPI series into a weighting of tradable (p_t^T) and non-tradable (p_t^{NT}) components using Engel's (1999) decomposition $(p_t = \alpha p_t^T + (1-\alpha)p_t^{NT})$, relative prices can be written as:

$$p_t - p_t^* = p_t^T - p_t^{T*} + (1-\alpha)(p_t^{NT} - p_t^T - (1-\alpha)(p_t^{NT} - p_t^{T*}) \tag{8}$$

where α represents the share of tradables in CPI. This can be simplified to a linear combination of relative tradables prices $(s_t^{f,T})$ and relative non-tradables

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[12] The test is whether the normalised price exhibits a stochastic trend, with a constant added to allow for a non-random drift. This implies that there need not necessarily be a long run relationship between the the exchange rates and its fundamental series for the null to be rejected. Instead, it implies that the normalised asset price experiences local exponential growth.

[13] Lee and Phillips (2016) provide a methodology for empirically assessing the importance of speculation on asset prices and investigating this question remains an important direction for future research.

prices ($s_t^{f,NT}$):

$$s_t^f = s_t^{f,T} + s_t^{f,NT} \tag{9}$$

Given the absence of direct proxies for tradable and non-tradable CPI, most papers use producer prices to capture tradable inflation and consumer prices to capture non-tradables inflation.[14] However, official tradable and non-tradable CPI series are available for both New Zealand and Australia at a quarterly frequency ($CPI_{i,t}^T$ and $CPI_{i,t}^{NT}$, respectively where $i = NZ, AU$).[15] These series can be used to construct tradable ($q_t^{f,T}$) and non-tradable ($q_t^{f,NT}$) real exchange rates for the bilateral New Zealand dollar (NZD): Australian dollar (AUD) exchange rate as the ratio of the nominal exchange rate to relative traded and non-traded inflation, respectively:

$$q_t^T = s_t - s_t^{f,T} \tag{10}$$

$$q_t^{NT} = s_t - s_t^{f,NT} \tag{11}$$

where

$$s_t^{f,T} = CPI_{NZ,t}^T - CPI_{AU,t}^T \tag{12}$$

$$s_t^{f,NT} = (CPI_{NZ,t}^{NT} - CPI_{NZ,t}^T) - (CPI_{AU,t}^{NT} - CPI_{AU,t}^T) \tag{13}$$

Under the assumption that purchasing power parity (PPP) holds, the real exchange rate should be stationary. In this context, the existence of a unit root in the exchange rate can be interpreted as evidence that there is a misalignment between relative prices and the exchange rate. Having accounted for relative tradable and non-tradable prices, explosiveness in the exchange rate implies the existence of a bubble.

The weakness of this theoretical framework is that, empirically, exchange rates tend to deviate substantially from what relative prices alone would imply. This could reflect, amongst other things, real shocks affecting domestic demand

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[14] Using producer prices to proxy tradable prices tends to lower the contribution of non-tradables to overall real exchange rate volatility compared to using consumer prices, see Steenkamp (2013) and Drozd and Nosal (2010).

[15] For New Zealand, the CPI series are based on RBNZ backdates of official tradable and non-tradable CPI series. For Australia, CPI is based on a splice of 8 city average quarterly percent change series for 1982Q2 to 1983Q1 and then year on year changes to 1998Q3 and then the official national index series from Haver from then onwards. Non-seasonally adjusted data is used as seasonal adjustment may bias the unit root tests.

and per capita income over the long run, including productivity changes (i.e. Balassa Samuelson effects), terms of trade shifts or cross-country differences in relative government consumption or debt.

Two other standard approaches to modeling exchange rate determination are also applied.

4.3 Model 2: Uncovered interest parity with risk adjustment

The second modeling approach used in this paper is the uncovered interest parity (UIP) model of Munro (2015), where bilateral real exchange rates are jointly modeled with expected future returns and risk.[16] A structural approach using co-movement of the relative yield curve and the exchange rate is used to net out bond premia from currency 'excess returns'. Bond premia are netted out from expected relative returns, so that the bilateral real exchange rate q_t is a combination of two components:

$$q_t = -R_t^f - \lambda_t^{FX} \tag{14}$$

where R_t^f is an 10 year sum of expected future relative risk free interest rate returns (USD less foreign returns net of a bond premium) and λ_t^{FX} is a residual reflecting current and future expected currency premia plus expected long run fundamentals that determine the equilibrium exchange rate.[17] Having accounted for relative interest rates and risk, this paper applies tests for explosiveness to the ratio of real exchange rates for the NZD:USD and NZD:AUD cross rates over their respective λ_t^{FX} estimates.

