FINDING THEORETICAL AND EMPIRICAL SOLUTIONS TO THE THREE MAJOR PUZZLES OF EXCHANGE RATE ECONOMICS: APPLICATIONS IN RESPECT OF SOUTHERN AFRICAN MACROECONOMIC DATA

by

THABO MISHACK MOKOENA

Submitted in partial fulfilment of the requirements
for the degree

PhD (Economics)

in the

Faculty of Economic and Management Sciences

at the

University of Pretoria

PRETORIA   MARCH 2008

SUMMARY

Finding theoretical and empirical solutions to the three major puzzles of exchange rate economics: applications in respect of Southern African macroeconomic data

by

Thabo Mishack Mokoena

SUPERVISOR:	**PROF R VAN EYDEN**
CO-SUPREVISOR:	**PROF R GUPTA**
DEPARTMENT:	**ECONOMICS**
DEGREE:	**PhD (ECONOMICS)**

The thesis focuses on finding solutions to major exchange rate puzzles, which were discussed in detail by Obstfeld and Rogoff (2000). The first puzzle is the purchasing power parity puzzle. The first version of the latter puzzle is concerned with whether a real exchange rate reverts in the mean. To resolve the puzzle in the context of Southern African Development Community countries, the thesis uses Bayesian unit root testing and nonlinear nonstationarity tests associated with the smooth transition autoregressive family of models. According to Bayesian unit root test results, the nonstationarity hypothesis received small posterior probability relative to other hypotheses. In this setting, the Bayesian results strongly supported the hypothesis that all the real exchange rates were trend-stationary autoregressive processes. However, it should be pointed out that Ahking (2004) has found these tests to be biased toward trend stationarity.

Nonlinear nonstationarity tests presented evidence that four out of ten of SADC's real exchange rates could be regarded as nonlinear globally ergodic processes, while others could be considered random walks.

The thesis relies on local-to-unity asymptotic theory and Rossi (2005a) to deal with the half-life version of the PPP puzzle. The half-life version is that a high degree of exchange rate volatility is generally associated with an implausibly slow speed of mean reversion. Depending on the robustness of the methods used, empirical evidence points to several half-lives of less than 36 months, but the confidence intervals of half-life deviations from PPP are found in all cases, as in Rossi's work, to be too wide to be informative enough to resolve the puzzle.

In addition, the thesis undertakes Hinich and Chong (2007) class tests of fractional integration to ensure that a long memory process is not mistaken for a nonstationary process in finding solutions to the PPP puzzle. The results show that at 1 per cent and 5 per cent significance levels, the real exchange rates associated with South Africa, Mauritius and Swaziland are not fractionally integrated. Tanzania's real exchange rate was found to be stationary-fractionally integrated but with the antipersistence property. Other currencies were found to be nonstationary-fractionally integrated.

The third puzzle is the exchange rate determination puzzle, which is as follows: In the short run there seems to be no reliable determinants of exchange rates. The thesis relies on the market microstructure approach to find the determinants of South Africa's exchange rate. In this context, the thesis utilises autoregressive distributed lag model of cointegration to identify the fundamental and non-fundamental determinants of the rand/dollar exchange rate.

The main contribution of the thesis to the economic literature is the usage of newly developed methods in an attempt to resolve the above-mentioned puzzles.

Table of Contents

List of Tables

Acknowledgements

Table 1   List of acronyms

ADF test:	Augmented Dickey-Fuller test
ADF-GLS:	ADF test proposed by Elliot, Rothemberg and Stock (1996)
AIC:	Akaike information criterion
ARDL:	Autoregressive distributed lag
$AR(p)$:	Autoregressive order p process
CCBG:	The Committee of Central Bank Governors in SADC
CES:	Constant elasticity of substitution
CI:	Confidence interval
CIP:	Covered interest parity
CMA:	Common monetary area
CPI:	Consumer price index
DGP:	Data generating process
DSGE:	Dynamic stochastic general equilibrium
ESTAR:	Exponential smooth transition autoregressive
FISTAR:	Fractionally integrated smooth transition autoregressive
GDP:	Gross domestic product
GE:	General equilibrium
GIRF:	Generalised impulse response function
HDR:	Highest density region approach
$I(d)$:	Integrated of order d, where d is a fraction
IRF:	Impulse response function
IMF:	International Monetary Fund
KSS:	Kapitanios, Shin and Smith
LM-type test:	Lagrange-Multiplier-type test
LSTAR:	Logistic smooth transition autoregressive
MAIC:	Modified Akaike information criterion
NLADF:	Nonlinear ADF
OLS:	Ordinary least squares
PP test:	Phillip-Perron test
PPP:	Purchasing power parity
SADC:	Southern African Development Community
SBC:	Schwarz's Bayesian Information Criterion
SETAR	Self-exciting transition autoregressive
STAR:	Smooth transition autoregressive
$\sup-t$:	Supremum t-test

1 Chapter 1: Background to the Thesis

1.1 Background to the Thesis

International macroeconomics continues to have a menu of puzzles that require new theoretical and empirical explanations. Obstfeld and Rogoff (2000) have identified 6 major puzzles of international macroeconomics. Three of these relate to exchange rate economics and they are the purchasing power parity puzzle (PPP), the exchange rate disconnect puzzle, and the exchange rate determination puzzle[1].

This Thesis is motivated by the basic recognition that there continues to be a need to find solutions to major exchange rate puzzles mentioned above. In the context of this thesis, the puzzles of interest are the purchasing power parity puzzle (PPP), the exchange rate disconnect puzzle, and the exchange rate determination puzzle.

Since most international studies in exchange rate economics do not include the Southern African Development Community (SADC), this author considered it to be a real contribution to analyse the PPP puzzle in the context of SADC. Currently the SADC is constituted by Angola, Botswana, the Democratic Republic of Congo (DRC), Lesotho, Malawi, Madagascar, Mauritius, Mozambique, Namibia, South Africa, Swaziland, Tanzania, Zambia, and Zimbabwe. Owing to a lack of reliable data, four countries have been excluded in the analysis: the DRC, Lesotho, Namibia, and Zimbabwe.

It should be pointed out at the very beginning that this Thesis does not focus on the topics of optimal currency areas in the context of SADC. Nor does it concern itself with issues of macroeconomic convergence, which would typically include budget deficit ratios, inflation rates, public debt ratios, external balance, exchange rates and interest rates. In the context of PPP analysis, this study only seeks to identify dollar-based mean-reversion in the SADC.

---

[1] For the purposes of this thesis, we have excluded the forward premium puzzle, which has been discussed extensively by Meredith and Ma (2002). In brief, the forward premium puzzle represents the finding that forward rates in the foreign exchange markets are biased predictors of future spot

An analysis of SADC exchange rates within and beyond the PPP hypothesis generally faces several conceptual hurdles and possible pitfalls. First, outside South Africa, capital markets are less advanced and less liquid, and cross-border capital flows tend to be limited, making the real interest rate differentials as fundamentals less likely to play a significant role in equilibrium. Second, low-income SADC countries tend to be heavily indebted, with debt service and/or official grants constituting a significant fraction of gross domestic product (GDP), a situation that likely influences the real exchange rate determination more than the market forces. Also, low-income SADC countries tend to be commodity exporters with only a small share of manufacturing exports. Thus, the preponderance of world prices of certain commodities is likely to affect both the external current account of the balance of payments and the equilibrium real exchange rate. Additional pitfalls in respect of PPP analysis have been discussed in detail by Taylor (2000).

That said, it is not clear how these institutional factors affect the statistical properties of the real exchange rate time series.

1.2   A brief overview of the foreign exchange markets in the SADC

Generally speaking, an analysis of SADC foreign exchange markets has hardly been done in a coherent manner. This subsection is dedicated to a brief overview of the SADC foreign exchange markets. It uses information obtained from the Secretariat of the Committee of Central Bank Governors (CCBG) in SADC. The locus of concern is the exchange rate environment of the 10 countries appearing in the analysis.

Within the SADC there are members of the Common Monetary Area (CMA): South Africa, Namibia, Lesotho and Swaziland. Within the CMA, all member countries apply the same exchange control regulations. All foreign exchange transactions are to be routed via authorised dealers. Foreign exchange earnings by member states' enterprises have to be brought into the CMA within three months of exports. The foreign exchange acquired by the authorised dealers has offshore limits, which they

---

rates. Furthermore, it has been found that currencies that command a forward premium tend to depreciate, while those that command a forward discount tend to appreciate.

can hold as a balance with their external correspondent banks. The prudential requirements on currency risk containment in terms of their foreign assets and liabilities, allow commercial banks to have an open position, limited to 15 per cent of each bank's capital and reserves.

In the case of Botswana, the national currency is Pula, which is pegged to a weighted basket of currencies comprising Special Drawing Rights currencies of the IMF and the South African rand. According to CCBG (2006), a crawling band exchange rate mechanism was introduced in Botswana in May 2005, with the objective of avoiding the need for periodic discrete large adjustment of the exchange rate to maintain real effective exchange rate stability. At the same time the foreign exchange trading margin of the Bank of Botswana for foreign exchange transactions was increased from ± 0.125 per cent around the central rate to ± 0.5 per cent in order to encourage trading on the interbank market.

Mauritius has a managed floating exchange rate regime with no pre-announced path for the exchange rate. The foreign exchange market is totally liberalised: foreign exchange dealers and money-changers transact foreign exchange. From time to time the Bank of Mauritius intervenes in the market to smooth out seasonal and cyclical fluctuations.

Since 1994, Madagascar adopted the floating exchange rate system and established the foreign currency interbank market where the national currency rate, the ariary, is traded against major foreign currencies such as the euro and the US dollar.

Tanzania practices a managed float exchange rate system. The foreign exchange market is a daily interbank foreign exchange market. The Bank of Tanzania intervenes by selling and buying only to smooth fluctuations. The Tanzanian currency (the shilling) is not convertible outside East Africa. In the spirit of East African co-operation, a currency convertibility agreement was reached in 1995. Under the agreement, commercial banks and foreign exchange bureaux in the region are allowed to buy and sell regional currencies just like the other convertible currencies.

In Zambia the foreign exchange market has been liberalised since 1992. The exchange rate is fully market-determined depending on supply and demand conditions.

1.3   The evolution of South Africa's foreign exchange system

It is important to note that South Africa had a dual exchange rate during the years 1961-1995 (excluding a two-year period between 1983 and 1985). According to Barnard and de Clerk (2007), the system comprised a commercial- and blocked rand (1961-1976), with the commercial rand remaining unaltered ever since. However, the blocked rand was subsequently substituted by the securities rand in 1976. This duality remained in place until 1979 when it was once again renamed the financial rand. According to the authors, the financial rand continued to remain in place during the periods 1979-1983 and 1985-1995, alongside the commercial rand. The reintroduction of a dual exchange rate in 1985 was necessitated by the pressure on the SA rand and the gold and foreign exchange reserves of the country, which at the time coincided with the introduction of a foreign debt standstill to foster political change. The financial rand was finally abolished in March 1995 after the first democratic election in South Africa the preceding year.

1.4   Objectives of the Thesis

The Thesis focuses on finding solutions to the 3 major exchange rate puzzles mentioned above. The objectives of the thesis regarding the puzzles are discussed in sections 1.5 to 1.8.

1.5   Resolving the mean reversion version of the PPP puzzle

To test for the long-run purchasing power parity relation, this study uses SADC country real exchange rate data to undertake Bayesian unit root tests, Augmented Dickey-Fuller tests, as well as nonlinear nonstationarity tests associated with smooth

transition autoregressive (STAR) family of models. In addition, this research goes further to deal with the issue of long-memory in real exchange rates. In this context, the Thesis uses "a class test of fractional integration" pioneered by Hinich and Chong (2007). This test is able to determine whether a series is a long memory process or not.

1.6   Resolving the half-life version of the PPP puzzle

The study relies on Rossi (2005a) to calculate confidence intervals of half-life deviations from equilibrium. Rossi uses several methods, some of which are robust for highly persistent data.

1.7   Resolving the exchange rate determination puzzle

The study relies on market microstructure approaches to find the short run and long-run determinants of the nominal rand-dollar exchange rate. In this context, the thesis utilises autoregressive distributed lag (ARDL) model of cointegration to address the exchange rate determination puzzle. ARDL models have the benefit that they avoid the issue of verifying whether a variable is $I(0)$ or $I(1)$. They rely instead on bounds testing.

1.8   Resolving the exchange rate disconnect puzzle

The current literature on the exchange rate disconnect puzzle is in a state of flux. Since there has yet to be a detailed survey of DSGE models in respect of the disconnect puzzle, the study surveys competing theoretical dynamic general equilibrium approaches that attempt to make the disconnect less of a puzzle. We critically review the usefulness of the models and indicate which models are likely to gain popularity.

1.9   **Contributions of the Thesis to economic literature**

Concerning the contributions of the Thesis to economic literature, the author believes the Thesis represents an earnest effort to find solutions to the main puzzles of exchange rate economics using SADC data and the latest econometric techniques. The Thesis uses nonlinear tests of nonstationarity with high power (an approach representing hypothesis testing when nuisance parameters exist only under the alternative hypothesis), Bayesian unit root tests, fractional integration tests, point estimates and confidence intervals for exchange rate half-life deviations from PPP, and ARDL form of cointegration.

1.10   **The structure of the Thesis**

Having discussed the background to this study, the rest of the thesis is organised such that chapter 2 introduces the puzzles. Chapter 3 covers recent theoretical and empirical developments. Chapter 4 presents empirical results pertaining to PPP using SADC dollar-based exchange rates. Chapter 5 presents the results of half-life deviations from PPP in the SADC. Chapter 6 undertakes tests of long memory regarding the PPP puzzle and presents the results of frequency domain fractional integration tests. Chapter 7 cover the results of the microstructure approach to the determination puzzle. Conclusions and implications are found in Chapter 8.

2   Chapter 2: Introducing the puzzles

2.1   Introduction

Chapter 2 introduces the puzzles that were identified by Obstfeld and Rogoff (2000). Three of these relate to exchange rate economics and they are the purchasing power parity puzzle (PPP), the exchange rate disconnect puzzle and the exchange rate determination puzzle.[2]

Below we provide a brief overview of each puzzle. For convenience, the thesis treats them as independent puzzles.

2.2   The PPP puzzle: mean-reversion

This subsection borrows from Mokoena (2006, 2007), among other sources. An ordinary definition of absolute purchasing power parity (PPP) is that the latter represents the exchange rate between two currencies multiplied by the relative national price levels. The relative form of this hypothesis is that PPP exists when the rate of depreciation of, say, the home currency relative to the foreign currency matches the difference in aggregate price inflation between the two countries in point (Sarno and Taylor, 2002).

The PPP hypothesis implies that the real exchange rate should be constant such that any deviations from equilibrium should be transitory. Yet most studies have found that real exchange rates exhibit a large degree of volatility and that their deviations from equilibrium are highly persistent.

Formally, the relative form of PPP admits the following logarithmic representation:

---

[2] For the purposes of this thesis, we have excluded the forward premium puzzle, which has been discussed extensively by Meredith and Ma (2002). In brief, the forward premium puzzle represents the finding that forward rates in the foreign exchange markets are biased predictors of future spot rates. Furthermore, it has been found that currencies that command a forward premium tend to depreciate, while those that command a forward discount tend to appreciate.

$$y_t \equiv s_t - p_t + p_t^*, \tag{2.1}$$

where y_t is a measure of deviation from PPP, s_t is the nominal exchange rate, p_t denotes the domestic price level, and p_t^* represents the foreign price level.

From a historical perspective, real exchange rates play an important role in establishing parities and in estimating national income levels for comparative purposes (Taylor, Peel and Sarno, 2001). In addition, there are policy implications in determining the degree of persistence of real exchange rates. For instance, if the real exchange rate is highly persistent or near unit root, its adjustment is likely to impact upon the real side of the economy -- productivity and tastes. By contrast, a low level of persistence is associated with shocks on the aggregate demand.

Today it is still a matter of debate whether the PPP relation holds in both the long-run and the short run. At the level of theoretical discussion, the violation of PPP in the short run can be explained through the theory of exchange rate overshooting, in which the PPP deviations are expected to occur as explained by Dornbusch (1976). However, in the long-run, for the PPP to hold, it must admit mean reversion. So, empirically speaking, an econometrician would like to see the real exchange rate remain stationary, while the alternative hypothesis would suggest that the exchange rate was a unit root process or a random walk. Formally, a manifestation of mean-reversion implies that, under the assumption of linearity, the following relation from (2.1) should hold:

$$y_t = \alpha + \rho y_{t-1} + \varepsilon_t, \quad 0 < \rho < 1. \tag{2.2}$$

When $\rho = 1$, equation (2.2) becomes a unit root process. It means the process does not allow the system to come back to equilibrium. An implication of a real exchange rate with a unit root is that, among other things, it limits the usefulness of the PPP exchange rates used for policy purposes.

On balance, evidence on the long-term PPP, while in some cases is supportive of the relation, is influenced by the techniques used by researchers. For instance, the current literature focuses on linear and nonlinear tests of nonstationarity, linear and nonlinear cointegration tests, and panel data studies, to name a few.

As far as panel data techniques are concerned, Abuaf and Jorion (1990) analysed a system of 10 $AR(1)$ regressions for real dollar exchange rates. They tested the null hypothesis that the real exchange rates were jointly nonstationary for all the 10 series over the sample period 1973 to 1987. Their results indicated a positive support for the stationarity of real exchange rates at conventional levels of significance, suggesting that there was evidence in favour of PPP. Other panel data studies include Levin and Lin (1992), who tested the null hypothesis that each individual series was an $I(1)$ against the alternative that all the series as a panel were stationary. Frankel and Rose (1995), Wu (1996) and Oh (1995) have relied on Levin and Lin(1994) panel unit root test to establish mean reversion in real exchange rates.

There are other studies utilising univariate approaches and multivariate methods and these are surveyed extensively by Sarno and Taylor (2002).

Moreover, as shown in Bailie and Kapetanios (2005), exchange rates seem to harbour neglected nonlinearities of unknown form. A detailed discussion concerning nonlinear mean-reversion is found in Taylor, Peel, and Sarno (2001). In the latter study the authors provide evidence of nonlinear mean reversion in a number of major real exchange rates during the post-Bretton Woods period. The study undertakes multivariate unit root tests with high power to reject the null hypothesis of unit root behaviour in exchange rates.

Moreover, there is a growing realisation that, due to their lack of power, the standard tests of nonstationarity in the univariate context are unable to provide a strong foundation for inference that reduces the high probability of committing type 2 error in the PPP studies.

More formally, traditional unit root tests involve testing the null hypothesis of

$z_t = z_{t-1} + \varepsilon_t$ against equation (2.2). This leads to the application of an augmented Dickey-Fuller test statistic:

$$\Delta z_t = \phi_0 + \phi_1 t + \phi_2 z_{t-1} + \sum_{i=1}^{n-1} \beta_i \Delta z_{t-i} + v_t \ . \qquad (2.3)$$

The poor power performance of the standard unit root tests has been reported by many studies, including Balke and Fomby (1997), Pipenger and Goering (1993), Diebold and Rudebusch (1991), and Taylor, Peel and Sarno (2001).

Due to the problems mentioned above, the resolution of the PPP will require fairly robust tests of nonstationarity and nonlinearity. The details of the empirical results are found in Chapter 4.

2.3   The half-life version of the PPP puzzle

Following Rossi (2005a), consider that a real exchange rate follows an autoregressive process of order one such that $y_t - y_0 = \alpha + \rho(y_{t-1} - y_0) + \varepsilon_t$, where y_0 is the long-run equilibrium value and ε_t is white noise. At horizon h the percentage deviation from equilibrium is ρ^h. Then the half-life deviation is the smallest h such that $h = \dfrac{\ln(1/2)}{\ln(\rho)}$. Traditionally half-life deviations have been used for AR(1) processes. For higher orders the process may become cyclical and half-lives may become meaningless.

The half-life version of the PPP puzzle is that a high degree of exchange rate volatility is generally associated with an implausibly slow speed of mean reversion. According to sticky price theories, a half-life of an exchange rate is supposed to be less than 3 years. However, according to Rogoff (1996), the consensus is that the speed of mean reversion is between three and five years. Other authors such as Grilli and Kaminski (1991) and Lothian and Taylor (1995)) have used approximately 100 years of annual data to find evidence of significant mean reversion, with an average half life across these studies being around 4 years. Diebold, Husted and

Rush (1991) also used long time spans of annual data, ranging from 74 to 123 years, to analyse the real exchange rates of 6 countries using a fractional integration framework. They found evidence that PPP held as a long-run concept, generally reporting half-lives of around 3 years.

Taylor (2000) has noted possible pitfalls associated with the calculation of half-lives, the main problem being a downward bias in the magnitude of point estimates. Some of the problems have to do with the linearity assumption, the choice of sample frequency, and the treatment of nonlinearities. Clearly therefore the calculation of half-lives that are free of biases is challenging.

The latest approaches are associated with, among others, Kim, Silvapulle and Hyndman (2006), Norman (2007) and Rossi (2005a). In the light of problems identified by Rossi (2005a), Kim, Slivapulle and Hyndman (2006) use the highest density region (HDR) approach to propose a bias-corrected bootstrap procedure for the estimation of half-life in the context of point and interval estimation. The authors report that their approach generates accurate point estimators and tight confidence intervals with superior coverage properties to those of its alternatives. Norman (2007) uses nonlinear impulse response analysis and Monte Carlo integration methods (MCIM) in the context of STAR models to assess how well nonlinear mean reversion solves the PPP puzzle. Rossi (2005a) uses local-to-unity asymptotic theory in the context of $AR(p)$ processes to construct confidence intervals that are robust to high persistence in the presence of small sample sizes.

Chapter 5 relies on Rossi (2005a) to determine the extent to which the half-life puzzle can be resolved. The promising approach of Kim, Silvapulle and Hyndman (2006) is left for future research due to software availability and programming issues.

2.4 The exchange rate disconnect puzzle

For the last 30 years of floating exchange rates, academic economists have not had consensus regarding the impact of exchange rate fluctuations on real economic variables, such as exports and output. Indeed, if we accept the premise that an exchange rate is one of the significant "prices" in an economy such as South Africa's,

then to an economist an exchange rate would seem likely to have a wide-ranging impact on a number of economic variables, and therefore seem likely to have a strong connection with the real economy. In some economic models regarding South Africa,[3] an expansionary monetary policy is supposed to raise domestic demand while lowering the exchange value of the rand. This implies the existence of a correlation between exchange rate changes and business-cycle expansions and contractions. However, in real life, it is debatable whether such a strong relationship exists. Moreover, in international studies that examined data at the aggregate or macroeconomic level, it has been generally found that there is a small or an insignificant effect of exchange rate fluctuations on the real variables. In particular, Stockman and Baxter (1989) showed that the exchange rate volatility seems to have no systematic impact on macroeconomic variables. Moreover, empirical work by Mussa (1986), and Flood and Rose (1995), have found that high exchange rate volatility is not related to high volatility of other macroeconomic variables. This lack of association between real quantities and the exchange rate is called the "exchange rate disconnect puzzle," a conundrum discovered by Meese and Rogoff (1983).

The exchange rate disconnect puzzle is particularly important for policymakers. For instance, if central bankers, in particular, do not have a clear understanding of how exchange rates affect the economy or the monetary transmission mechanism, they are likely to make mistakes when they have to respond to historically high and unexpected currency volatility. This is an important issue for less-developed countries, where capital markets may be underdeveloped, and the exchange rate volatility can cause significant welfare losses to the economy. In addition, exchange rate volatility can trigger welfare-inefficient resource allocations across sectors of the country in point.

2.5 The exchange rate determination puzzle

The exchange rate determination puzzle suggests that the exchange rate has 'a life of its own' and there are hardly reliable determinants of the exchange rates in the short run. In recent years the market microstructure approaches to the exchange rate

---

[3] See Smal and de Jager (2001) and Aron and Muellbauer (2000a and 2000b).

determination puzzle have gained popularity because they have identified order flow or the imbalances between 'buyer-initiated and seller-initiated trades' in foreign exchange markets as indicative of the transmission link between exchange rates and fundamental determinants of exchange rates (Vitale, 2006).

2.6   **Conclusion**

This chapter discussed the three main exchange rate puzzles, namely, the PPP puzzle, the disconnect puzzle and the exchange rate determination puzzle. These puzzle are studies empirically in subsequent chapters, focusing on the data from the SADC region.

3 Chapter 3: Recent theoretical and empirical developments

3.1 Introduction

As noted in Chapter 1, economists have attempted to resolve the three puzzles in several ways. In all the puzzles, economists have tried to provide a new theoretical framework or a new empirical approach.

In the context of PPP, this chapter discusses recent developments associated with seminal contributions by authors such as Enders and Granger (1998), Berben and van Dijk (1999), Caner and Hansen (2001), Lo and Zivot (2001), Shin and Lee (2001), Kapetanios and Shin (2002), Bec, Ben Salem and Carrasco (2004), and Kapetanios, Shin and Snell (2003). These authors have developed various nonlinear tests of nonstationarity that tend to have better power than the PP and ADF tests.

In the context of half-lives, the chapter discusses seminal contributions by Kim, Silvapulle and Hyndman (2006), Norman (2007) and Rossi (2005a).

As far as the disconnect puzzle is concerned, the chapter briefly discusses the general equilibrium approaches.

As far as the exchange rate determination puzzle is concerned, the chapter discusses the market microstructure approach, a paradigm that attempts to explain exchange rate determination by paying attention to order flow — the difference between the buyer-initiated and seller-initiated orders in a securities market. In particular, Evans and Lyons (2005) argue that order flow might be able to anticipate future exchange rate movements.

3.2 Recent developments: PPP mean-reversion puzzle

At the theoretical level, economists are beginning to develop nonlinear models of exchange rate adjustment in which transaction costs play an important role. Dumas (1992) has demonstrated that for markets which are spatially separated, and feature

'iceberg' transactions costs, deviations from PPP should follow a non-linear mean-reverting process, with the speed of mean reversion depending on the size of the deviation from PPP. The upshot of this is that within the transaction band, deviations are persistent and take a considerable time to mean-revert. In this setting, the real exchange rate behaves like to a random walk. However, large deviations, those that occur outside the band, will rapidly dissipate and for them the observed mean reversion speeds up. A similar model is authored by Sercu, Uppal and Van Hulle (1995), and includes transport costs which create a band for the real exchange rate within which the cost of arbitrage is larger than the benefit at the margin, creating a no-trade corridor. This approach results in a two regime threshold model, whereby the real exchange rate is reset by arbitrage to an upper or lower inner threshold whenever it hits the corresponding outer threshold (Smallwood, 2005).

A more formal example is associated with Obstfeld and Taylor (1997), who develop a band transition autoregressive model using demeaned and detrended data. The model is of the following form:

If $y_{t-1} > c$, then $\Delta y_t = \phi^{out}(y_{t-1} - c) + \varepsilon_t^{out}$

If $c \geq y_{t-1} \geq -c$, then $\Delta y_t = \phi^{in} y_{t-1} + \varepsilon_t^{in}$

If $-c > y_{t-1}$, then $\Delta y_t = \phi^{out}(y_{t-1} - c) + \varepsilon_t^{out}$,

where errors, denoted ε_t^{out} and ε_t^{in} are normally distributed with mean zero and constant standard deviations. In this setting $\phi^{in} = 0$ and ϕ^{out} is the speed of convergence outside the transaction cost band. Using the data set of Engel and Rogers (1995), Obstfeld and Taylor find that for inter-country CPI-based real exchange rates, the adjustment speed was only 12 months for the TAR model. When disaggregate price series were used to test the law of one price the B-TAR model produced evidence of mean-reversion which was well below 12 months.

3.3 **Threshold and STAR approaches to the PPP puzzle**

The STAR approach takes nonlinearities into account when testing for unit roots. The most referenced contributions in the context of threshold autoregressive (TAR) models are associated with Enders and Granger (1998), Gonzalez and Gonzalo (1998), Berben and van Dijk (1999), Caner and Hansen (2001), Lo and Zivot (2001), Shin and Lee (2001), Kapetanios and Shin (2002), Seo (2003), Bec, Ben Salem and Carrasco (2004), and Kapetanios, Shin and Snell (2003) in the context of an exponential smooth transition autoregressive specification. This has led to the employment of non-standard asymptotic theory and joint tests of nonlinearities and nonstationarity in which nonlinear methods tend to require transition autoregressive modelling. The difficulty with these models is that the model parameters are only defined under the alternative hypothesis, a problem identified by Davies (1987). An important feature of any nonlinear approach is that the parameter space must be clearly defined to achieve proper asymptotic null distributions, the critical values of which form the basis of inference. When the parameters are defined only under the alternative hypothesis, usually a truncated Taylor expansion of the transition function becomes the basis of an auxiliary regression that can be estimated using commercial software.

Following van Dijk, Terasvirta, and Franses (2002), the smooth transition autoregressive (STAR) representation requires the following descriptions.

Let y_t be a time series observed at $t = 1 - p, 1 - (p-1), ... - 1, 0, 1 ... T - 1, T$. Let $x_t = (1, y_{t-1}, ... y_{t-p})$. Denote $\Omega_{t-1} = \{y_{t-1}, y_{t-2}, ..., y_{1-(p-1)}, y_{1-p}\}$. Assume that $E[\varepsilon_t | \Omega_{t-1}] = 0$ and that $E[\varepsilon^2_t | \Omega_{t-1}] = \sigma^2$. Let the transition function be:

$$F(s_t; \gamma, c) = [1 + \exp(-\gamma(s_t - c))]^{-1} \tag{3.1}$$

such that $F(s_t; \gamma, c)$ is continuous and is bounded between 0 and 1.

Consider the following representation of the STAR model:

$$y_t = \theta'_1 x_t (1 - F(s_t; \gamma, c)) + \theta'_2 x_t F(s_t; \gamma, c) + \varepsilon_t \qquad (3.2)$$

Equation (3.2) can be written as:

$$y_t = (\theta_{1,0} + \theta_{1,1} y_{t-1} + \dots + \theta_{1p} y_{t-p})(1 - F(s_t; \gamma, c)$$

$$+ (\theta_{2,0} + \theta_{2,1} y_{t-1} + \dots + \theta_{2p} y_{t-p}) F(s_t; \gamma, c) + \varepsilon_t \qquad (3.3)$$

In equation (3.3), s_t is a transition variable such that $s_t = y_{t-d}$ where d is an integer and represents a delay parameter. We note that the extreme values of the transition function are 0 and 1. So, for $F(s_t, \gamma, c) > 0$ and $F(s_t, \gamma, c) < 1$, the model exhibits a smooth regime-switching behaviour. When the transition function is represented by the first-order logistic equation (3.1), this gives rise to a logistic STAR (LSTAR) model. The parameter c denotes a threshold between the regimes, while γ determines the smoothness of the transition from one regime to another. For large values of γ and for $s_t = c$, there is an instantaneous change for $0 < F(s_t, \gamma, c) < 1$. Consequently, $F(s_t, \gamma, c)$ becomes an indictor function such that, say, for $I = 1$, $s_t > c$ and $I = 0$, otherwise.

We note that, when the transition parameter is $s_t = y_{t-d}$, the model becomes a self-exciting smooth transition autoregressive (SETAR) model. When γ approaches zero, the logistic function becomes a constant, such that $F(s_t, \gamma, c) = 1/2$. When $\gamma = 0$, the LSTAR becomes a linear model.

There are special cases that can be convenient in the analysis of macroeconomic variables. Suppose the threshold parameter value is 0, that is, $c = 0$ and that y_t represents a country's GDP growth rate. Then for $s_t = y_{t-d}$, the model depicts periods of positive and negative growth rates. When the model is applied to exchange rates the transition function becomes an exponential function, such that

$$F(s_t, \gamma, c) = 1 - e^{\{-\gamma(s_t - c)^2\}} \quad \text{where } \gamma > 0. \qquad (3.4)$$

17

This leads to what is called the exponential smooth transition autoregressive (ESTAR) model. We note that as $s_t \to \pm\infty$, then the transition function $F(s_t, \gamma, c) \to 0$. In addition, as $\gamma \to 0$ or $\gamma \to \infty$, then $F(s_t, \gamma, c) = 0$. This leads to a linear model.

Luukkonen, Saikkonen and Teräsvirta (1998), Teräsvirta (1994), Saikkonen and Luukkonen (1988), Gonzalez-Rivera (1998), Escribano and Jorda (2000), and others have truncated the transition function around $\gamma = 0$ as a means to overcome the nuisance parameter problem, which is normally accompanied by nonstandard asymptotic distribution theory (Hill, 2004). The Taylor expansion approximation leads to a simple auxiliary regression. Tests on subsets of coefficients can be used to infer whether the process is linear or not.

From Luukkonen, Saikkonen and Teräsvirta (1998), the nature of the auxiliary regression from (3.1) and (3.2) is of the following form:

$$y_t = a_0 + \sum_{j=1}^{p} a_{1j} y_{t-j} + \sum_{j=1}^{p} b_{1j} y_{t-j} y_{t-d} + \sum_{j=1}^{p} b_{2j} y_{t-j} y^2_{t-d} + \sum_{j=1}^{p} b_{3j} y_{t-j} y^3_{t-d} + \xi_t \qquad (3.5)$$

where ξ_t are the white noise residuals with zero mean and constant variance under the null hypothesis of linearity. Under the null, all the $b's$ are equal to zero, whereas under the alternative, at least one b is not equal to zero.

The test statistic required, denoted LM_{LST}, is of the following form:

$$LM_{LST} = \frac{T(SSR_1 - SSR_0)}{SSR_1}, \qquad (3.6)$$

where T is the sample size, SSR_1 and SSR_0 are residual sum of squares of the restricted and unrestricted regressions, respectively.

The LM_{LST} statistic has an asymptotic χ^2 distribution with $3p$ degrees of freedom. Large values of the statistic lead to the rejection of the null of linearity, suggesting that linear $AR(p)$ specification is inadequate in characterizing the process under consideration.

Applications of these threshold regime switching models can be found in Obstfeld and Taylor (1997) and Michael, Nobay and Peel (1997), and Bec, Ben Salem and Carrasco (2004).

Recently, Kapetanios, Shin and Snell (2003) have proposed a new testing procedure for the null hypothesis of a unit root against an alternative of a nonlinear stationary ESTAR process. In particular, the authors have shown that their suggested test is more powerful than the Dickey-Fuller test against the stationary STAR alternative. They call this test the nonlinear augmented Dickey-Fuller (NADF) test statistic. The result is based on the univariate exponential smooth transition autoregressive model of order 1:

$$y_t = a_1 y_{t-1} + a_2 y_{t-1} \Phi(\theta; y_{t-d}) + \varepsilon_t \qquad (3.7)$$

where $\varepsilon_t \sim iid(0, \sigma^2), d \geq 1$.

The transition function is of the form: $\Phi(\theta; y_{t-d}) = 1 - e^{(-\theta y^2_{t-d})}$.

To test the null hypothesis of a unit root in the above case implies that $a_1 = 1$ and that $a_2 = 1$. Because of the Davies (1987) problem mentioned earlier, the hypothesis testing requires an auxiliary regression of the form:

$$\Delta y_t = \delta y^3_{t-1} + error \qquad (3.8)$$

In the presence of serial correlation, the auxiliary regression takes the form:

$$\Delta y_t = \sum_{j=1}^{p} \varphi_j \Delta y_{t-j} + \delta y^3_{t-1} + error \qquad (3.9)$$

KSS developed a NLADF t-test of the form:

$$NLADF = \frac{\hat{\delta}}{s.e(\hat{\delta})},$$

(3.10)

which is accompanied by the asymptotic distribution of the following form:

$$NLADF \Rightarrow \frac{\{\tfrac{1}{4}B(1)^4 - \tfrac{3}{2}\int_0^1 B(r)^2 \, dr\}}{\sqrt{\int B(r)^6 \, dr}},$$

(3.11)

where $B(r)$ is the standard Brownian motion defined on $r \in [0,1]$

Another paper distinguishing a nonstationary linear process from a stationary nonlinear ESTAR process is Kilic (2004). The author develops a supremum or $\sup\!-t$ test for unit roots against a globally stationary exponential STAR model, simultaneously allowing for the presence of a drift term and trend term. The distribution is found to be nuisance parameter free, allowing for the calculation of critical values. The t-test is found to have a substantial power compared to the ADF and Phillip-Perron test.

Kilic relies on the ESTAR framework defined as:

$$y_t = \phi y_{t-1} + \phi^* y_{t-1} F(\gamma, c, z_t) + u_t,$$

(3.12)

where $u_t \sim NID(0, \sigma^2)$ and z_t is stationary and can take the form $z_t = \Delta y_{t-d}$.

The $\sup\!-t$ statistic is defined as:

$$\sup\!-t = \sup_{(\gamma,c) \in \Gamma XC} t_{\phi^*} = \sup_{\gamma,c \in \Gamma XC} \{\frac{\hat{\phi}^*(\gamma,c)}{s.e(\hat{\phi}^*(\gamma,c))}\} \phi^*$$

(3.13)

Its asymptotic distribution was found to be:

$$\text{sup}-t \Rightarrow \sup_{(\gamma,c)\in\Gamma XC} \frac{\{\frac{1}{2}[1-C_0(\gamma,c)][B(1)^2-1]\}}{1-2C_0(\gamma,c)+C_1(\gamma,c)\}^{1/2}\{\int_0^1 B(r)^2\,dr\}^{1/2}}, \tag{3.14}$$

where the parameter space is defined as $\Gamma = [\underline{\gamma},\overline{\gamma}]$ and $C = [\underline{c},\overline{c}]$ such that $0 < \underline{\gamma} < \gamma < \overline{\gamma}$ and $0 < \underline{c} < c < \overline{c}$. Also, $C_0(\gamma,c) = E(\exp(-\gamma(\Delta y_{t-1}-c)^2))$ and $C_1(\gamma,c) = E(\exp(-2\gamma(\Delta y_{t-1}-c)^2))$.