4.4 Model 3: Neutral real exchange rate

Another framework used in this paper to determine the fundamental value of the exchange rate is the concept of the 'neutral real exchange rate', defined as the level of the exchange rate which puts no pressure on the domestic output

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[16] The empirical performance of the UIP framework has been shown to improve when accounting for the possibility of time varying risk premia in currencies (see Chinn 2006, for example). Risk premia could reflect factors such as differences in perceived sovereign default risk or currency liquidity risk.

[17] The estimates in Munro (2015) show that, when risk is accounted for, λ_t^{FX} dominates the variance of the real exchange rate.

gap or inflation rate. The neutral exchange rate is unobservable, so it has to be estimated. This paper uses a Kalman smoother to estimate the neutral real exchange rate jointly with the neutral real rate of interest, inflation target, and potential output.[18] The model used to link interest rates, output, inflation and the exchange rate is the semi-structural small open economy model with time-varying trends of Kirker (2008). The model features an IS relationship between the output gap (defined as the difference between actual output and its potential level) and its past values, real interest rate gap (the difference between its observed level and the natural real rate of interest), and the real exchange rate gap (the difference between the real exchange rate and the neutral real exchange rate). Inflation within the domestic economy is modeled using a hybrid new Keynesian Phillips curve (specifying the relationship between the rate of inflation and the output gap) incorporating the real exchange rate to capture pass-through to import prices. The monetary policy reaction function is based on a forward-looking Taylor-type rule. The exchange rate is modeled using a modified UIP relationship incorporating an equilibrium risk premium which is a function of the neutral level of the real exchange rate, the neutral real interest rate of the domestic economy and the neutral real interest rate of the foreign economy.

Two versions of the model are estimated. The first is a two-country model using the United States as its proxy for the foreign economy and producing an estimate of the real neutral NZD:USD cross rate. For both countries, interest rates are based on the 90-day bank bill rate. The foreign economy is a de-trended closed-economy version of the domestic economy, with all neutral rates assumed to be zero. The second version uses a combination of New Zealand's largest trading partners to proxy the foreign economy. This version of the model produces an estimate of New Zealand's neutral trade-weighted exchange rate index (TWI) exchange rate. The real TWI is calculated using the Reserve Bank's official TWI series and a CPI-17 series corresponding to the countries including in the TWI. Output in this version is based on a 16 economy GDP measure and world interest rates are constructed by weighting US and Australian interest rates together.

The models are estimated using Bayesian estimation. A Kalman smoother is then used to extract estimates of the unobservable variables within the model (i.e. the neutral real interest rate, inflation target, neutral nominal

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[18] A Kalman smoother is an exponential smoother that is run backwards on a filtered series. The advantage of using a Kalman smoother is that it produces time-varying estimates of the neutral real exchange rate, accounting for the possibility of parameter instability not just in the UIP relationship governing the real exchange rate but also the processes determining inflation and interest rates over the full sample.

interest rate, output gap, and neutral real exchange rate) corresponding to a state where inflation equals the inflation target and the actual output equals the potential output.[19] To account for relative business cycle fundamentals, this paper applies tests for explosiveness to the ratio of the real NZD:USD and the real TWI and their respective neutral rates.