3.4   Recent developments: Half-lives

In this subsection we take a selective overview of suggested ways to calculate half-lives. Some of the methods take nonlinearities into account. Traditional half-life calculation of half life is generally based on an autoregressive model of order one, $y_t = \varphi y_{t-1} + \varepsilon_t$, with concomitant regularity conditions on the structure of errors, as explained by Rossi (2005a). As demonstrated by Chortareas and Kapetanios (2004), the calculation of the half-life $\hat{H}$ of the process is based on the following:

$$\hat{H} = \ln(0.5)/\ln(\hat{\varphi}), \tag{3.15}$$

where $\hat{\varphi}$ represents the estimate of φ. Based on the sticky price theory, estimates of $\hat{\varphi}$ leading to an estimated half-life of less than 3 years would be deemed acceptable.

It is understood that the above-mentioned approach has severe limitations and not applicable to $AR(p)$ processes. In addition, several authors have found the estimate $\hat{\varphi}$ to biased downward. Also, according to Kim, Silvapulle and Hyndman (2006), the statistic appearing in equation (3.15) suffers from the weakness that it is biased in small samples, that it has unknown and possibly complicated distribution and that it may not possess finite sample moments since it takes extreme values as the estimated coefficient approaches one.

Kim, Silvapulle and Hyndman (2006) propose a bias-corrected bootstrap procedure for the estimation of half-life deviations from PPP by adopting Hyndman (1996) highest density region (HDR) approach to point and interval estimation. The authors' approach necessitates the use of the Kilian (1998) bias-corrected bootstrap to approximate the sampling distribution of the half-life statistic. In addition, the kernel density of the bootstrap distribution is estimated by adopting the transformed kernel density method of Wand, Marron, and Ruppert (1991).

As indicated earlier, due to software constraints, this promising approach is left for future research.

3.4.2 Chortareas and Kapetanios (2004) half-life approach

Chortareas and Kapetanios (2004) provide an alternative half-life measure. They define the half-life $h*$ as a point in time at which half the absolute cumulative effect of the shock has dissipated. In this setting, $h*$ solves by means of numerical methods the following equation:

$$2\sum_{j=1}^{p}\frac{c_j\lambda_j^{h*}}{\ln(\lambda_j)}=\sum_{j=1}^{p}\frac{c_j}{\ln(\lambda_j)},\tag{3.16}$$

where λ_j are eigenvalues of an $AR(p)$ process and c_j is given by:

$$c_j=\frac{\lambda_j^{p-1}}{\Pi_{k=1,k\neq i}(\lambda_j-\lambda_k)}.\tag{3.17}$$

It is to be noted that (3.16) is not an easy equation to solve. For instance, in the case of an $AR(2)$ process, when simplified, (3.16) takes the following form:

$$2[x_1^{h*}+x_2^{h*}]=z.\tag{3.18}$$

Hence, numerical methods are required and more so for higher order lags. The application of this method is left for future research.

3.4.3 Rossi (2005a) approach to half-life deviations from PPP

Rossi (2005a) introduces a half-life measure for an $AR(p)$ process that produces improved asymptotic approximations in the presence of a root close to unity. Thus the analysis is based on the local-to-unity asymptotic theory. In this context, a half-life can diverge to infinity at the rate of the sample size.

In chapter 6 we provide a detailed exposition of Rossi (2005a) approach.

3.4.4 Nonlinear approach to half-life deviations

Another alternative approach to the calculation of exchange rate half-lives in the context of nonlinearities is associated with the work of Koop, Pesaran and Potter (1996) and Norman (2007). In the nonlinear frameworks, impulse response functions have been used to assess the dynamic nature of the effects of shocks on the behaviour of time series in both the univariate and multivariate contexts. By definition, an impulse response function is a change in the conditional expectation of the variable or vector Y_{t+s} as a result of an exogenous shock ε_t :

$$IRF_Y = E[Y_{t+s} \mid \Omega_{t-1}, \varepsilon_t] - E[Y_{t+s} \mid \Omega_{t-1}] , \qquad (3.19)$$

where Ω_{t-1} represents the history of the process. In linear models impulse response functions are based on the Wold representation:

$$y_t = \sum_{j=0}^{\infty} \psi_j \varepsilon_{t-j} \qquad (3.20)$$

Consider a univariate case of a stationary variable y_t such that it is represented by an autoregressive model:

$$y_t = \phi y_{t-1} + \varepsilon_t \tag{3.21}$$

where $|\phi| < 1$. The associated impulse response function takes the following form:

$$IRF(y_{t+n}) = \theta \frac{1 - \phi^{n+1}}{1 - \phi}, \tag{3.22}$$

where θ is the size of the shock and $n = 1,2,3,....$.

It has been observed by Beaudry and Koop (1993), Potter (1995), and Pesaran and Potter (1994) that linear models are restrictive in that their symmetry property implies that shocks occurring in one regime are as persistent as the shocks occurring in another regime. Furthermore, linear models cannot adequately capture asymmetries that may exist in the various stages of the business cycle, which is problematic in the light of the evidence that the degree of persistence varies over the business cycle.

Moreover, according to Koop, Pesaran, and Potter (1996), the nonlinear impulse response functions depend on the size of the shock, the sign of the shock, and the history of the system. This has led to the development of the concept of generalised impulse response functions (GIRF). By definition similar to the one appearing above, a generalised impulse response function for an n-period horizon, for multivariate models is of the following form:

$$GIRF_Y(n, \Phi, \Omega_{t-1}) = E[Y_{t+n} \mid \Phi_t, \Omega_{t-1}] - E[Y_{t+n} \mid \Omega_{t-1}], \tag{3.23}$$

where Φ is a vector of shocks and Ω_{t-1} is the history of the system. The generalised impulse response function is a function of Φ and Ω_{t-1}. In this setting, future shocks are averaged out.

In the threshold framework, consider an ESTAR bivariate model:

$$Y_t = AY_{t-1} + BY_{t-1}1_{(\Delta X_{t-1} \geq 0)} + U_t, \qquad (3.24)$$

where A and B are 2X2 matrices and U_t and Y_t are vectors or variables. The shock to the $j-th$ variable of Y_t occurs in period 0, and responses are computed for l periods thereafter. The shock is a one or two standard deviation shock, consistent with the Cholesky factorisation framework. Under these circumstances, Koop, Pesaran and Potter (1996) and Atanasova (2003) recommend the following bootstrap-based algorithm:

a. Pick a history $\Omega^h{}_{t-1}$ where $h = 1,2,...,H$. Pick a sequence of (m-dimensional) shocks $\varepsilon^b{}_{t+l}$, $b = 1,2,...,B$ and $l = 0,1,2,...,L$.

b. The shocks are drawn with replacement from the estimated residuals of the model. If one does not want to make any assumptions about the form of dependence but has some knowledge of conditional heteroskedasticity, then one can draw weighted shocks from the joint empirical distribution.

c. Using $\Omega^h{}_{t-1}$ and $\varepsilon^b{}_{t+l}$, simulate the evolution of Y_{t+k} over $l+1$ periods. The resulting path is denoted $Y_{t+n}(\Omega^h{}_{t-1}, \varepsilon^b{}_{t+k})$.

d. Substitute ε_{j0} for the j_0 element of $\varepsilon^b{}_{t+k}$ and simulate the evolution of Y_{t+k} over $l+1$ periods. Denote the resulting path $Y_{t+n}(\varepsilon_{j0}, \Omega^h{}_{t-1}, \varepsilon^b{}_{t+k})$.

e. Repeat steps a to d B times.

f. Repeat steps a to e H times and compute $[Y_{t+n}(\varepsilon_{j0}, \Omega^h{}_{t-1}, \varepsilon^b{}_{t+k}) - Y_{t+n}(\Omega^h{}_{t-1}, \varepsilon^b{}_{t+k})]$/HB for the average impulse response function.

3.4.5   Nonlinear impulse response functions by means of MCIM

According to Gallant, Rossi and Tauchen (1993) and Norman (2007) the following algorithm can be used to generate nonlinear impulse response functions:

- With the j initial conditions set to zero, use the estimated model to generate observations based on innovations distributed as a mean zero normal distribution with variance, denoted $\hat{\sigma}^2$ where the latter represents the estimated variance of the error term.

- After the first 200 observations are generated, each observation, y^*_t, produced must satisfy $(\mu - \xi) \leq y^*_t \leq \mu + \xi$, where ξ is a small number.

- After 5000 such observations have been found, no additional data are generated. The 5000 observations and their lags form the basis for the initial conditions, denoted $(y_{-p+1},...,y_0)$. These are used to calculate the impulse response function. For each set of initial conditions, 2 time series of 120 observations each are generated from the initial conditions $(y_{-p+1},...,y_0)$ and $(y_{-p+1},...,y_0 + \theta)$ where θ is the shock used.

- The innovations are distributed as a mean zero normal distribution with variance $\hat{\sigma}^2$. The average difference between these two series among the 5000 replications is taken as the impulse response function.

3.4.6   Norman (2007) ESTAR-related half-lives

In the context of nonlinear mean reversion of an exponential smooth transition type, Norman (2007) makes the assumption that "the question of how long it should be expected for a process to return to its long-run equilibrium is more relevant than how persistent are one period innovations" (p.6). This leads to the following definition of a shock, denoted θ_t:

$$\theta_t = E[y_t] - y_t.$$

(3.25)

In the context of purchasing power parity analysis, y_t can define an exponential smooth transition model of the form:

$$y_t - \mu = \alpha_1(y_{t-1} - \mu) + (\alpha_2 - \alpha_1)(y_{t-1} - \mu)F(y_{t-d} - \mu) + \varepsilon_t,$$ (3.26)

where the mean of the process is denoted μ and the transition function is of the form:

$$F(y_{t;}\gamma,\mu) = 1 - \exp[-(\gamma/\hat\sigma y_t)(y_t - \mu)^2].$$ (3.27)

.

Norman (2007) uses the definition of a half-life appearing in Gallant, Rossi, and Tauchen (1993), denoted H, which is :

$$\min[H]\text{ such that } E[y_{t+h} \mid y_{t-1} = \mu + \theta] - E[y_{t+h} \mid y_{t-1} = \mu] \le \frac{\theta}{2}.$$ (3.28)

Norman (2007) uses the following algorithm for the calculation of half-lives:
- Select the initial condition such that it equals the mean of the process.
- Specify and estimate the ESTAR model.
- For $t \in [1...T]$, calculate the shock associated with each observation y_t as $\theta_t = y_t - \hat\mu$, where $\hat\mu$ is the estimated mean of the ESTAR process.
- Use the Monte Carlo integration method to calculate the impulse response function associated with each shock.
- The half-life corresponding to each shock is then calculated according to equation (3.28).
- Draw with replacement from the set of shocks and associated half-lives.

3.5 Testing for long memory in respect of the PPP puzzle

Another new approach to resolving the purchasing power parity puzzle is through fractional integration. The concept of long memory is gaining popularity in econometrics, because econometricians wish to ensure that a nonlinear stationary process is not mistaken for a nonstationary process or a fractionally integrated process. In this context, it is well-known that the presence of unit roots in a time

series implies the autocorrelation function of the time series process does not die out and that the variance of the process is unbounded and model innovations will have permanent effects on the level of the process. In equilibrium terms, the process will not revert to a long-run mean. In addition, the presence of unit roots implies that the regressors will have nonstandard asymptotic distributions, thereby invalidating standard tools of inference.

In the STAR framework long memory was introduced by van Dijk, Franses, and Paap (2000). Other works on fractional integration in the behaviour of exchange rates include Cheung (1993), Baillie (1996), Ballie and Kapetanios (2004), Robinson (2003), Smallwood (2005), Kapetanios (2006).

In Smallwood (2005), the tests of nonlinearity utilise the following model of fractional integration:

$$(1-L)^d y_t = \{\varphi_{1,0} + \sum_{i=1}^{p} \varphi_{1,i}(1-L)^d y_{t-i}\} \tag{3.29}$$

$$+ \{\varphi_{2,0} + \sum_{i=1}^{p} \varphi_{2,i}(1-L)^d y_{t-i}\}F(y_{t-d};\gamma,c) + \varepsilon_t$$

The associated auxiliary regression is given by:

$$(1-L)^d y_t = \{\varphi_{1,0} + (\sum_{i=1}^{p} \varphi_{1,i}(1-L)^d y_{t-i}) + \sum_{i=1}^{p} \varphi_{2,i}(1-L)^d y_{t-j}y_{t-d}\} \tag{3.30}$$

$$+ \{\sum_{i=1}^{p} \varphi_{3,i}(1-L)^d y_{t-i}\}y^2_{t-d} + e_t$$

To test the null hypothesis of linearity – that the time series process is a long memory ARFIMA(p,d,0) – is the same thing as testing as follows:

$Ho: \varphi_{2,i} = \varphi_{3,i} = 0 \qquad i = 1,...,p$

$Ha: \varphi_{2,i} \neq 0 \qquad or \, \varphi_{3,i} \neq 0$ for at least one i.

In this setting, hypothesis testing is based on an LM-type statistic, which is derived using the following algorithm:

Estimate the ARFIMA(p,d,0) model and store the residuals $\hat{\varepsilon}_t$;

Obtain an optimal estimate of d and denote it $\hat{d}$;

Construct the restricted sum of squared errors, denoted SSR_R;

To obtain the unrestricted squared sum of errors, denoted SSR_{UR}, regress $\hat{\varepsilon}_t$ on

$$1, (1-L)^{\hat{d}} y_{t-1}, ..., (1-L)^{\hat{d}} y_{t-p}, \quad -\sum_{i=1}^{t-1} \frac{\hat{\varepsilon}_{t-i}}{i}$$

$$(1-L)^{\hat{d}} y_{t-1} y_{t-d}, ..., (1-L)^{\hat{d}} y_{t-p} y_{t-d} \text{ and}$$

$$(1-L)^{\hat{d}} y_{t-1} y^2_{t-d}, ..., (1-L)^{\hat{d}} y_{t-p} y^2_{t-d}.$$

The chi-squared version of the LM statistic is calculated as:

$$LM_{\chi^2} = T(SSR_R - SSR_{UR})/SSR_R \tag{3.31}$$

and is distributed as a $\chi^2(2p)$.

The F version of the statistic is calculated as:

$$LM_F = \frac{(SSR_R - SSR_{UR})/2p}{SSR_{UR}/(T-3p-1)}. \tag{3.32}$$

In chapter 6 we use the latest techniques to test for long memory. In particular, we utilise a class test for fractional integration developed by Hinich and Chong (2007). The benefit of this test is that it is able to determine whether or not a time series falls under a class of fractionally integrated processes.

3.6   **Recent developments: Exchange rate disconnect puzzle**

There are currently two strands of research trying to explain the exchange rate disconnect puzzle. There is currently no survey of the models proposed in respect of the disconnect puzzle. The first strand of research is theoretical in that it attempts to explain the conditions under which "the disconnect" between the economic fundamentals and exchange rate movements is expected to exist. Such studies include Devereux and Engel (2002), Xu (2005), Duarte and Stockman (2005), Evans and Lyons (2005), and Bacchetta and van Wincoop (2006). The second strand is the market microstructure approach that attempts to find reliable short-run determinants of exchange rates.

Below a survey of general equilibrium approaches to the disconnect puzzle is undertaken. Below we begin by discussing in detail the Deveroux and Engel (2002) model. However, the discussion of Bacchetta and van Wincoop (2004), Duarte and Stockman (2005), Xu (2005), and Evans and Lyons (2005) will be more descriptive, with emphasis on the main results rather than the mathematical structure of the model. With the exception of Evans and Lyons (2005), the approach used by the above-mentioned authors is similar to the one appearing in Chapter 10 of Obstfeld and Rogoff (1999).

3.7   **A survey of GE models in respect of the disconnect puzzle**

We begin with one of the "older" models, which laid the foundation for subsequent studies.

3.7.1   **The Devereux-Engel (2002) model**

Devereux and Engel (2002) develop a general equilibrium model of the exchange rate that is in line with the view espoused by Krugman (1989) that the volatility of the exchange rates is high because ordinary fluctuations in the exchange rate generally do not matter much for the economy. The authors explain that a combination of local

currency pricing, heterogeneity in international price setting and goods distribution, as well as biases in expectations in international financial markets may produce very high exchange rate volatility without significant repercussions for the volatility of other macroeconomic variables. The authors stress that "there ought to be a greater disconnect when the degree of local-currency pricing is high and the wealth effects of exchange rate changes are small."

Devereux and Engel (2002) develop static and dynamic versions of the general equilibrium model. Below we present the dynamic model. In this context, households trade in non-contingent nominal domestic and international bonds in incomplete markets. Households are assumed to trade in domestic currency denominated bonds. Home country trading is carried out by foreign exchange dealers who buy and sell foreign currency denominated bonds to maximise profit.

More formally, a representative consumer in the home country maximises expected utility as follows:

$$E_0 \sum_{t=0}^{\infty} \beta^t U(C_t, \frac{M_t}{P_t}, L_t) \qquad \beta < 1 \tag{3.33}$$

where $U = (1-\rho)^{-1} + \chi \ln\left(\frac{M_s}{P_s}\right) - \frac{\eta}{1+\psi} L_s^{1+\psi} \qquad \rho > 0$; $\tag{3.34}$

C_t denotes consumption;

$\frac{M_t}{P_t}$ are real money balances;

L_t is the labour supply.

In this setting, C_f and C_h are consumption indexes that are CES function of goods produced at home and in the foreign country.

$$C = \left(n^{1/\omega} C^{1-i/\omega} + (1-n)^{1/\omega} C_f^{1-1/\omega}\right)^{\omega/(1-\omega)} \tag{3.35}$$

We note that ω denotes the elasticity of substitution between home and foreign consumption aggregates. The model assumes that there are n identical households in the home country, such that $0 < n < 1$. C_h and C_f are defined as:

$$C_h = \left[n^{-1/\lambda} \int_0^n C_h(i)^{\lambda-1/\lambda} di \right]^{\lambda/\lambda-1} \qquad C_f = \left[(1-n)^{-1/\lambda} \int_n^1 C_h(i)^{\lambda-1/\lambda} di \right]^{\lambda/\lambda-1} \tag{3.36}$$

The price index, P, is defined by:

$$P = \left[nP_h^{1-\omega} \_ (1-n)P_f^{1-\omega} \right]^{1/1-\omega}$$

where $\quad P_h = \left[\frac{1}{n} \int_0^n P_h(i)^{1-\lambda} di \right]^{1/1-\lambda} \qquad P_f = \left[\frac{1}{(1-n)} \int_n^1 P_h(i)^{1-\lambda} di \right]^{1/1-\lambda} \tag{3.37}$

We note that optimal behaviour of households is dictated by the following equations:

$$d_t = E_t \beta \frac{P_t C_t^{\rho}}{P_{t+1} C^{\rho}_{t+1}}, \tag{3.38}$$

$$\frac{M_t}{P_t} = \frac{\chi C_t^{\rho}}{(1 - E_t q_t)} \tag{3.39}$$

where q_t is the discount factor.

The home country household budget constraint is given by:

$$P_t C_t + d_t B_{t+1} + M_t = W_t L_t + \Pi_t + \Pi^f_t + M_{t-1} + T_t + B_t, \tag{3.40}$$

where d_t is the price of bonds, B_t is the number of domestic currency denominated bonds in the hands of home country household, Π_t denotes profit income from domestic firms, and Π^f_t income from foreign exchange dealers, T_t are government transfers.