5   Results

The explosiveness of exchange rate after normalisation after applying a PPP model, UIP approach and neutral exchange rate model is considered for the NZD:USD and NZD:AUD (1996M03-2015M05, 231 observations), NZD:AUD (1982Q2-2016Q1, 136 observations) and NZD:AUD and NZD TWI (1993Q1-2015Q3, 90 observations), respectively. A constant is added to account for non-random drift and the lag length length set to one in the benchmark results.[20] Simulations are based on 2000 replications and the size of the initial test window, r_0, is set following the rule of thumb suggested by Phillips et al. (2014), implying a minimum window of 22 quarters for the tests in Section 5.1.1, 29 months for the results in Section 5.1.2 and 17 quarters for the tests in Section 5.1.3.[21] A 2 period minimum window size is used to eliminate bubbles with very short duration but the robustness of the results to these thresholds is discussed. Given the possibility that exchange rates exhibit heteroscedasticity, critical values from a wild bootstrap version of the explosiveness test are compared to those from the standard PSY test. As mentioned earlier, exchange rates are specified as up for appreciation in the NZD.

5.1   Accounting for fundamentals

5.1.1   PPP results

Figures 1 to 2 plot the NZD:AUD exchange rate and the traded and non-traded real exchange rates, along with the BSADF statistics for each series. While the non-traded real exchange rate with Australia is flat over the sample

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[19] The priors used in the USD version of the model are the same as those from Kirker (2008), while those for the TWI version are currently in use at RBNZ.

[20] Lag selection based on a Bayesian information criterion (BIC) did not significantly affect the results

[21] Phillips et al. (2014) propose the following size rule: $r_0 = 0.01 + \frac{1.8}{\sqrt{T}}$.

since 1983, the nominal exchange rate and the real tradable-goods exchange rate show an upward trend, and a strong appreciation since 2010. Against the Australian dollar, the exchange rate appreciated rapidly in 1985, in late 1992, between late 2000 and early 2003, and again in late 2012 to early 2015. The nominal rate also depreciated rapidly in the second quarter of 1984 and fourth quarter of 1987. The test identifies whether the exchange rate experienced explosive growth at the same time as economic fundamentals (in this case, relative prices). The date-stamping procedure is only valid if the GSADF test rejects the null of no bubble. The GSADF test does not suggest that the nominal NZD:AUD exchange rate exhibits explosive behaviour, both when critical values from the standard test or a wild bootstrap version thereof are used.[22] Likewise, the null of no bubble during the sample is not rejected for the tradable and non-tradable exchange rates.

Table 1

PPP model (Sample: 1982Q2 - 2016Q1)

Variable		PSY	PSY WB
	GSADF	**95% CV**	**95% CV**
S_t	0.895	2.396	2.710
$S_t - S_t^{f,T}$	0.774	2.396	2.762
$S_t - S_t^{f,NT}$	0.623	2.396	2.363

* 10 percent, ** 5 percent, *** 1 percent significance level on the basis of wild bootstrap (WB) critical values.

Figure 1: Nominal NZD:AUD (quarterly, log)

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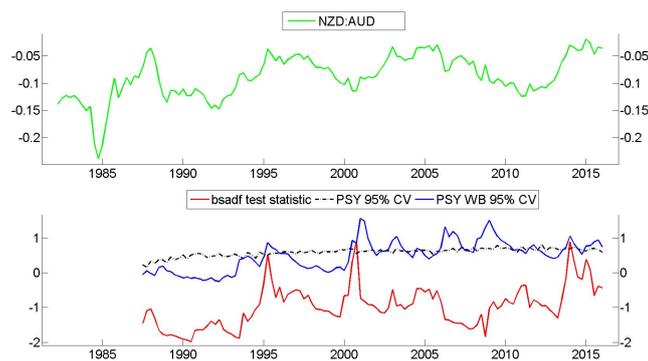
[22] Tests for heteroscedasticity such as the Breusch-Pagan-Godfrey and White tests reject the null of no heteroscedasticity for these series at a 5 percent significance level.