In this model, firms set prices to equal marginal costs:

$$p_{ht} = E_{t-1} w_t \qquad\qquad p^*_{ht} = E_{t-1}(w_t - s_t),$$ (3.41)

The home country goods market clearing condition is given by the following relation:

$$L_t = n\left(\frac{P_{ht}}{P_t}\right)^{-\omega} C_t + (1-n)\theta\left(\frac{P_{ht}^{P*}}{P^*_{ht}}\right)^{-\lambda}\left(\frac{P^*_{ht}}{P^*_t}\right)^{-\omega} C^*_t$$

$$+ (1-n)(1-\theta)\left(\frac{P_{ht}^{D*}}{P^*_{ht}}\right)^{-\lambda}\left(\frac{P^*_{ht}}{P^*_t}\right)^{-\omega} C^*_t$$ (3.42)

where θ is a proportion of home country firms selling directly to foreign households and $1-n$ is the of home firms who distribute foreign products.

Other details are as follows:

Incomplete goods market and local distribution

- Foreign firms are owned by foreign-owners and local firms by the locals. In each country there are producers and distributors. Producers sell directly to the local residents. When the producers market their products to foreign market, they have the option of either selling directly or relying on foreign-owned distributors. In the case the home producer sells directly to foreign households, the prices are set in foreign currency. When trade takes place through foreign-owned distributors, the pricing is in home currency, making the distributor the absorber of the exchange-rate risk because it buys at prices set in the home currency, but it sets prices for foreign consumers in foreign currency.

- The authors avoid using the PPP relation because the "expenditure-switching" effect of exchange rate changes will lead to substitution between domestically-produced goods and internationally-produced goods, leading to the conclusion that that the exchange rate volatility could be transferred to macroeconomic fundamentals. They instead eliminate any expenditure-

switching role for exchange rates to highlight the role of the contribution of local-currency pricing to exchange-rate volatility.

- Production firms operate as monopolists and set prices in advance to maximize expected discounted profits. The authors assume that distributors sign binding contracts in advance to distribute the composite good.

Noise trading

- At home the foreign exchange dealers buy or sell foreign-currency denominated bonds to maximize the discounted expected returns. The authors assume that foreign exchange dealers exhibit bias in their conditional forecasts of the future exchange rate, making them noise traders. This suggests the following representation of conditionally biased expectations:

$$E_t^n s_{t+1} = E_t s_{t+1} + u_t, \tag{3.43}$$

such that $var_t^n(s_{t+1}) = Var_t(s_{t+1})$ and the conditional expectation of the random error u_t is $E_{t-1}(u_t) = 0$.

- Foreign exchange dealers are assumed to form accurate expectations of the households state contingent discount factor q_t. In addition, there is the assumption that new foreign exchange dealers continue to exhibit biased expectations, driving the expected returns to zero. This suggests that

$$d_t^* = E_t^n \frac{q_t S_{t+1}}{S_t}. \tag{3.44}$$

Solution of the model

- The authors utilise log-linearisation to solve for the unanticipated movement in the exchange rate as:

$$\hat{s}_t = \frac{(1+\frac{\sigma}{r})(\hat{m}_t - \hat{m}_t^*) + \frac{\sigma}{r}u_t}{\frac{\sigma}{r} + \rho(\theta - (1-\theta^*))}, \tag{3.45}$$

where the variables with hats are of the form: $\hat{s}_t = s_t - E_{t-1}s_t$. The results derive from a relationship between the consumption differential and the initial net foreign asset condition:

$$E_{t-1}(c_t - c_t^*) = \frac{1-\beta}{\sigma} \frac{dB^*_{ht}}{(1-n)PC},$$
(3.46)

where $\sigma \equiv (1 - \frac{(1-\omega)\rho}{(1+\psi\omega)})$.

The conditional variance of the exchange rate is given by:

$$Var_{t-1}(\hat{s}_t) = \frac{(1+\frac{\sigma}{r})^2 \, \text{var}_{t-1}(\hat{m}_t - \hat{m}_t^*)}{\left[\frac{\sigma}{r} + \rho(\theta - (1-\theta^*))\right]\left[1 - \left\{\frac{\kappa\sigma}{r\left[\frac{\sigma}{r} + \rho(\theta - (1-\theta^*))\right]}\right\}^2\right]}$$
(3.47)

- In this setting, the volatility of the conditional bias in noise traders' expectations is generated by exchange rate volatility, which depends only on the volatility in relative money supplies. We note that when $\theta + \theta^* \to 1$ the conditional volatility of the exchange rate rises without bound, with no associated unbounded volatility in the fundamentals/money supplies.

Stochastic deviations from uncovered interest parity are obtained from the log-linearization of equations (3.43), (3.44) and (3.46). The result is:

$$\rho E_t(c_{t+1} - c_t) + E_t(p_{t+1} - p_t) =$$
$$\rho E_t(c_{t+1}^* - c_t^*) + E_t(p_{t+1}^* - p_t^*) + E_t s_{t+1} - s_t + v_t$$
(3.48)

Equation (3.48) shows that the presence of conditionally biased expectations of future exchange rate introduces a stochastic deviation from uncovered interest rate parity.

As it is clear from the above information, Deveroux and Engel combine local currency pricing, asymmetric marketing, and the presence of noise-trading liquidity premiums in foreign exchange markets to show the 'disconnect' between exchange rates and fundamentals. The final conclusion is that the "combined presence of local currency pricing, asymmetric marketing, and `noise-trader' conditionally-biased expectations in foreign exchange markets generates the possibility for a degree of short-term exchange rate volatility that is completely out of proportion to all shocks impacting on the economy."

3.7.2 The Xu (2005) model

Xu studied under Deveroux and her model is not that different in structure from that of Deveroux and Engel (2002). Xu (2005) develops a welfare-based model which can explain exchange rate volatility and its relationship with macroeconomic fundamentals and provides a well-defined framework for policy evaluations regarding policies that are designed to control non-fundamental exchange rate volatility.

As explained above, the Deveroux-Engel model included, among other components, a well-defined structure of international pricing and product distribution to minimize the wealth effect of exchange rate changes, incomplete international financial markets for asymmetric risk sharing, and stochastic deviations from the uncovered interest parity. Xu (2005), in addition to these components, puts more emphasis on the micro-structural aspects of noise trading. In this setting, noise traders and rational traders are assumed to be risk-averse, utility-maximising agents, allowing for the analysis of Tobin tax ─ an international transaction tax on the purchases and sales of foreign exchange ─ to appraise the feasibility of reducing non-fundamental exchange rate volatility.

Rational traders and noise traders

Xu models traders as overlapping generations of investors who decide how many one-period foreign nominal bonds to buy in the first period of their lives. Traders who are able to form accurate expectations on risk and returns are called rational traders,

and those with inaccurate expectations about future returns are called noise traders. The informed trader is denoted by a superscript I and the noise trader is denoted by a superscript N.

There are two specifications of the model. In the first case the number of incumbent noise traders is exogenously determined, while in the second specification the traders have to pay a fixed entry cost to trade on the foreign exchange market, making it possible to endogenise the noise component of the market.

To trade in the foreign exchange market, traders face entry costs such as tax, information costs for investment in the foreign bond market, and other costs when investing abroad. Rational traders are assumed to have a superior knowledge of the economy, enabling them to minimise the cost of acquiring information to zero. Noise traders, by contrast, have to pay an entry cost that is greater than zero because they are assumed to have a limited innate ability to acquire and process the information about the economy.

Additional details in Xu (2005)

The following are the main results:

- The consumption-based interest parity condition is of the form:

$$E_t(c_{t+1} - c^*_{t+1}) = (c_t - c^*_t) - \frac{1}{\rho}[s_t - (1 - N_I)v_t,$$

$$+ \frac{a(1+r)S}{P}\mathrm{var}_t(s_{t+1})dB^*_{h,t+1} \tag{3.49}$$

where $(1 - N_I)$ is the number of noise traders.

- The deviation of the exchange rate from expectations depends on the expectation error of the noise traders. The exchange rate equation for the exogenous entry by traders is of the following form:

$$\hat{s}_t = E_t(\hat{s}_{t+1}) - \beta(dr_{t+1} - dr^*_{t+1}) + (1 - N_I)v_t - a\frac{(1+\bar{r})\bar{S}}{\bar{P}}\mathrm{var}_t(s_{t+1})dB^*_{h,t+1} \tag{3.50}$$

For the endogenous trade, the equation becomes:

$$\hat{s}_t = E_t(\hat{s}_{t+1}) - \beta(dr_{t+1} - dr^*_{t+1}) + \frac{1}{N_I} n_t v_t - a\frac{(1+\bar{r})\overline{S}}{\overline{P}N_I} \text{var}_t(\hat{s}_{t+1})dB^*_{h,t+1} \qquad (3.51)$$

where $n_t = \dfrac{E_t(\hat{s}_{t+1}) - s_t - \beta(dr_{t+1} - dr^*_{t+1})}{2a\,\text{var}\,t(s_{t+1})}\left(\dfrac{(1-N_I)}{\overline{c}}\right)$ $\qquad (3.52)$

is the number of incumbent noise traders.

When Tobix tax, denoted τ, is imposed, for the exogenous case the exchange rate equation takes the form:

$$\hat{s}_t = E_t(\hat{s}_{t+1}) - \beta(dr_{t+1} - dr^*_{t+1}) + (1-N_I)v_t$$
$$-\frac{P\tau dB^*_{h,t+1}}{\overline{S}(1+\bar{r})} - a\frac{(1+\bar{r})\overline{S}}{\overline{P}}\text{var}_t(s_{t+1})dB^*_{h,t+1} \qquad (3.53)$$

For the endogenous case the exchange rate equation takes the form:

$$\hat{s}_t = E_t(\hat{s}_{t+1}) - \beta(dr_{t+1} - dr^*_{t+1}) + \frac{1}{N_I}n_t v_t$$
$$-\frac{\overline{P}\tau B^*_{h,T+1}}{N_I \overline{S}(1+r)} - a\frac{(1+\bar{r})\overline{S}}{\overline{P}N_I}\text{var}_t(\hat{s}_{t+1})dB^*_{h,t+1.} \qquad (3.54)$$

3.7.3   The Duarte and Stockman (2005) model

The second sub-strand of research related to theoretical explanations does away with the notion of the purchasing power parity but retains the covered interest parity

condition. This work is associated with Duarte and Stockman (2005). The authors focus on the effects of rational speculation in the foreign exchange markets. They argue that as new information comes becomes public, the risk premia associated with exchange rates adjust in such a way that the changes take place in asset markets but not in the goods market. The premise is that international market segmentation coupled with incomplete risk sharing can invalidate the fundamental equilibrating condition, namely, the equality between relative prices and the marginal rate of substitution. This break-down of the link between product markets and foreign exchange market allows the asset markets to determine the changes such that expectations and premia change the exchange rates without changing the fundamental variables such as GDP growth rates.

The Duarte-Stockman model is a stochastic general equilibrium model that can be summarised as follows:

- Basic assumptions: there are two countries — called home and foreign. They specialise in the production of a composite good. There are segmented markets, with monopolistically competitive firms in each country. These firms set prices one period in advance in the currency of the buyer. Asset markets are incomplete and restrict the households to trade a risk-free, "no-Ponzi-game" discount nominal bond denominated in home currency and a risk-free nominal bond denominated in foreign currency.
- Households: the expected utility function of a representative household depends on consumption, labour effort, and real money balances. There is a continuum of domestic and foreign goods, which are imperfect substitutes.
- Budget constraints: The intertemporal budget constraint depends on the real transfers from government, profits of domestic firms, and nominal labour earnings.
- The risk premium at time t is defined as the covariance of expected exchange rate at period t+1, denoted e_{t+1}, and the nominal marginal utility of consumption of the home household λ :

$$rp_t = \frac{\text{cov}(e_{t+1}, \lambda_{t+1})}{E_t(\lambda_{t+1})} . \tag{3.55}$$

- The main exchange rate equation is given:

$$e_t = \frac{\lambda_t^* E_t(\lambda_{t+1})}{\lambda_t E_t(\lambda_{t+1}^*)}(rp_t + E_t[e_{t+1}]),$$ (3.56)

where λ_t^* represents the nominal marginal utility of consumption of the foreign household. The equation shows that the exchange rate depends on the risk premium of holding bonds.

Duarte and Stockman utilise home representative household intertemporal budget constraint of the following form:

$$B_1 + \varphi_1 + Q\varphi_2 = 0,$$

such that $\varphi_t = P_t w_t l_t + m_{t-1} + \Pi_t + P_t T_t - M_t - P_t c_t$. The variables are described as follows:

P_t is the price index

B_1 is the price of a bond at time 1

c_t is the consumption index

M_t nominal balances

Π_t denotes profits of domestic firms

T_t represents transfers from the domestic government

$P_t w_t l_t$ denotes nominal labour wages.

Analogous conditions hold for the foreign country. The exchange rate equation is approximated by

$$e_1 = \Theta e_2$$

for some parameter Θ, the increase of which would signal a rise in the risk premium associated with holding a home-currency denominated bond.

When the exchange rate equation is solved by incorporating the foreign budget constraint, the final results is as follows:

$$e_2 = \frac{-(\varphi_1 + Q\varphi_2)}{\Theta\varphi_1^* + Q\varphi_2^*},$$ (3.57)

$$e_1 = \frac{-\Theta(\varphi_1 + Q\varphi_2)}{\Theta\varphi_1^* + Q\varphi_2^*}.$$

From the above equations, we note that a rise in the risk premium affects the exchange rate in both periods: the exchange rate rises in the first period and declines in the second period. "If the home country is a net international creditor at the beginning of the first period, …the extent to which an increase in Θ reduces the *future* exchange rate is proportional to the share of initial debt that the foreign country repays in he first period… so that the *current* exchange rate depends inversely on that share."

3.7.4 The Evans and Lyons (2005) model

Rather than make an effort to empirically link exchange rates directly to macro variables, Evans and Lyons (2005) attempt to describe the microeconomic mechanism by which information concerning macro variances is impounded in exchange rates by the market. They approach the problem through the present value relation in which the log spot exchange rate is expressed as the sum of the present value of measured fundamentals and the present value of unmeasured fundamentals.

Additional details unique to the model:

Financial intermediaries

Evans and Lyons provide a more realistic structure of financial markets. There are dealers who act as intermediaries in four financial markets: the home money markets and bond markets; the foreign money markets and bond markets. In this setting, dealers quote prices at which they stand ready to buy or sell securities to households and other dealers. They also have the opportunity to initiate transactions with other dealers at the prices they quote. In essence the behaviour of the exchange rates and interest rates is determined by the securities prices dealers choose to quote. An

equilibrium in this setting is described by a set of dealer quotes for the prices of bonds and foreign currency, and consumer prices set by firms that clear markets, given the consumption and portfolio choices of households and dealers; and a set of consumption and portfolio rules that maximize expected utility of households and dealers, given the prices of bonds, foreign currency and consumer goods. It is to be noted that dealers quote bond prices without precise knowledge of household consumption plans, so the actual currency orders they receive may differ from what was initially planned. Usually dealers can offset the effects of any unexpected currency orders by trading with central banks, so they hardly find themselves with unwanted currency balances at the end of trading in each period.

Order flow

In this model, order flow depends upon the portfolio allocation decisions of domestic and foreign households, the level and international distribution of household wealth and the outstanding stock of foreign bonds held by dealers from last period. These elements suggest that order flow contains both backward-looking and forward-looking components. In particular, there will be positive order flow for foreign bonds if households are more optimistic about the future value of the exchange rate than home dealers.

Transaction flows and fundamentals

In the Evans and Lyons (2005) model spot rates are determined by dealer expectations regarding fundamentals, while order flow reflects the differences between household and dealer expectations regarding future spot rates.

The authors point out that if households have more information about the future course of fundamentals than dealers, and dealers are expected to assimilate at least some of this information from transactions flows each period, than order flow will be correlated with variations in the forecast differentials for fundamentals.

They point out that the household orders driving order flow are adjusted solely by the desire to optimally adjust portfolios. Households have no desire to inform dealers about the future state of the economy, so the information conveyed to dealers via transaction flows occur as a by-product of their dynamic portfolio allocation decisions. "The transactions flows associated with these decisions establish the link between order flow, dispersed information, and the speed of information…."

Data

The authors utilise a new data set that comprises end-user transaction flows, spot rates and macro fundamentals over six and a half years. By end users the authors refer to three main segments: non-financial corporations, institutional investors, and leveraged traders such as hedge funds. Empirical analysis also utilises new high-frequency real-time estimates of macro fundamentals for the US and Germany: specifically GDP growth, CPI inflation, and M1 money growth. 'Real time' implies the estimates corresponding to actual macroeconomic data available at any given time.

The main results

The main results are as follows:

- Order flows forecast future macro variables such as output growth, money growth, and inflation better than spot rates do.
- Order flows forecast future spot rates.
- Order flows appear to be the main driver in the process by which expectations of future macro variables are impounded into exchange rates.

3.7.5   The Bacchetta and van Wincoop (2006) model

Bacchetta and van Wincoop (2006) present a dynamic general equilibrium model that is premised on the heterogeneity of information in a monetary model of exchange rate determination, which consists of money market equilibrium, purchasing power parity, and an interest rate arbitrage equation. In this context, a continuum of investors has symmetrically dispersed information about future macroeconomic fundamentals but face different exchange rate risk exposure. To mitigate risk,

investors rely on hedge trades. A unique characteristic of the Bacchetta-van Wincoop model is that order flow is modelled explicitly in a general equilibrium setup. Also, equilibrium is a result of auction market driven by orders.

The model can be summarised by the following equations:

$$p_t = p^*_t + s_t,$$
(3.59)

where s_t is the log of the nominal exchange rate, and p_t and p^*_t are the logs of domestic and foreign prices. Thus equation (8.30) represents the purchasing power parity relation. The money demand equation of the form

$$m_t - p_t = -\alpha i_t$$
$$m^*_t - p^*_t = -\alpha i^*_t$$
(3.60)

where m_t and m^*_t are the domestic and foreign money supplies in logs.