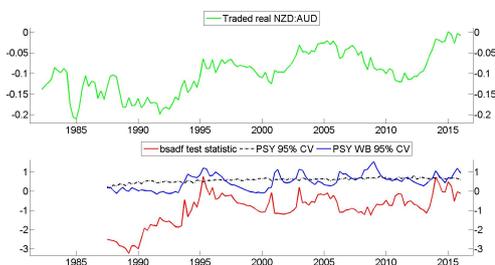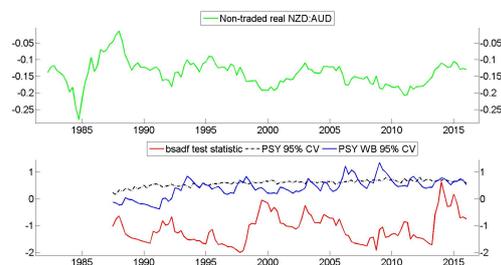Figure 2: Traded real NZD:AUD (quarterly)

Figure 3: Non-Traded real NZD:AUD (quarterly)

This result is in contrast to the results for the pound sterling by Bettendorf and Chen (2013), who find that explosiveness in relative traded good inflation can explain the observed explosiveness of the nominal Sterling:USD exchange rate. Their result is surprising given the well-documented exchange rate disconnect puzzle.[23] On the other hand, the results are consistent with those from Hu and Oxley (2017, *forthcoming*), who do not find explosive periods in G10 currencies in monthly data.[24]

5.1.2 UIP results

Figures 4 and 5 plot monthly exchange rates with Australia and the United States along with the residual component λ_t^{FX} of the risk adjusted-UIP models of the NZD:USD and NZD:AUD cross rates, respectively.[25] There have been many rapid appreciations and depreciations against the AUD and USD: notably the NZD strengthened substantially against the AUD between late 2001 and late 2002 and between 2012 and early 2015, while it fell rapidly against the USD following the GFC in early 2008. The fundamental component of the bilateral rate with Australia that remains after having

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[23] The results from Bettendorf and Chen (2013) were reproduced using Caspi's (ming) code, and their result that the GSADF test does not reject the null of no bubbles in this ratio over the full sample is confirmed, although there are several instances when the BSADF statistics exceed the simulated critical values.

[24] They do find that the GBP:CHF and GBP:JPY are explosive based on the conventional PSY test. However, they do not find significant evidence of explosiveness once the intercept is excluded from the model specification. They argue that such a specification allows them to distinguish between collapse episodes and episodes where a collapse is followed by a recovery, although the asymptotic properties of such an approach is not studied.

[25] As mentioned earlier, this component can be interpreted as the currency premium on the NZD compared with the USD.

accounted for relative risk free returns and relative inflation declines over the corresponding period. This implies that the NZD was moving closer to its UIP-consistent level against the AUD over this period. Against the US dollar, the NZD appreciated substantially against between late 2001 and late 2004 and again between 2009 and mid-2011. In contrast, the UIP-based fundamental component was above zero for much of the period before 2008, before falling and remaining relatively flat over the period of real appreciation between 2010 to 2014. Table 2 shows that the results suggest that there have not been any explosive periods in the NZD:AUD, irrespective of whether the standard PSY critical values or wild bootstrap critical values are used.[26] For the NZD:USD cross rate, the wild bootstrap critical values suggest that there is no evidence of explosiveness during the sample, although the standard PSY test statistics reject the null of no bubbles. However, it is important to use wild bootstrap critical values for inference to provide consistent results given the potential for heteroscedasticity in exchange rate data.[27]

Figure 4: Real NZD:USD (monthly, log)
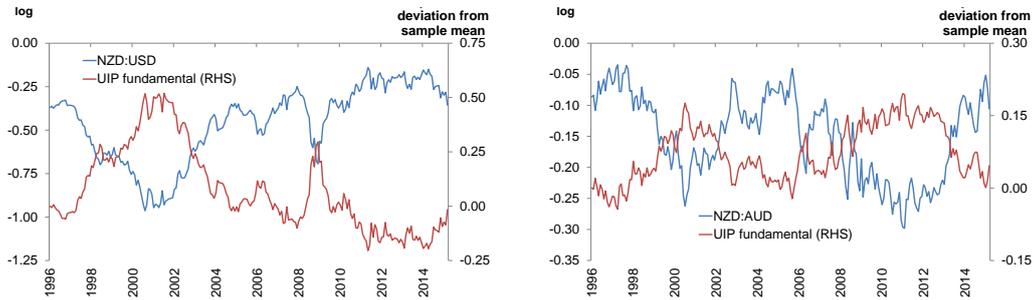
Figure 5: Real NZD:AUD (monthly, log)

Table 2

UIP exchange rate model (Sample: 1996M03-2015M05)

Variable		PSY	PSY WB
	GSADF	95% CV	95% CV
$S_t^{NZD:USD}$	2.570	2.411	3.196
$S_t^{NZD:USD}-\lambda_t^{NZD:USD}$	2.074	2.411	2.652
$S_t^{NZD:AUD}$	1.186	2.411	2.794
$S_t^{NZD:AUD}-\lambda_t^{NZD:AUD}$	1.274	2.411	3.137

* 10 percent, ** 5 percent, *** 1 percent significance level on the basis of wild bootstrap (WB) critical values.