The demand for foreign bonds takes the form:

$$b^i_{Ft} = \frac{E^i_t(s_{t+1}) - s_t + i^*_t - i_t}{\gamma \sigma^2_t} - b^i_{it}$$
(3.61)

where i^*_t and i_t are foreign and domestic interest rates, and σ^2_t is the conditional variance of s_{t+1}. Market equilibrium leads to the following interest rate arbitrage condition

$$\bar{E}_t(s_{t+1}) - s_t = i_t - i^*_t + \gamma b_t \sigma^2_t,$$
(3.62)

where the average expectation of individual investors is denoted $\bar{E}_t$. The observable fundamental is defined as a money supply differential $f_t = m_t - m^*_t$. The authors derive the following equilibrium exchange rate under higher order expectations:

$$s_t = \frac{1}{1+\alpha} \sum_{k=0}^{\infty} \left(\frac{\alpha}{1+\alpha}\right)^k \overline{E}_t^{\,k} (f_{t+k} - \alpha\gamma\sigma^2{}_{t+k} b_{t+k}) \qquad (3.63)$$

where $\overline{E}^0{}_t(x_t) = x_t$, $\overline{E}^1{}_t(x_{t+1}) = \overline{E}_t(x_{t+1})$ and higher-order expectations are of the form:

$$\overline{E}^k{}_t(x_{t+k}) = \overline{E}_t \overline{E}_{t+1} \dots \overline{E}_{t+k-1} \, x_{t+k}. \qquad (3.64)$$

Information structure

The information structure can be that of a common knowledge or heterogeneous information. In the context of common knowledge, a common signal is of the form, $v_t = f_{t+T} + \varepsilon^v{}_t$. In the model heterogeneous investors receive one signal about fundamentals. In this context, let i denote an investor. Then the signal is of the following form $v^{it} = f_{t+T} + \varepsilon^{vi}{}_t$ such that $\varepsilon^{vi}{}_t \sim N(0, \sigma^2{}_v)$ and $\varepsilon^{vi}{}_t \perp f_{t+T}$. Define $\beta^v \equiv 1/\sigma^2{}_v$ and let $D = \beta^v + \beta^f + \beta^s$. The authors conjecture that the equilibrium exchange rate is of the form:

$$s_t = (1+\alpha)^{-1} f_t + \lambda_f f_{t+1} + \lambda_b b_t. \qquad (3.65)$$

From the signal takes the form:

$$\frac{\tilde{s}_t}{\lambda_f} = f_{t+1} + \frac{\lambda_b}{\lambda_f} b_t, \qquad (3.66)$$

where $\tilde{s}_t = s_t - (1+\alpha)^{-1} f_t$, with the variance of the error being $(\lambda_b / \lambda_f)^2 \sigma_b^2$.

The equilibrium exchange rate is

$$s_t = (1+\alpha)^{-1} f_t + z\alpha(1+\alpha)^{-2} \frac{\beta^v}{D} f_{t+1} - z\alpha(1+\alpha)^{-1} \gamma\sigma^2 b_t \qquad (3.67)$$

where the magnification factor is defined as

$$z = 1/(1 - \alpha(1+\alpha)^{-2} (\beta^s / \lambda_f D) > 1 \qquad (3.68)$$

45

Order flow

In the model there is a simple relationship between order flow and the exchange rate. For instance, aggregate order flow is defined as $\Delta x_t = \dfrac{\beta^v}{(1+\alpha)\gamma\sigma^2 D} f_{t+1} - b_t$

and equilibrium exchange rate is a function of order flow and an observable fundamental:

$$s_t = \frac{1}{1+\alpha} f_t + z \frac{\alpha}{1+\alpha} \gamma\sigma^2 \Delta x_t. \qquad (3.69)$$

As pointed out by the authors, the main implications of the above model are that in the short run, investor confusion leads to the disconnection of the exchange rate from observed fundamentals. At that point, investors do not know whether future fundamentals or an increase in hedge trades drive exchange rate changes. "This implies that unobserved hedge trades have an amplified effect on the exchange rate since they are confused with changes in average private signals about future fundamentals."

Model dynamics and numerical analysis

Bacchetta and van Wincoop make the following observations regarding the dynamics of the model:

- Transitory nonobservable shocks have a persistent effect on the exchange rate, due to the learning behaviour of investors.
- Hedge shocks are further magnified by the presence of higher-order expectations, but the overall impact on the connection between the exchange rate and observed fundamentals is ambiguous.
- In the common knowledge model, 1.3 per cent of the variance of a one-period change in the exchange rate is driven by the unobservable hedge trades, while in the heterogeneous model it is 70 per cent. In the short run

unobservable factors dominate exchange rate volatility, but in the long-run it is the observable fundamentals that dominate.

- At a one-period horizon 84 per cent of the variance of one-period exchange rate changes can be accounted for by order flow as opposed to public information.

3.8   Critical assessment of the models and conclusions

What has been central to the above models is the respective role of expectations, fundamental and nonfundamental factors such as risk premia and order flows. In the case of Deveroux and Engel, local currency pricing, asymmetric marketing, as well as rational and noise trading, play an important part in creating a disconnect between fundamentals and exchange rate movements. To the extend that reliable short run determinants of exchange rate movements can be established, it would appear that the Evans and Lyons model and Bacchetta and van Wincoop models are the front runners in the arena of general equilibrium models. Evans and Lyons and Bacchetta and van Wincoop have established that order flows play an important role in short run exchange rate dynamics.

It is therefore our judgement that Bacchetta-van Wincoop and Evans-Lyons models can explain the exchange rate determination puzzle.

The relevance of this chapter in relation to the rest of the current study is that it highlights the likely trajectories of future research. The Bacchetta-van Wincoop and Evans-Lyons models are seen as suitable for future research in that they can both explain the exchange rate determination puzzle and also provide meaningful insights in respect of the reliable determinants of exchange rates. In short, these models constitute a theoretical and empirical bridge for at least two strands of research in exchange rate economics.   Moreover, the fact there exists a relationship among order flow, spot rates and fundamentals implies that short-term forecasting is likely to be reliable in the context of policy and corporate foreign exchange related strategies.

3.9   Recent developments: Exchange rate determination puzzle

The current literature in respect of the exchange rate determination puzzle attempts to find reliable determinants of exchange rates in the short run. Market microstructure theory, in particular, attempts to explain exchange rate determination by paying to order flow — the difference between the buyer-initiated and seller-initiated orders in a securities market. In particular, Evans and Lyons (2005) argue that order flow might be able to anticipate future exchange rate movements. Other variables taken into account are interest rate differentials.

The market microstructure approach is discussed in Chapter 7, where we discuss the short-run and long-run dynamics in respect of the determinants of exchange rates.

4 Chapter 4: Testing for PPP using SADC real exchange rates

4.1 Introduction

Recent literature recognizes the need to assess nonlinearities in the adjustment dynamics of real exchange rates. The main reason for this paradigm shift is that, due to lower power in small sample sizes, the standard Dickey-Fuller-type tests do not provide a solid foundation for an inference that reduces the probability of committing a Type 2 error. This has been the case even when stronger versions of Dickey-Fuller tests – such as the one suggested by Elliot, Rotenberg and Stock (1996) – were used.

The focus on nonlinearities has been reinforced by Taylor, Peel and Sarno (2001) who provide strong evidence that four major real bilateral dollar exchange rates were characterized by nonlinear mean-reversion. One influential study that has also corroborated nonlinear mean-reversion is by Michael, Nobay and Peel (1997). In the nonlinear models, an equilibrium level of the real exchange rate in the regime in which the log-level of the real exchange rate is close to a random walk becomes increasingly mean reverting as the absolute size of the deviation from equilibrium increases. This is consistent with the recent theoretical literature on the nature of real exchange rate dynamics in the presence of transaction costs (See Sercu, Uppal and van Hulle (1995)).

This chapter presents hypothesis testing in respect of joint tests of nonlinearity and stationarity associated with the seminal contribution by Kapetanios, Shin and Snell (2003), henceforth denoted KSS. It also presents the results of ADF tests and Bayesian unit root tests at conventional levels.

In addition to non-ESTAR alternative unit root testing, the chapter provides a background description of the Bayesian unit-root testing framework.

4.2   The ESTAR testing framework

In the context of nonlinearities, the testing framework is the smooth transition autoregressive modelling. In particular, we focus on the exponential version of the model, which is often used when the economic agents can have arbitrage opportunities by facing some deviation from the long-run equilibrium. In such a case, the unit root regime becomes an inner regime, and the mean-reverting regime becomes the outer regime.

In this setting, let y_t be real exchange rate time series observed at $t = 1 - p, 1 - (p-1), \dots - 1, 0, 1 \dots T - 1, T$. Denote $\Omega_{t-1} = \{y_{t-1}, y_{t-2}, \dots, y_{1-(p-1)}, y_{1-p}\}$. When time series is stationary we can assume that $E[\varepsilon^2_t \mid \Omega_{t-1}] = \sigma^2$.

Consider the following representation of the exponential STAR model:

$$y_t = a_1 y_{t-1} + a_2 y_{t-1} F(\gamma y_{t-d}) + \varepsilon_t \tag{4.1}$$

where $F(\gamma y_{t-d}) \equiv 1 - \exp(-\gamma y^2_{t-d})$. $\tag{4.2}$

In equation (4.1), y_{t-d} is a transition variable, making this ESTAR model a self-exciting one. The delay parameter d is an integer, which can be fixed or be determined endogenously by means of a supremum LM test in the spirit of Norman (2006a). In equation (4.2), $F(y_{t-d})$ represents the exponential transition function. We note that the extreme values of the transition function are 0 and 1. So, for $F() > 0$ and $F() < 1$, the model exhibits a smooth regime-switching behaviour. The parameter γ determines the smoothness of the transition from one regime to another. We note that as $y_t \to \pm\infty$, then the transition function $F() \to 0$. In addition, as $\gamma \to 0$ or $\gamma \to \infty$, then $F(s_t, \gamma, c) = 0$.

The null hypothesis of a unit root or no long-run equilibrium implies:

$$H_0 : a_1 = 1$$

This leads to an AR(1) model:

$$y_t = a_1 y_{t-1} + \varepsilon_t \tag{4.3}$$

where $a_1 = 1$.

Under the alternative hypothesis, the model becomes

$$y_t = \{a_1 + a_2 y_{t-1}[1 - \exp(-\gamma y^2_{t-d})]\} y_{t-1} + \varepsilon_t \tag{4.4}$$

and

$$H_1 : \gamma > 0.$$

The null hypothesis cannot be tested directly due to the fact that a_2 and γ are not identified under the null hypothesis. This is called the Davies (1987) problem. According to KSS, testing for nonlinearity in the context of possible nonstationarity requires an auxiliary regression of the form:

$$\Delta y_t = \delta y^3_{t-1} + error. \tag{4.5}$$

In the presence of serial correlation, the auxiliary regression takes the form:

$$\Delta y_t = \sum_{j=1}^{p} \varphi_j \Delta y_{t-j} + \delta y^3_{t-1} + error. \tag{4.6}$$

KSS developed a nonlinear ADF t-test, denoted $NLADF - t$, of the form:

$$NLADF - t = \frac{\hat{\delta}}{s.e.(\hat{\delta})}, \tag{4.7}$$

where $\hat{\delta}$ is the estimator of δ in (4.4) or (4.5) and *s.e.* is the standard error of regression. The $NLADF - t$ statistic is accompanied by a nuisance-parameter-free asymptotic distribution of the following form:

$$NLADF \Rightarrow \frac{\{\frac{1}{4}B(1)^4 - \frac{3}{2}\int_0^1 B(r)^2 dr\}}{\sqrt{\int B(r)^6 dr}}$$

(4.8)

where $B(r)$ is the standard Brownian motion defined on $r \in [0,1]$.

In essence, the unit root test is for testing the null hypothesis of non-mean reverting time series against the alternative hypothesis of a globally ergodic nonlinear process.

4.3 **Bayesian unit root testing**

Over and above the ESTAR testing, for comparative purposes we employ Bayesian unit root tests in conjunction with the ADF tests. Bayesian unit root testing was introduced by Zellner and Siow (1980) but was popularised by Koop (1992) and Ahking (1997, 2004), among others. Under the null hypothesis, a times series is an autoregressive model of order p with a linear time trend. In short, hypothesis testing takes the following form:

$$H_1 : y_t = \beta_0 + \sum_{i=1}^p \beta_i y_{t-i} + \beta_{p+1} t + \varepsilon_{1t}$$

(4.9)

$$H_2 : y_t = \beta_0 + \sum_{i=1}^p \beta_i y_{t-i} + \varepsilon_{2t}, \quad \beta_{p+1} = 0$$

$$H_3 : \Delta y_t = \beta_0 + (\sum_{i=2}^p \beta_i)\Delta y_{t-i} - (\sum_{i=3}^p \beta_{p+i})\Delta y_{t-i} - \beta_p \Delta y_{t-(p-1)}) - ... - \beta_p \Delta y_{p-1} + \varepsilon_{3t}$$

$$\sum_{i=1}^p \beta_i = 1, \beta_{p+1} = 0,$$

$$H_4 : \Delta y_t = \beta_0 + (\sum_{i=2}^{p} \beta_i) \Delta y_{t-i} - (\sum_{i=3}^{p} \beta_{p+i}) \Delta y_{t-2} - \beta_p \Delta y_{t-(p-1)} - \ldots - \beta_p \Delta y_{p-1} + \varepsilon_{3t}, \sum_{i=1}^{p} \beta_i = 1,$$

where t denotes a linear deterministic time trend; and ε_{jt}, $j = 2,3,4$ represents a serially uncorrelated error process with zero mean and constant variance. H_1 represents the null model, hypothesising a trend-stationary auto-regressive process of order p. The first alternative against the null, hypothesises a stationary $AR(p)$ process, while the second alternative hypothesises an $AR(p)$ process with a unit root. It is to be noted that H_2 and H_3 are special cases of the null hypothesis, with linear restrictions imposed on the null model. The trend-stationary hypothesis is included because it is the leading alternative to unit-root non-stationarity in macroeconomic time series. According to Ahking (2004) the stationary alternative is included to appraise the extent to which the Bayesian test can distinguish between nonstationary series and a stationary one with a high degree of persistence, as is frequently encountered in time series econometrics.

We compare the four hypotheses, based on both prior and sample information, by calculating the posterior odds ratios:

$$K_{1j} = \frac{[P(H_1)P(H_j)]P(H_1 \mid \tilde{y})}{P(H_j \mid \tilde{y})} \tag{4.10}$$

where $\tilde{y}$ is the sample data; $P(H_1)/P(H_j)$ denotes the prior odds ratio, and $P(H_i \mid \tilde{y})$ is the posterior probability that H_2, H_3 and H_4 were true given the sample data. We note that the posterior odds ratio gives the ratio of the probabilities of the two hypotheses holding given the sample data. On the assumption that all three hypotheses have equal prior probability, then the posterior odds ratio becomes:

$$K_{1j} = \frac{P(H_1 \mid \tilde{y})}{P(H_j \mid \tilde{y})}, j = 2,3,4 . \tag{4.11}$$

According to Ahking (1997), the Zelner-Siow posterior odds ratio is approximated by the following:

$$K_{1j} = \frac{\sqrt{\pi} / \Gamma[(r+1)0.5](0.5v)^{0.5r}}{(1+rF/v)^{(1/v)/2}},$$ (4.12)

where

$\Gamma[.] =$ the Gamma function, which, in mathematics, is an extended factorial function to complex and non-integer numbers;

$T =$ the number of observations;

$v = T - K$ number of observations less the number of linear restrictions;

$k =$ the number of regressors in the null model;

$r =$ the number of linear restrictions to be tested, and

$F =$ the F-statistic for testing the set of linear restrictions.

The following are the particularly relevant values of the gamma function:

$\Gamma[1/2] \approx 1.772$; $\Gamma[1] = 1$; $\Gamma[1,5] \approx 0.886$; $\Gamma[2] = 1$; $\Gamma[5/2] = 1.329$.

The calculated posterior odds ratios are used to compute the posterior probability for each of the four hypotheses. The results of this analysis appear in the next subsection.

4.4   Empirical evidence

SADC dollar-based real exchanges were chosen on the basis of adequate data availability. We used the International Financial Statistics database of the International Monetary Fund. Real exchange rates were derived from the relative form of the purchasing power parity hypothesis, namely:

$$y_t = \ln Y_t = \ln S_t - \ln \overline{P_t} + \ln P_t,$$ (4.13)

where $\ln Y_t$ is the logarithm of a real exchange rate (domestic price of foreign currency) at time t; $\ln \overline{P}_t$ and $\ln P_t$ are the logarithms of foreign and domestic price levels, respectively. The United States consumer price index (CPI) inflation is the all-item CPI inflation and the foreign CPI inflation rates are the general CPI inflation rates of the chosen countries. Sample periods varied according to data availability in respect of CPI inflation and nominal exchange rate series.

4.4.1 The results of Bayesian unit root testing

According to the results appearing in Table 2, nonstationarity hypothesis receives small posterior probability relative to other hypotheses. In this setting, the Bayesian results strongly support the hypothesis that all the real exchange rates are trend-stationary autoregressive processes.

It is necessary to point out that the Bayesian unit root test results are sharply at odds with the ADF results in that the hypothesis of a unit root does not receive significant posterior probability in all cases. Instead the results seem to support the hypothesis of trend-stationarity for all cases. That been said, Ahking (2004) found that that the Bayesian test used in this paper could not distinguish between a trend-stationary autoregressive model from a stationary autoregressive one, especially when the time trend effect was relatively small, and the time series was highly persistent. The latter author found that the bias was in favour of finding a trend-stationary model. Thus, the results should be treated with caution.

Table 2   The results of Bayesian unit root tests

Country	AR(p)	Trend stationary	Stationary	Unit root	Two trends
Angola	1	0.53	0.22	0.03	0.22
Madagascar	2	0.58	0.20	0.03	0.20
Botswana	1	0.62	0.18	0.02	0.18
Malawi	1	0.62	0.18	0.02	0.18
Mauritius	6	0.62	0.18	0.02	0.18
Mozambique	3	0.57	0.20	0.03	0.20
South Africa	6	0.62	0.18	0.02	0.18
Swaziland	5	0.61	0.18	0.02	0.18
Tanzania	2	0.55	0.21	0.03	0.21
Zambia	1	0.62	0.18	0.02	0.18

4.4.2   Results from nonlinear tests of nonstationarity

In the context of nonlinear analysis, we used partial autocorrelation function to determine the optimal lags. This approach is recommended by Granger and Terasvirta (1993) and Terasvirta (1994). The usage of PACF over that of information criteria represents an effort to avoid possible bias when choosing lag length. The delay parameter was fixed at 1. In general, the appropriate choice of the delay parameter is the one associated with the highest test statistic. However, fixing the delay parameter is generally of little consequence since economic intuition would suggest that smaller values of the delay parameter were to be preferred.

We employed an auxiliary regression appearing in (4.5) or (4.6). In this setting, the null and alternative hypotheses are of the form:

$H_0 : \delta = 0$,

$H_1 : \delta < 0$.

Failing to reject the null implies that the real exchange rate should be treated as nonstationary. By contrast, the rejection of the null hypothesis in favour of the alternative implies that the exchange rate is mean-reverting and nonlinear.

KSS provide the simulated asymptotic critical values for the nonlinear unit root tests. For both the nonlinear Dickey-Fuller test and nonlinear ADF tests, the 1, 5 and 10 per cent critical values for the demeaned series are –3.48, -2.93 and –2.66 respectively, whereas for the demeaned and detrended series are, in the same order, –3.93, –3.40 and –3.13.

In the context of linear analysis, our dataset has log-levels of real exchange rates and demeaned series. In the case of non-demeaned data, we apply the ADF test. When testing for unit roots, we allow for a constant but no deterministic time trends in the test regression.

The above being said, the pitfalls of the tests should be noted. As was noted by Hall (1994) and Ng and Perron (1995), the ADF tests suffer from low power when the lag length is too small. In some cases, lag selection alone may be responsible for the difference in rejections rates.

Table 3 summarises key inferences that can be made from the above estimation. The results from KSS nonlinear unit root and linear ADF tests are based on the demeaned series and suggest that the null hypothesis of nonstationarity should be rejected at 1 per cent significance level for 4 real exchange rates (Mauritius, South Africa, Swaziland, and Tanzania) out of 10 country exchange rates under study. This suggests that a linear specification for these countries would be inappropriate. In addition, these real exchange rates are mean-reverting but in a nonlinear fashion.

At 1 per cent significance level, all the series were nonstationary. However at 10 per cent significance level the real exchange rates of 6 countries were stationary: Mozambique, Madagascar, Mauritius, South Africa, Swaziland, and Tanzania were found to be stationary.

Table 3   ADF and Nonlinear ADF test results

	Sample periods	Critical values, ADF (10%)	Linear ADF	Nonlinear ADF
Angola	1995M9-2006M6	-1.62	-0.55	-1.98
Botswana	1990M1-2006M6	-1.62	-1.04	-1.41
Madagascar	1990M1-2003M3	-1.62	-1.05	-2.55
Malawi	1990M12006M6	-1.62	-0.39	-0.50
Mauritius	**1990M1-2006M6**	**-1.62**	**-3.71**	**-6.25**
Mozambique	1993M7-2006M5	-1.62	-2.60	-2.15
South Africa	1990M1-2006M6	-1.62	-2.43	**-6.89**
Swaziland	1990M1-200M6	-1.62	-2.06	**-5.42**
Tanzania	1994M12-2006M6	-1.62	-2.26	**-5.95**
Zambia	1994M1-2006M5	1.61	-1.09	-2.08
NADF Demeaned data significance levels				
10%				-2.66
5%				-2.93
1%				-3.48

4.5   Conclusions

This chapter has sought to present evidence indicating that the PPP puzzle is becoming less of a puzzle. It presented the results of Bayesian unit root tests, ADF test and nonlinear tests of nonstationarity. The Bayesian tests were found to be biased in favour of a trend stationary model in all cases.

It is argued that nonlinear approaches to exchange rate adjustments are likely to provide a firmer basis for inference and stronger support for the PPP in the long-term. This is more so at 1 per cent and 5 per cent significance levels.

The results obtained from the KSS tests suggest that the behaviour of 4 dollar-based real exchange rates should be treated as nonlinear rather than linear. This finding of nonlinear behaviour provides statistical evidence in support of a smooth transition

mean-reverting behaviour in 4 out of 10 real exchange rates. As such, any deviation from the PPP, either over- or under-appreciation of real exchange rates is temporary.

5   Chapter 5: Half-life deviations from PPP in the SADC

5.1   Introduction

This chapter discusses the half-life version of the PPP puzzle. According to the sticky price theories of international macroeconomics, the purchasing power parity (PPP) hypothesis is compatible with half-lives of real exchange rate of less than three years. However, economists are puzzled by the slow rate at which real exchange rates adjust to the PPP (Taylor and Taylor, 2004). This is an issue dealt with at length by Rogoff (1996), who points out that the high short-term volatility of real exchange rates is not compatible with the extremely slow rate at which shocks appear to die off.

Empirical analysis of the persistence of real exchange rate deviations from PPP is generally based on impulse response analysis. In this setting, the concept of a half-life is used to estimate how long it takes for the impulse response to a unit shock to dissipate by one half (Chortareas and Kapetanios, 2004). In this context, consider for instance that PPP holds continuously. This implies that the following relation should remain constant:

$$y_t = \ln\left[\frac{S_t P_t}{P^*_t}\right], \qquad\qquad (5.1)$$

where S_t represents the nominal exchange rate, P_t and P^*_t are the price levels in the domestic and foreign country, respectively. Following Rossi (2005a), suppose that the deviations of the real exchange rate, y_t, from its long-run value y_0 follow a stationary autoregressive order one process such that

$$y_t = \varphi y_{t-1} + \varepsilon_t.\qquad\qquad (5.2)$$

Then the half-life of a process can be defined as the minimum value of H such that

$$E[y_{t+h} - y_0 \mid y_{t-s} - y_0] \le \frac{1}{2}(y_t - y_0),$$ (5.3)

where E is the expectation operator and $s \le 0$. Based on equation (5.2), estimates of H are obtained as follows:

$$\hat{h} = \ln(0.5)/\ln(\hat{\varphi}),$$ (5.4)

where $\hat{\varphi}$ represents the estimate of φ. It is to be noted that for $\hat{\varphi} \ge 1$, the process has no half-life because it approaches infinity.

Kim, Silvapulle and Hyndman (2006) have identified the three main statistical properties of the half-life statistic as calculated using equation (5.4), namely, it has an unknown and possibly intractable distribution; it may not possess finite sample moments since it takes extreme values as the coefficient approaches one; that it is biased in small samples; and that it is a nonlinear function of φ which is also biased downward.

Empirical evidence is generally mixed when it comes to point estimates of half-life deviations. For instance, Parsley and Wei (1996) found that the half-lives for the European Monetary System countries were 4.25 years. Other studies on real exchange rates, such as Frankel (1990), found that the half-life of the dollar-pound real exchange rate was 4.6 years. In addition, Lothian and Taylor (1996) estimated that the corresponding numbers were 2.8 for the franc-pound and 5.9 for the dollar-pound real exchange rate.

In the context of panel data analysis, the evidence on point estimates is also mixed. Frankel and Rose (1995) found that for 150 countries the half-life averaged 4 years. Moreover, Cheung and Lai (2000) estimated that the half-lives ranged between 2 and 5 years for industrial countries but under 3 years for developing economies. A study by Manzur (1990) assessing seven industrial countries found that the half-lives of their real exchange rates were 5 years, while Fung and Lo (1992) put the half-lives at 6.5 years for the sample of six industrial countries they consider.

The main contribution of this chapter is that it follows Rossi's (2005a) to generate point estimates and confidence intervals for the SADC in which deviations from PPP are in some cases compatible with nominal price and wage stickiness. To the author's knowledge, no published article has ever produced these half-life confidence intervals for the SADC countries. The motivation for using Rossi's methodology is that she uses local-to-unity asymptotic theory in the presence, in most cases, of highly persistent data. As it is commonly observed, real exchange rates manifest themselves as processes with roots near-unity. This characteristic makes them provide no good small-sample approximation to the distribution of estimators and test statistics. In such cases econometricians use an alternative approach by modelling the dominant root of the autoregressive lag order polynomial as local-to-unity (Diebold, Killian, and Nerlove, 2008). This approach leads to an alternative asymptotic approximation that provides a better small-sample approximation than imposing the order of integration.

The second reason for following Rossi (2005a) is that she derives a measure of the half-life for a general $AR(p)$ process that allows for better asymptotic approximations in the presence of a root close to unity.

The rest of the chapter is organised as follows: section 5.2 discusses Rossi (2005a) approach to measuring half-life deviations. Section 5.3 covers econometric issues and empirical evidence. Section 5.4 concludes.

5.2 Rossi (2005a) methodology for general $AR(p)$ processes

The approach followed is based on the factorization of the data generating process (DGP) of the following form:

$$y_t = d_t + u_t \qquad t = 1,2,..,T \tag{5.5}$$

$$u_t = \rho u_{t-1} + v_t \tag{5.6}$$

$$\rho = e^{c/T} \approx 1 + c/T \tag{5.7}$$

where d_t is a deterministic component, v_t is a zero mean, stationary and ergodic process, with finite autocovariances. Equation (5.7) represents local-to-unity asymptotics in the spirit of Stock (1991). The factorisation process produces:

$$(1-\lambda_1 L)(1-\lambda_2 L)...(1-\lambda_p L)(y_t - d_t) = \varepsilon_t$$

where λ_j are eigenvalues of an $AR(p)$ process. The half-life statistic for an $AR(p)$ process has been suggested by Rossi (2005a) and takes the following form:

$$\hat{h} = Max\left\{\frac{\ln(0.5)b(1)}{\ln(\hat{\varphi})},0\right\},$$

(5.8)

where $b(1) = (1-\lambda_2)(1-\lambda_3)...(1-\lambda_p)$ is the correction factor of an $AR(p)$ process, whereby p denotes the number of lags. Rossi(2005a) treats a unit root process as having an infinite half-life. The author points out that the data generating process (5.5), can be rearranged to generate the following ADF regression:

$$y_t = \tilde{\mu}^o + \alpha(1)y_{t-1} + \sum_{j=1}^{p-1}\alpha^*_{j-1}\Delta y_{t-j} + \varepsilon_t$$

(5.9)

where $\alpha(1) = 1 + \dfrac{c}{T}b(1)$, $\tilde{\mu}_0 = -\dfrac{c}{T}\mu_0 b(1)$, $\alpha^*_j = -\sum_{i=j+1}^{p-1}\alpha_j$ (5.10)

The half-life associated with the above regression is of the form:

$$H_a = max\left\{\frac{\ln(0.5)}{\ln\alpha(1)},0\right\}$$

(5.11)

A conventional 95 per cent confidence interval associated with the above half-life statistic is of the following form:

$$\hat{H}_a \pm 1.96\hat{\sigma}_{\hat{\alpha}(1)}\left[\frac{\ln(0.5)}{\hat{\alpha}(1)}[\ln(\hat{\alpha}(1))]^{-2}\right].$$

(5.12)

To construct confidence intervals, this chapter follows Rossi (2005a) by relying on Stock (1991), Elliott and Stock (2001), and Hansen (1999). The details of the strengths and weaknesses of these methods have been discussed at length by Rossi (2005a). At this point it is worth pointing out that when the data are highly persistent, a bootstrap method that is valid is Hansen's (1999) grid-α bootstrap method, which has the range-preserving property. This method is supposed to ensure that the calculated half-life is nonnegative. In the latter context, negative half-lives are treated as invalid and cannot be interpreted meaningfully.

The biggest pitfall associated with the calculation of half-lives using Elliot and Stock (2001) and Stock (1999) is that the confidence intervals for half-lives are too wide and their upper bounds can approach infinity. The excessively wide confidence intervals are associated with a high degree of uncertainty in the magnitudes of point estimates. Thus, deviations from the parity condition may represent the absence of mean-reversion, calling to question the empirical validity of the PPP hypothesis in the case in point.

5.3   **Empirical results**

Table 4 presents the results of confidence intervals using standard asymptotic theory. MAIC was used to determine the lag length based on the demeaned data. According to the results, half-lives of less than 36 months would be compatible with the PPP hypothesis. Due to their lower power as discussed in chapter 4, the ADF and ADF-GLS results cannot be interpreted with high degree of confidence. It is better not to focus too much on them. According to the results appearing on Table 4, point estimates of half life deviations less than 36 months depend on the method used. Such cases include all countries except Tanzania, Zambia, and Malawi.

Table 5 presents the empirical results based on Stock (1991) approach. The main weakness of the approach is that is does not guarantee non-negative half lives. So, the Stock (1991) method can be seen as not reliable in respect of confidence intervals. It is noteworthy, however, that the median unbiased point estimates appear quite reasonable in the context of PPP.

In Table 5 the results associated with Mauritius results remain incomplete and those of Tanzania are invalid, while those associated with Zambia and Malawi have infinite half-lives. The reason for these problems is that the exchange rates of those countries may not be compatible with local-to-unity asymptotic theory used.

It is seen from table 6 that Hansen's method is supposed to guarantee non-negative numbers. However, Tanzania is a serious problem. The Tanzania results are invalid owing to the negative numbers. The large numbers associated with Zambia under the Elliot and Stock (2001) method should be treated as infinity.

Taken together, the current approaches used in this analysis are not informative in terms of confidence intervals. However, point estimates in the case of Hansen's method may be biased.

Table 4   Confidence intervals based on standard asymtotics and ADF tests

Countries	$\hat{\alpha}(1)$	ADF	ADF-GLS	$\hat{h}_a$	$\left(\hat{h}_a{}^l, \hat{h}^u{}_a\right)$	$\hat{h}^*{}_a$	$\hat{\gamma}$
Angola	0.972	-2.37	-0.53	24.10	3.84; 44.30	24.10	0.10
Botswana	0.961	-2.29	-1.18	17.40	2.18; 32.60	16.20	0.06
Madagascar	0.966	-1.99	-1.16	20.20	0;40.40	18.10	0.01
Malawi	0.991	-0.79	0.01	81.00	0; 284.00	86.00	0.00
Mauritius	0.861	-3.95	-2.61	4.63	1.99; 7.30	4.91	0.20
Mozambique	0.949	-2.13	-0.48	13.30	0.76; 25.90	14.10	0.20
SA	0.964	-1.72	-0.68	19.00	0; 41.10	20.10	0.10
Swaziland	0.882	-2.73	-2.13	5.51	1.29; 9.73	4.66	0.01
Tanzania	0.96	-1.40	0.53	16.90	0, 40.90	-28.80	-0.30
Zambia	0.99	-1.29	1.51	70.50	0, 178.00	70.50	0.03

Note: For each bilateral real exchange rate the chapter reports the estimated test statistic of the demeaned ADF regression, the estimated coefficient of the lagged regressor $\hat{\alpha}(1)$ as defined in (5.9) and the DF-GLS test proposed by Elliott, Rothemberg and Stock, 1996 (ADF-GLS). The lag lengths are selected by the modified AIC criterion based on the OLS and on the GLS detrending methods proposed by Ng and Perron (2001).

Table 5   Confidence intervals based on Stock (1991)

Countries	$\hat{c}_l ; \hat{c}_u$	$c_l^{0.05}$	$h^a_{0.05}$	h^a_{median}	$\hat{b}(1)$	$h^*_{0.05}$	h^*_{median}
Angola	-19.0; 2.62	4.79	5.29	11.43	1.00	4.7	5.29
Botswana	-18.0; 2.77	19.02	21.07	47.75	0.4	17.69	19.60
Madagascar	-14.5; 3.31	20.71	23.35	70.74	0.37	18.59	20.96
Malawi	-4.15; 4.62	45.89	67.26	∞	0.72	48.71	71.38
Mauritius	*	*	*	*	*	*	*
Mozambique	-16.10;3.02	8.25	9.21	23.48	0.81	8.71	9.72
South Africa	-11.6 ;3.78	15.05	17.25	128.83	0.79	15.94	18.26
Swaziland	-23.8;1.64	4.47	4.86	9.04	1.25	3.77	4.11
Tanzania	-8.53;4.18	3.79	4.49	∞	2.98	6.49	-7.68
Zambia	-7.65;4.28	17.86	21.61	∞	0.99	17.87	21.62

Note. As in the previous Table, for each real exchange rate we ran a demeaned ADF regression. The two-sided and one-sided median unbiased confidence intervals for c, denoted respectively by $(\hat{c}_l ; \hat{c}_u)$ and $\hat{c}_{0.05}$ were obtained as discussed in Rossi (2005a, Table 3). We report one-sided lower bounds for the median unbiased confidence intervals for the half-life (h) with 95 per cent coverage. Upper bounds were infinity for all currencies. h_{median} is the median unbiased estimate of the half-life (based on the median unbiased estimate of c).

Table 6   Confidence intervals based on Elliot and Stock (2001) and Hansen (1999)

Countries	Elliot and Stock (2001)		Hansen (1999)	
	$h^a_{0.05}$	$h^*_{0.05}$	$h^a_{0.05}$	$h^*_{0.05}$
Angola	89.45	68.28	6.07	6.79
Botswana	42	17.54	6.44	7.19
Madagascar	46.44	31.8	5.45	6.09
Malawi	117.01	94.79	6.45	7.2
Mauritius	1.53	1.16	6.44	7.2
Mozambique	22.31	17.2	6.42	7.17
South Africa	34.39	19.14	6.43	6.61
Swaziland	4.25	2.74	6.43	5.74
Tanzania	95.04	-124.14	-10.4	-11.61
Zambia	2092.56	1598.29	6.43	6.79

Note: We report the one-sided confidence intervals for the alternative half-lives (as described in Table 4) with 95 per cent coverage. Upper bounds are not reported because they diverted to infinity.

5.4   **Conclusions**

The objective of this chapter has been to utilise various methods to obtain better approximations to the half-life for highly persistent processes in the presence of small samples and to generate confidence intervals for half-life deviations from PPP. The robust methods of Stock (1991), Elliott and Stock (2001), and Hansen (1999) imply that point estimates of less than 36 months exist, making them compatible with PPP. Specifically, the Elliot and Stock (2001) approach point to Mauritius, Mozambique, South Africa, and Swaziland as the main examples. However, the results of ADF and ADF-GLS tests render the SADC real exchange rates as nonstationary processes, a result that is patently at odds with mean-reversion, implying at the same time the possibility of infinite half-lives. Therefore the empirical results appearing in this chapter do not convincingly resolve the half-life puzzle of the PPP hypothesis. It has been pointed out by Kim, Silvapulle and Hyndman (2006) that the half-life statistic has an unknown and possibly intractable distribution and that it may not possess finite sample moments since it takes extreme values as the coefficient $\hat{\rho}$ approaches one. Another implausible characteristic is that the half-life statistic it is biased in small samples. Moreover, the authors indicated that a tiny estimation error in $\hat{\rho}$ could result in extreme variability of $\hat{h}$, which makes it uncertain and unreliable.

When the results of this chapter are compared with those appearing in chapter 4, in which PPP was found to hold in some countries, one is inclined to believe that a different and improved framework with regard to the calculation of half-lives is necessary to achieve consistent results that include tighter confidence intervals. For future research, the most promising approach seems to be in the spirit of Kim, Silvapulle, and Hyndman (2006). They authors propose a non-parametric method for point and interval estimation of half-life. This method relies on the use of the bias-corrected bootstrap to approximate the sampling distribution of the half-life. It estimates the kernel density of the above bootstrap distribution, by adopting the transformed kernel density method and the data-based bandwidth selection method. It uses the highest density region method for point and interval estimation of half-life.

Besides the latter work, recently Pesavento and Rossi (2005) have developed a method that provides median unbiased confidence intervals with accurate coverage properties regardless of whether the root is unity or close to unity.

The results of this chapter should be taken as suggestive and not definite, because of the problems mentioned above.

6 Chapter 6: Tests of long memory regarding the PPP puzzle

6.1 Introduction

This chapter employs "a class test for fractional integration" associated with the seminal contribution of Hinich and Chong (2007) to appraise the possibility that Southern African Development Community (SADC) country real exchange rates can be treated as long memory processes. The justification for considering fractional integration arises from the general failure to reject the unit-root hypothesis in real exchange rates when standard Dickey-Fuller unit-root tests are used. In allowing for only integer orders of integration in the series dynamics, the linear tests of nonstationarity were found by authors such as Diebold and Rudebusch (1991) to have low power against fractional alternatives.

The concept of long memory is gaining popularity in econometrics, because econometricians wish to ensure that a stationary process is not mistaken for a non-stationary or a fractionally integrated process. The introduction of the concept of long memory in time series econometrics is associated with the seminal work on fractional integration by Granger and Joyeux (1980) who, according to Smallwood (2005: 4), observed that "the spectral density function of the differenced process appeared to be overdifferenced, while the level of the series exhibited long-run dependence that was inconsistent with stationary ARMA dynamics". In short, Granger and Joyeux (1980) developed the concept of long memory or fractional integration to fill the gap between a covariance stationary process and a linear autoregressive moving average (ARMA) process. The model of fractionally integrated time series allows for a fractional exponent in the differencing process of the time series, thereby avoiding the unit-root distinction while admitting persistence, or long memory, which characterises many macroeconomic time series. Some major works on fractional integration in the behaviour of exchange rates include Cheung (1993), Baillie (1996), Kapetanios and Shin (2003), Baillie and Kapetanios (2004), Robinson (2003), and Smallwood (2005). A more general approach to long-range dependence is associated with Guégan (2005).