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[26] Note however that the Breusch-Pagan-Godfrey and White tests do not reject the null of no heteroscedasticity for the monthly series considered so the wild bootstrap critical values are only shown here for illustrative purposes only.

[27] See Steenkamp (2017) for more detail.

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5.1.3 Neutral exchange rate results

The real NZD:USD rate and real TWI and the neutral NZD:USD rate and real TWI and real neutral TWI are plotted in Figures 6 and 7, respectively. The real USD and real TWI series have similar profiles, both appreciated strongly between 2001 and 2005. Apart from rapid falls in 2006 and around the time of the global financial crisis, the NZD:USD and TWI remained at historically elevated level for much for the period between 2005 and 2015. Table 3 shows that the null of no explosiveness is not rejected for either the real NZD:USD or the real TWI when the test statistic is compared to wild bootstrap PSY critical values. However, the null of no heteroscedasticity for these series is rejected for for most test specifications for tests such as the Breusch-Pagan-Godfrey and White tests, so these critical values are shown for illustrative purposes only. The PSY GSADF test does not reject the null of no explosiveness in the NZD:USD or NZD TWI over the full sample.

Figure 6: Real NZD:USD (quarterly, log)
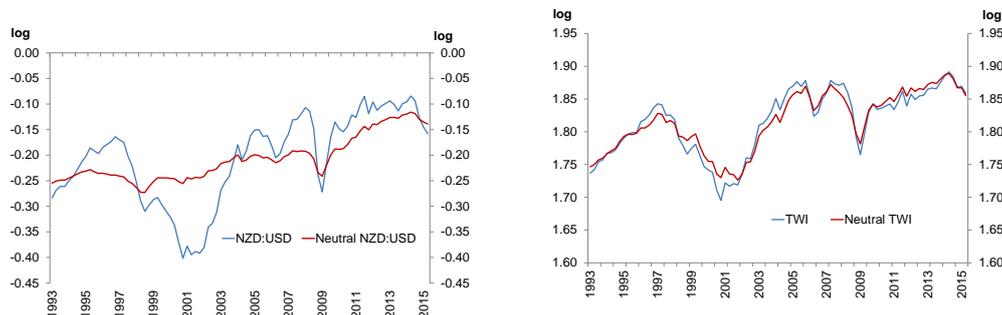
Figure 7: Real TWI (quarterly, log)

Table 3

Neutral exchange rate model (Sample: 1993Q1-2015Q3)

Variable		PSY	PSY WB
	GSADF	95% CV	95% CV
$S_t^{NZD:USD}$	1.774	2.406	2.310
$S_t^{NZD:USD}$-$S_t^{Neutral}$	0.503	2.406	2.383
S_t^{TWI}	1.442	2.406	2.699
S_t^{TWI}-$S_t^{Neutral}$	0.766	2.406	2.336

* 10 percent, ** 5 percent, *** 1 percent significance level on the basis of wild bootstrap (WB) critical values.

6   Conclusion

This paper tests for the existence of bubbles in the value of the New Zealand dollar. There are many exchange rate models that could be used to define the fundamental value of the exchange rate. Rather than take a stand on the determination of the value of the NZD or its fundamental value at a given point in time, this paper uses three commonly used models of the underlying value of the exchange rate to gauge whether any instances of explosiveness in the value of the NZD have been accompanied by explosiveness in fundamentals.

Based on monthly and quarterly data for selected currency crosses, this paper finds no episodes of explosiveness in the New Zealand dollar. No evidence of explosiveness in NZD fundamentals is found either.

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