The rest of the paper is organised as follows: Section 2 describes the concept of long memory. Section 3 describes the Hinich-Chong testing methodology used. Section 4 presents the results of the testing algorithm and Section 5 concludes.

6.2   Concept of fractional integration

According to the definition in Baillie (1996), a time series process y_t with autocorrelations ρ_k possesses a long memory if:

$$\lim_{n \to \infty} \sum_{k=-n}^{n} |\rho_k| \to \infty .$$ (6.1)

In addition, a process is integrated of order d, denoted $I(d)$, if

$$(1-L)^d y_t = u_t ,$$ (6.2)

where u_t is ergodic and stationary when $-0.5 < d < 0.5$. It is noted that when u_t is $I(0)$ the process is covariance stationary. In addition, the series y_t has an invertible moving average representation when $d > -0.5$. When $d > 0$, y_t has long memory, and the autocovariances of y_t are not absolutely summable.

The autoregressive fractionally integrated moving average representation for a time series process y_t can be written as:

$$\varphi(L)(1-L)^d (y_t - \mu) = \theta(L)\varepsilon_t$$ (6.3)

where the characteristic polynomials $\varphi(z) = 0$ and $\theta(z) = 0$ have all their roots outside the unit circle. In this setting, $\{\varepsilon_t\}$ is a martingale difference sequence, d is a real number, and $(1-L)^d$ is the generalised factorial function of the form

$$(1-L)^d = \sum_{k=0}^{\infty} \Gamma(k-d)\{\Gamma(-d)\Gamma(k+1)\}^{-1} L^k$$

where $\Gamma(k-d) = \{(k-d-1)(k-d-2)...(2-d)(1-d)(-d)\}\Gamma(-d)$ (6.4)

According to Baillie (1996), the Wold representation of a fractional white noise process is given by the following equivalent relations:

$$y_t = \sum_{k=0}^{\infty} w_k \varepsilon_{t-k} \tag{6.5}$$

$$y_t = (1-L)^{-d} \varepsilon_t \tag{6.6}$$

$$y_t = \{1 + dL + d(d+1)L^2/2! + d(d+1)(d+2)L^3/3! + ...\}\varepsilon_t \tag{6.7}$$

The autocorrelation function of the process appearing in equation (6.3) decays at a hyperbolic rate. In the frequency domain, the spectral density function of y_t, denoted $f_y(\lambda)$, is of the following form:

$$f_y(\lambda) = \frac{\sigma^2}{2\pi}(2\sin \lambda/2)^{-2d}\frac{|\theta(e^{i\lambda})|^2}{|\phi(e^{i\lambda})|^2} \tag{6.8}$$

where λ is the frequency. In the context of long-range dependence, the spectral density approaches infinity as frequency approaches zero.

It should be pointed out that there are several concepts of long memory in the frequency domain and time domain. For instance, Guégan (2005) discusses several concepts, one of which is Parzen's (1981) concept of long memory. In this setting, Guégan (2005) shows that there are processes that are long memory in the covariance sense but may not be so in a spectral density sense. In addition, he shows that there are processes that are long memory in both the covariance sense and spectral density sense. Furthermore, there are processes that are long memory only in the spectral density sense.

While generally useful in economics and finance, the concept of fractional long memory is not without controversy. For instance, Ashley and Patterson (2007) argue that long memory is "an artefact of unmodelled nonlinear serial dependence and/or structural shifts in the generating mechanisms for these time series." Other works that espouse similar views include Granger and Hyung (1999), and Diebold and Inoue (2000). Guégan (2005) points out that there is a possibility that long memory may be confused with structural change. Furthermore, Charfeddine and Guégan (2007) point out that observing a long memory in a specific data set does not necessarily mean that the data generating mechanism is a long memory process. It is for the latter reason that we employ the Hinich-Chong test for fractional integration to avoid spurious long memory.

As far as the testing strategy is concerned, the Hinich and Chong (2007) methodology is followed to test for long memory using what the authors call "a class test of fractional integration", a test that is able to distinguish fractionally integrated processes from other time series processes. In this context, the null hypothesis is that $\{y_t\}$ is a long memory process, while the alternative is that $\{y_t\}$ does not follow an $I(d)$ process, where $-0.5 < d < 0.5$.

In the context of long memory and the purchasing power parity (PPP) puzzle as discussed by Rogoff (1996), an interesting question is whether deviations from the PPP are transitory or permanent. Thus, the empirical tests generally take the form of testing for stationarity of the real exchange rate. If deviations from PPP are transitory, the time series of the real exchange rate is a stationary series, meaning it is $I(0 < d < 0.5)$. By contrast, if deviations from PPP are permanent, then the time series of the real exchange rate is nonstationary, which implies that the process is $I(d \geq 1)$. It should be noted that for $I(0.5 < d < 1)$ the process is mean-reverting, even though it is not covariance stationary, as there is no long-run impact of innovations on future values of the process.

6.3   Testing methodology

The development of the Hinich-Chong fractional integration test begins by supposing a regression of y_t on $y_{t-1}, y_{t-2}, ..., y_{t-n}$. In this context, the following is considered:

$$Y = \begin{pmatrix} y_1 \\ y_2 \\ \vdots \\ y_T \end{pmatrix}' \text{ and } Z_n = \begin{pmatrix} 0 & 0 & \cdots & 0 & 0 \\ y_1 & 0 & \cdots & 0 & 0 \\ y_2 & y_1 & \cdots & 0 & 0 \\ \vdots & y_2 & & & 0 \\ \vdots & \vdots & & & 0 \\ \vdots & \vdots & & y_1 & \\ \vdots & \vdots & & \vdots & \\ y_{T-1} & Y_{T-2} & \cdots & y_{T-n} \end{pmatrix} \tag{6.9}$$

$$\hat{\beta}(n) = (Z_n'Z_n)^{-1}Z_n'Y = (\hat{\beta}_{n1}, \hat{\beta}_{n2} \cdots \hat{\beta}_{nn-1}, \hat{\beta}_{nn})' \tag{6.10}$$

According to the authors, a long memory process has a unique feature in the sense that if it is approximated by an $AR(n)$ model via a regression, then the probability limits of the autoregressive coefficient estimates are functions of d and n. It follows that if $T \to \infty$, then

$$\beta_{n,j} \xrightarrow{\ \ p\ \ } -\binom{n}{j} \frac{\Gamma(j-d)\Gamma(n-d-j+1)}{\Gamma(-d)\Gamma(n-d+1)} \tag{6.11}$$

where $\xrightarrow{\ \ p\ \ }$ represents convergence in probability and $\Gamma(d)$ is the Euler gamma function.

It is indicated that the estimated coefficients of y_{t-1} and y_{t-n} converge in probability to $nd(n-d)^{-1}$ and $d(n-d)^{-1}$, respectively, making it likely that the first estimate will be about n times the previous one. Therefore, to test whether the process follows an $I(d)$ process, a researcher can construct a test based on the relationship $\beta_{n,n}$ and $\beta_{n,1}$, such that

$$n\hat{\beta}_{n,n} - \hat{\beta}_{n,1} \xrightarrow{p} 0$$

The authors recommend that autoregressions $AR(2), AR(3),..., AR(n)$ be run to generate a test statistic of the form

$$W(d,n) = [B(n,1) - B(n,n)]\Lambda(n)\Omega(d)^{-1}[B(n,1) - B(n,n)]\Lambda(n)' \qquad (6.12)$$

where $B(n,1) = (\hat{\beta}_{2,1} \quad \hat{\beta}_{3,1} \cdots \hat{\beta}_{n,1})$

$\qquad B(n,n) = (\hat{\beta}_{22} \quad \hat{\beta}_{3,3} \cdots \hat{\beta}_{n,n})$

$\qquad \Lambda(n) = diag(2 \quad 3 \cdots n)$ and

$\qquad \Omega(d) = E[(B(n,1) - B(n,n)\Lambda(n)'(B(n,1) - B(n,n)\Lambda(n)]$

Theorem 1 of Hinich and Chong (2007) establishes that

$$W(\hat{d},n) \xrightarrow{l} \chi^2(n-1) \qquad (6.13)$$

where $\xrightarrow{l}$ represents weak convergence in distribution. To select a robust and consistent estimate $\hat{d}$, the authors recommend that a median of the following be taken:

$$\hat{d}_{j,1} = \frac{j\hat{\beta}_{j,1}}{j + \hat{\beta}_{j,1}} \qquad (6.14)$$

$$\hat{d}_{j,j} = \frac{j\hat{\beta}_{j,j}}{j + \hat{\beta}_{j,j}} \qquad (6.15)$$

whereby for $j = 1,2,3,...,n$, $\hat{d}_{j,1}, \hat{d}_{j,j}$ are arranged in an ascending order. In this setting, $\hat{\beta}_{jj}$ estimates the jth order partial autocorrelation of a fractionally integrated process.

A Monte Carlo experiment regarding the power and size of the Hinich-Chong test established that for non-fractional alternatives, the null hypothesis that a process is an $I(d)$ process was easily rejected. In addition, Hinich and Chong undertook 10 000

replications to assess the rejection rates of the test:

$$\Pr\left(W(d,n) > \chi^2_{\alpha=5\%}(n-1)\right) \text{ for } T = 50,100,200 \; ; \; n = 2,3,4,5,6,7.$$

They found that for the fractional alternatives, the size of the test was, for large T, between 0.039 and 0.060. Also, for non-fractional alternatives, the null hypothesis is eventually rejected as the sample size increases.

6.4   Results

This section utilises data from the International Monetary Fund's International Financial Statistics database to test for dollar-based long memory in respect of the SADC countries. The real exchange rate is defined as

$$y_t = \ln Y_t = \ln S_t - \ln \overline{P}_t + \ln P_t \tag{6.16}$$

where $\ln Y_t$ is the logarithm of a real exchange rate (domestic price of foreign currency) at time t; $\ln \overline{P}_t$ and $\ln P_t$ are the logarithms of foreign and domestic price levels, respectively. We demeaned y_t. The sample period for each country appears in table 7.

The null and alternative hypotheses are formulated as follows:

$$H_0 : \quad y_t \sim I(d)$$

$$H_1 : \quad y_t \; does \; not \; follow \; I(d)$$

for $-0.5 < d < 0.25$. Footnote one of the Hinich and Chong paper indicates that the authors allowed $-0.5 < d < 0.5$ in the estimation of the differencing parameter, but for $d > 0.25$ they point out that "the distribution of $W(d,n)$ will no longer be Chi-squared but something related to the Rosenblatt distribution as found in Hosking (1996)."

Table 7   Sample periods

	Sample periods
Angola	1995M9-2006M6
Botswana	1990M1-2006M6
Madagascar	1990M1-2003M3
Malawi	1990M12006M6
Mauritius	1990M1-2006M6
Mozambique	1993M7-2006M5
South Africa	1990M1-2006M6
Swaziland	1990M1-2005M12
Tanzania	1994M12-2006M6
Zambia	1990M1-2006M5

In Table 8 the estimated values of d are reported in parentheses and the calculated values of the $W(\hat{d},n)$ statistic are also reported. In the same table (*) and (**) represent significance levels at 1 per cent and 5 per cent, respectively. In most cases the estimated value of d is not affected by the choice of n. However, there are some negative values of the estimated differencing parameter, implying that real exchange rates are not long memory processes. The negative values represent antipersistence and as observed by Hualde and Velasco (2006), are empirically unappealing. The negative values are associated with the following countries: Madagascar, Malawi, Swaziland, and Tanzania. Other results are as follows: At the 1-per-cent and 5-per-cent significance levels the real exchange rates associated with Mauritius and South Africa are not fractionally integrated. For $n \geq 6$ Mozambique was found not be fractionally integrated. The currencies of Angola and Botswana, and Zambia were found to be fractionally integrated.

Table 8 $W(\hat{d},n)$ **based on the demeaned SADC real exchange rates**

	T	$W(\hat{d},2)$	$W(\hat{d},3)$	$W(\hat{d},4)$	$W(\hat{d},5)$	$W(\hat{d},6)$	$W(\hat{d},7)$
Angola	130	1.79 (0.13)	1.84 (0.13)	2.45 (0.13)	2.74 (0.13)	3.23 (0.14)	4.18 (0.15)
Botswana	198	2.94 (0.03)	3.32 (0.03)	3.35 (0.03)	3.72 (0.03)	3.81 (0.03)	3.83 0.03
Madagascar	159	0.36 (-0.02)	4.92 (-0.02)	5.37 (-0.02)	5.40 (-0.02)	4.50 (-0.02)	6.25 (-0.01)
Malawi	198	0.01 (-0.01)	0.62 (-0.01)	3.74 (-0.01)	4.38 (-0.01)	5.23 (-0.01)	6.00 (-0.01)
Mauritius	198	0.36 (0.14)	15.77* (0.14)	24.52* (0.13)	25.83* (0.13)	30.30* (0.13)	30.32* (0.13)
Mozambique	155	0.84 (0.16)	5.63 (0.16)	6.37 (0.16)	6.77 (0.16)	12.53* (0.16)	12.64* (0.17)
South Africa	198	4.77** (0.09)	5.14 (0.1)	10.08** (0.1)	11.57** (0.1)	13.43** (0.1)	14.72** (0.09)
Swaziland	192	18.99* (-0.05)	19.36* (-0.05)	25.67* (-0.05)	25.89* (-0.06)	26.84* (-0.07)	27.38* (-0.08)
Tanzania	139	1.13 (-0.46)	1.91 (-0.46)	2.56 (-0.45)	4.87 (-0.45)	5.88 (-0.44)	6.12 (-0.45)
Zambia	197	1.18 (0.03)	1.19 (0.03)	1.20 (0.03)	1.34 (0.03)	2.06 (0.03)	6.44 (0.03)
$\chi^2_{n-1,1\%}$		6.63	9.21	11.34	13.28	15.09	16.81
$\chi^2_{n-1,5\%}$		3.84	5.99	7.81	9.49	11.1	12.60

Note: The numbers in parentheses are the estimated values of d. The sample periods appear in Table 7.

A caveat regarding possible pitfalls of the above results is in order: In some studies, Angola's currency has been found to be nonstationary, which is likely to be the case, given its long history of war and high inflation. The real exchange rates of South Africa's and Swaziland's currencies were recently found by Mokoena (2007) to be nonlinear but ergodic. It is therefore likely that they are not long memory processes.

In chapter 4 we saw that Mauritius, South Africa, Swaziland, and Tanzania were mean-reverting in a nonlinear way. In the current chapter, Mauritius, Mozambique, South Africa and Swaziland have been reported as not having long memory. Mozambique is neither a stationary case nor a long memory. We must conclude that it is nonstationary.

6.5   **Conclusions**

This chapter sought to determine whether the SADC real exchange rates were generated by a long memory mechanism. A class test of fractional integration developed by Hinich and Chong (2007) was used. Antipersistence – an unappealing empirical result – was associated with Madagascar, Malawi, Swaziland, and Tanzania. At the 5 per cent significance level, the null hypothesis could not be rejected that the real exchange rate associated with Angola, Botswana, and Zambia were $I(d)$ processes. In the case of Mozambique the null hypothesis could be rejected when n was either 6 or 7. In addition, at the 5 per cent significance level, the real exchange rates associated with Mauritius, Swaziland and South Africa were found not to be fractionally integrated.

7 Chapter 7: Microstructure approach to the determination puzzle

7.1 Introduction

The market microstructure approach has been applied to the three major puzzles of exchange rate economics: the forward bias puzzle, the excess volatility puzzle, and the exchange rate determination puzzle. The details of how the microstructure approach addresses the first two puzzles mentioned above are found in Chapter 7 of Lyons (2001). In this chapter we focus on the market microstructure approach to the exchange rate determination puzzle. Later the chapter presents estimation results.

As pointed out in the previous chapter, Meese and Rogoff (1983) found that the out-of-sample performance of fundamentals-based monetary models have been unable to outperform a random walk model. This finding has remained largely robust ever since. In a survey, Frankel and Rose (1995) concluded that no model based on standard fundamentals like money supplies, real income, interest rates, inflation rates, and current account balances would succeed in explaining or predicting a high percentage of the variation in the exchange rate in the short- or medium-term frequencies. Moreover, Evans and Lyons (1999) have pointed out that the main weaknesses of the fundamentals-based models are that these models assume that all information relevant for exchange rate determination is common knowledge and that the transmission from that information to equilibrium prices is also common knowledge. The poor explanatory power of macro-based models, coupled with the empirical evidence that micro-structural aspects of the functioning of financial markets are a significant consideration in explaining short-term movements, have swayed the attention of economists toward what has been termed "order flow" in foreign exchange markets. In point of fact, order flow constitutes the mainstay of the market microstructure approach to the exchange rate puzzles. Order flow, as defined by Vitale (2006) is the difference between buyer-initiated and seller-initiated orders in a securities market.

The market microstructure approach has gained popularity because it recognises that, in the short run, the news associated with macroeconomic variables has an impact on the exchange rates. In different words, the arrival of news condition market expectations of future values of the exchange rate fundamentals, leading to immediate reactions by the markets in anticipation of the shifts in the fundamentals. In this context, the market microstructure approach claims that the imbalances between 'buyer-initiated and seller-initiated trades' in foreign exchange markets are indicative of the transmission link between exchange rates and fundamental determinants of exchange rates (Vitale, 2006).

To reinforce the usefulness of the microstructure approach, Love and Payne (2002) utilise 10 months of transaction-level exchange rate data on the dollar-euro, pound-euro and dollar-pound exchange rates and data on euro-area to test whether announcement surprises have a systematic and significant effect on both the order flow and prices. They find that, at a 1 minute sampling frequency, macroeconomic data releases have systematic effects on order flow and on exchange rate transaction prices. Their results show that the release of positive news tend to lead to exchange rate appreciation and that order flow tends to be positive, reflecting excessive buying pressure relative to aggressive selling. Furthermore, Love and Payne (2002) show that in periods just after macroeconomic announcements, the significance of order flow in exchange rate determination is much greater than in normal times. The results suggest that between 50 and 66 per cent of the final price reaction to news comes via this order flow mechanism.

With regard to the relationship between macro-based models and microstructure approaches, the authors conclude as follows:

Within the context of exchange rate determination our results suggest that the recent distinctions drawn between macroeconomic and microstructure models are not clear cut; the modelling of exchange rates should incorporate both elements of macro and microstructure. Further effort needs to be expended on theoretical and empirical work to merge the two sides of exchange rate determination in an attempt to more accurately explain how exchange rates are determined (Love and Payne, 2002: 2-3).

Another relevant study supportive of the microstructure approach is Danielsson, Payne and Luo (2002), which assesses the forecasting ability of the order flows in forecasting exchange rates. The authors use the Meese and Rogoff (1983) framework to establish whether the order flow model yields a better forecast in mean square error terms than does a random walk model. The authors find that the order flow model passes the Meese–Rogoff test that macroeconomic models have failed.

The above analysis suggests that, while microstructure approach represents a clear paradigm shift, it cannot substitute the fundamentals-based monetary models. In fact, Evans and Lyons, who are at the vanguard of the microstructure frontier, have emphatically clarified this point:

Note that order flow being a proximate determinant of exchange rates does not preclude macro fundamentals from being the underlying determinant. Macro fundamentals in exchange rate equations may be so imprecisely measured that order-flow provides a better "proxy" of their variation. This interpretation of order flow as a proxy for macro fundamentals is particularly plausible with respect to expectations: standard empirical measures of expected future fundamentals are obviously imprecise. Orders, on the other hand, reflect a willingness to back one's beliefs with real money (unlike survey-based measures of expectations). Measuring order flow under this interpretation is akin to counting the backed-by-money expectational votes (Evans and Lyons, 1999: 5).

7.2   **The basic model**

This brings us to the methodological issues pertaining to microstructure modelling. Evans (2001) develops a hybrid model that combines micro and macro fundamentals:

$$\Delta S_t = f(i, m, o) + g(X, I, Z)$$
(7.1)

where the function $f(i,m,o)$ denotes the macro component of the model and $g(X,I,Z)$ is the microstructure component, and ΔS_t represents the change in the exchange rate. The main variables in the function $f(i,m,o)$ include current and past values of home and foreign nominal interest rates, money supply m, and other macro determinants o. In the function $g(X,I,Z)$ there is the order flow X, a measure of dealer net positions I, and other micro determinants, denoted by Z. Lyons (2001) notes that $f(i,m,o)$ and $g(X,I,Z)$ depends on current and past values of their determinants as well as on expectations of determinants' future values, suggesting that rational markets are forward looking.

When they use the hybrid model, the authors report that their model explains more than 60 per cent of the daily changes in the log of the exchange rate between the Deutschemark and the US dollar and more than 40 per cent of the daily variations of the log of the exchange rate between the Yen and the US dollar. They also argue that their analysis bridges the gap between previous work on market microstructure, which utilises data transaction by transaction, and the macroeconomic studies utilising monthly data.

An apposite question facing the microstructure approach is whether causality runs strictly from order flow to the exchange rate, rather than running in both directions. According to Lyons (2001), causality runs strictly from order flow to price. This observation is based on the study by Killieen, Lyons, and Moore (2004), in which the authors test this by estimating the error-correction term in both the exchange rate and order flow equations. They find that the error-correction term to be significant in the exchange rate equation, whereas the error-correction term in the order flow equation was found to be insignificant, implying that the adjustment to long-run equilibrium occurred via the exchange rate. The appropriate conclusion is that order flow is weakly exogenous, meaning it must appear on the right hand side of an exchange rate model, if nothing else.

7.3   **Hybrid regression models**

This chapter tests empirically the variant of Lyons (2001) model in the South African foreign exchange market context. We wish to test this model for the exchange rate between the South African rand and the US dollar. In particular, we wish to test a country-risk-augmented and commodity-price index-augmented specification that might add explanatory power to the original model.

Our basic test regression takes the following form:

$$\Delta s_t = a_1 \Delta(i - i^*)_t + a_2 \Delta x_t + e_t \tag{7.2}$$

where Δs_t is the log of exchange rate change, $\Delta(i - i^*)$ denotes changes in interest rate differentials, a_1 and a_2 are regression parameters, Δx is the order flow, and the subscript t refers to time. From the stand point of the sticky price model, the coefficient a_1 is expected to be negative, because an increase in the foreign interest rate i^* requires an immediate increase in the exchange rate to compensate for the depreciation caused by the uncovered interest parity. The coefficient a_2 is also expected to have a negative sign, indicating that net purchases of the foreign currency result in a higher price of the domestic currency in terms of the foreign currency.

An important difference between the present study and that of Evans and Lyons (1999) is that the order flow variable used in this chapter is the net average daily turnover of foreign currency exchange transactions in the South African market in dollar terms, whereas in Evans and Lyons study order flow is based on the net quantity of foreign exchange transactions. The reason we adopted the transactions monetary flow instead of the number of transactions is simply the absence of transactions data in the public domain. It is necessary nonetheless to point out that preliminary regressions suggested that the transaction money volumes were statistically significant as a measure of the demand and supply pressures for dollar-denominated transactions.

7.3.1 Commodity-price-augmented exchange rate model

The relevance of links between commodity prices to exchange rate determination has been discussed in detail by Chen and Rogoff (2002). The study was based on the recognition that for Australia, Canada, and New Zealand, primary commodities constitute a significant component of their exports. It was therefore likely that world commodity price movements could potentially explain a major component of their terms-of-trade fluctuations and exchange rates.

This above analysis suggests the following test regression:

$$\Delta s_t = a_1 \Delta (i - i^*)_t + a_2 \Delta x_t + a_3 com_t + e_t, \qquad (7.3)$$

where com stands for the Economist commodity price index.

7.3.2 Country-risk-augmented exchange rate model

The traditional exchange rate models assume risk-neutrality. As a result, non-fundamental risk-related variables end up being excluded in those models. If indeed investors are risk averse, as it is usually the case, it becomes necessary to take into account the premium that compensates investors for the risk of holding assets in foreign currency. In this setting, a country risk premium serves to compensate the investor for "emerging market grouping" and other movements that may affect dollar-denominated returns to investment.

This suggests the following model:

$$\Delta s_t = a_1 \Delta (i - i^*)_t + a_2 \Delta x_t + a_3 com_t + a_4 risk_t + e_t \qquad (7.4)$$

7.4   Econometric issues and data analysis

The study utilises the autoregressive distributed lag model (ARDL) of Persaran, Shin and Smith (2001) and as explained in Persaran and Persaran (1997). The ARDL approach to cointegration, which does not require pre-testing for the integration properties of the individual series used in the empirical analysis, relies on a bounds testing procedure.

7.4.1   The autoregressive distributed lag model

Formally the ARDL model takes the following form:

$$\left[1 - \sum_{i=1}^{p} \theta_i L^i\right] y_t = \sum_{i=1}^{k} \beta_i (L, q_i) x_{it} + \delta' \mathbf{z} + \varepsilon_{\mathbf{t}}, \tag{7.5}$$

where $\beta_i(L, q_i) = \beta_{i0} + \beta_{i1} L + ... + \beta_{iq} L^{qi}$ for $i = 1, 2, ..., k$, L is a lag operator such that $Ly_t = y_{t-1}$ and $\mathbf{z_t}$ is a vector of exogenous variables with fixed lags and/or deterministic variables such as the time trends and an intercept term.

The error correction representation takes the following form:

$$\Delta y_t = \sum_{i=1}^{k} \beta_{i0} \Delta x_{it} + \varphi' \Delta \mathbf{z_t} - \sum_{j=1}^{p-1} \gamma \Delta y_{i,t-j} - \phi(1, \hat{p}) EC_{t-1}$$

$$- \sum_{i=1}^{k} \sum_{j=1}^{\hat{q}_i - 1} \lambda \Delta x_{i,t-j} + \varepsilon_t \tag{7.6}$$

where the error correction term is given by $EC_t = \left[y_t - \sum^{k} \hat{\theta}_i x_{it} - \Psi' z_t \right]$, and

$\phi(1, p) = 1 - \sum_{i=1}^{p} \hat{\phi}_i$ measures the quantitative significance of the error correction term.

The coefficients, γ and λ determine the short run dynamics of the model's convergence to equilibrium.

As a first step the econometrician determines the lag length of the model. This is done by estimating the model with and without the deterministic trend and the appropriate lag is selected on the basis of the Akaike Information Criterion (AIC), the Schwarz's Bayesian Information Criterion (SBC) or the Lagrange Multiplier (LM) test. The author prefers the Schwarz Bayesian Criterion as recommended by Persaran and Persaran (1997).

The second step is to test the existence of a long-run relationship between the variables. Essentially, the researcher must conduct an F-test on the significance of lagged levels of variables in the error correction form. As explained in Persaran and Persaran (1997), the F distribution is non-standard irrespective of the integration order of the variables.

7.4.2   ARDL algorithm for inference

Inference is based on the following algorithm:

- The calculated F-statistic is compared with the critical values tabulated by Pesaran, Shin and Smith (2001).
- If the calculated F-statistic *falls above* the upper bound, then the researcher can draw the conclusion that there exists a long-run relationship, without knowing the order of integration in the underlying variables.
- If the calculated F-statistic falls below the lower bound, the researcher cannot reject the null hypothesis of no cointegration.
- If the calculated F-statistic falls between the critical value bounds, the result is inconclusive. In this case, the researcher may have to test the order of integration of the underlying variables by using the standard unit roots techniques.

7.5   Empirical evidence

The dependent variable is the log-level of the ZAR/USD real exchange rate, denoted RAND. Denote the 'forcing' variables included in equation (7.4) in vector form as

$x_t = [USSA, TURN]'$ and let the exogenous variables be $z_t = [COMM, EMB, TIME, ITN]'$.

The variables are described as follows:

$USSA =$ The short-term interest rate differential between the US and South African interest rates;

$TURN =$ The dollar-denominated net average daily turnover on the South African foreign exchange market or SARB Quarterly Bulletin's time series number 5478M;

$COMM =$ Economist commodity price index in dollar terms;

$EMB =$ The spread between South Africa's dollar-denominated bonds and Global Emerging Market Bond Index, which is used as a measure of country risk.

$TIME =$ Time trend

$ITN =$ Intercept term.

The following are the Error Correction Model results using Microfit:

Table 9   Bounds-testing results for the Rand-dollar real exchange rate

Results of ARDL model based on Akaike Information Criterion			
The number of forcing variables is 2			
	10 per cent significance level		
	F-stat	I(0) Critical bounds	I(1) Critical bounds
Including time trend and intercept	4.77	4.19	5.06
Including intercept and no time trend	4.70	3.17	4.14
No intercept and no time trend	1.57	2.17	3.19

Results of ARDL model based on Schwarz Bayesian Criterion			
The number of forcing variables is 2			
	10 per cent significance level		
	F-stat	I(0) Critical bounds	I(1) Critical bounds
Including time trend and intercept	9.10	4.19	5.06
Including intercept and no time trend	6.22	3.17	4.14
No intercept and no time trend	2.96	2.17	3.19

Table 10 Error Correction Representation for the ARDL Model

```
            ARDL(1,0,0) selected based on Schwarz Bayesian Criterion
*******************************************************************************
Dependent variable is dDRAND
132 observations used for estimation from 1995M7  to 2006M6
*******************************************************************************
Regressor            Coefficient        Standard Error        T-Ratio[Prob]
dDTURN               -.0013712              .019860           -.069044[.945]
dDUSSA               -.012146               .0050295          -2.4150[.017]
dCOMM                .2626E-3               .2333E-3           1.1259[.262]
dEMB                 .0037617               .0034334           1.0956[.275]
dTIME                -.6057E-4              .8519E-4           -.71102[.478]
dITN                 -.030322               .034603            -.87628[.383]
ecm(-1)              -.74180                .090553            -8.1919[.000]
*******************************************************************************
List of additional temporary variables created:
dDRAND = DRAND-DRAND(-1)
dDTURN = DTURN-DTURN(-1)
dDUSSA = DUSSA-DUSSA(-1)
dCOMM = COMM-COMM(-1)
dEMB = EMB-EMB(-1)
dTIME = TIME-TIME(-1)
dITN = ITN-ITN(-1)
ecm = DRAND + .0018485*DTURN +  .016374*DUSSA -.3540E-3*COMM -.0050711*EMB +
.8165E-4*TIME +  .040876*ITN
*******************************************************************************
R-Squared                     .35699    R-Bar-Squared                    .32613
S.E. of Regression            .035141   F-stat.   F( 6, 125)   11.5666[.000]
Mean of Dependent Variable  .7862E-3    S.D. of Dependent Variable     .042808
Residual Sum of Squares       .15436    Equation Log-likelihood       258.2842
Akaike Info. Criterion      251.2842    Schwarz Bayesian Criterion    241.1944
DW-statistic                  1.8451
*******************************************************************************
R-Squared and R-Bar-Squared measures refer to the dependent variable
dDRAND and in cases where the error correction model is highly
restricted, these measures could become negative.
```

The inference is based on the results appearing in Table 10. The most consistent results are the one based on the Schwarz Bayesian Criterion. In this context, a long-run relationship is confirmed at 10 per cent significance level.

7.6   Conclusions

The results, based on the Schwarz Bayesian Criterion and ten per cent significance level, show that a long-un relationship between the rand-dollar real exchange rate and the interest differential and the proxy for order flow, which is proxied by the dollar-denominated daily net turnover on the South African markets. However, the t-statistic for order-flow proxy was insignificant. The specification favoured by SBC and AIC is the one that includes the intercept term with no time trend.

The results support the view that the market microstructure approach is a viable way of finding reliable determinants of exchange rates. As indicated in Chapter 3, the market microstructure approach can be enriched to accommodate many components of the foreign exchange markets. For instance, we have seen that Evans and Lyons (2005) incorporate dealers who act as intermediaries in four financial markets: the home money markets and bond markets; the foreign money markets and bond markets. In their model the authors suggest that order flow contains both backward-looking and forward-looking components.

The jury is still out as to whether the market microstructure approach can resolve the major puzzles of exchange rate economics. However, the approach is promising.

8 Chapter 8: Conclusions and implications

8.1 Background summary

The thesis focused on finding solutions to major exchange rate puzzles, which were discussed in detail by Obstfeld and Rogoff (2000). The first puzzle of concern was the purchasing power parity (PPP) puzzle. To resolve the puzzle, the thesis used Bayesian unit root testing and nonlinear nonstationarity tests associated with smooth transition autoregressive (STAR) family of models.

Chapter 3 argued that nonlinear approaches to exchange rate adjustments are likely to provide a firmer basis of inference and stronger support for the PPP in the long-term. The results obtained from the KSS tests suggested that the behaviour of 4 dollar-based real exchange rates should be treated as nonlinear and stationary rather than linear and nonstationary. At 10 per cent significance level the real exchange rates of 4 countries were stationary: Mozambique, Madagascar, Mauritius, South Africa, Swaziland, and Tanzania were found to be stationary. This finding of nonlinear behaviour provides statistical evidence in support of a smooth transition mean-reverting behaviour in 4 out of 10 real exchange rates. As such, any deviation from the PPP, either over- or-under-appreciation of real exchange rates should be seen as temporary.

In Chapter 4 we presented hypothesis testing in respect of Bayesian unit root tests and joint tests of nonlinearity and stationarity associated with the seminal contribution by Kapetanios, Shin and Snell (2003). We also presented the results of Augmented Dickey-Fuller tests at conventional levels.

In the context of Bayesian unit root testing, the nonstationarity hypothesis received small posterior probability relative to other hypotheses. In this setting, the Bayesian results strongly supported the hypothesis that all the real exchange rates were to be treated as trend-stationary autoregressive processes. The Bayesian unit root test results were found to be sharply at odds with the ADF results in that the hypothesis

of a unit root does not receive significant posterior probability in all cases. However, Ahking (2004) found that that the Bayesian tests could not distinguish between a trend-stationary autoregressive model from a stationary autoregressive one, especially when the time trend effect was relatively small, and the time series was highly persistent. The latter author found that the bias was in favour of finding a trend-stationary model. Thus, the results in the context of Bayesian analysis should be treated with caution.

Chapter 5 dealt with the half life version of the PPP puzzle. It followed Rossi (2005a) to generate for the SADC point estimates and confidence intervals in which deviations from PPP are in some cases compatible with nominal price and wage stickiness. The motivation for using Rossi's methodology is that she used local-to-unity asymptotic theory in the presence, in most cases, of highly persistent data. As it is commonly observed, real exchange rates manifest themselves as processes with roots near-unity. This characteristic makes them provide no good small-sample approximation to the distribution of estimators and test statistics. We used an alternative approach by modelling the dominant root of the autoregressive lag order polynomial as local-to-unity. This approach led to an alternative asymptotic approximation that provided a better small-sample approximation than imposing the order of integration. According to the empirical results, point estimates of half life deviations less than 36 months depended on the method used. Such cases include all countries except Tanzania, Zambia, and Malawi. It is noteworthy, however, that the median unbiased point estimates appear quite reasonable in the context of PPP.

Chapter 6 employed "a class test for fractional integration" associated with the seminal contribution of Hinich and Chong (2007) to appraise the possibility that Southern African Development Community (SADC) country real exchange rates can be treated as long memory processes. The justification for considering fractional integration arises from the general failure to reject the unit-root hypothesis in real exchange rates when standard Dickey-Fuller unit-root tests are used. In allowing for only integer orders of integration in the series dynamics, the linear tests of nonstationarity were found by authors such as Diebold and Rudebusch (1991) to have low power against fractional alternatives.

Empirical results showed cases of antipersistence – an unappealing empirical result. Antipersistence, which represents the negative values of the long memory parameter, were associated with Madagascar, Malawi, Swaziland, and Tanzania. At the 5-per-cent significance level, the null hypothesis could not be rejected that the real exchange rate associated with Angola, Botswana, and Zambia were $I(d)$ processes. In the case of Mozambique the null hypothesis could be rejected when n was either 6 or 7. In addition, at the 5 per cent significance level, the real exchange rates associated with Mauritius, Swaziland and South Africa were found not to be fractionally integrated.

Chapter 7 relied on the market microstructure approach, which has been applied to exchange rate determination puzzle. It claims that the imbalances between 'buyer-initiated and seller-initiated trades' in foreign exchange markets are indicative of the transmission link between exchange rates and fundamental determinants of exchange rates. In the context of the exchange rate determination puzzle, Chapter 7 discussed the market microstructure approach from the stand point of hybrid models that integrate order flow, fundamentals and non-fundamental variables to establish the determinants of the rand-dollar exchange rate. Among the non-fundamentals considered was the Economist commodity price index, the relevance of which is based on Chen and Rogoff (2002). Another non-fundamental variable included was a proxy for country risk — the differential between the Global Emerging Market Bond Index and the South African long-term bond.

The main objective was to find reliable determinants of exchange rates. Chapter 7 relied on the autoregressive distributed lag (ARDL) model of Persaran, Shin and Smith (2001) and as explained in Persaran and Persaran (1997). The ARDL approach to cointegration does not require pre-testing for the integration properties of the individual series used in the empirical analysis. Instead, it relies on a bounds testing procedure. In this setting, inference was based on an F-test on the significance of lagged levels of variables in the error correction form. The results, based on the Schwarz Bayesian Criterion for choosing a model's lag length, showed that the there was a long-run relationship between the rand-dollar real exchange rate, the fundamentals and the proxy for order flow, which is the dollar-denominated daily net turnover on the South African markets. Interest-rate differentials were found to be

a statistically significant fundamental. The proxy for order flow proxy was found to be statistically insignificant.

Chapter 3 dealt with the exchange rate disconnect puzzle. Economists have generally found exchange rates to be disconnected from macroeconomic fundamentals. Chapter 3 surveyed the latest approaches to the exchange rate disconnect puzzle. In particular, it presented the details of the general equilibrium models that are being developed to make the exchange rate disconnect puzzle less of a puzzle. The latest models are associated with the works of Devereux and Engel (2002), Xu (2005), Duarte and Stockman (2005), Evans and Lyons (2005), and Bacchetta and van Wincoop (2006). We found that the Evans and Lyons (2005) model and Bacchetta and van Wincoop (2006) model are the most promising research areas and have the potential to resolve the puzzle in point.

8.2   Conclusions

Based on the results of the above analysis, we advance the following conclusions:

The PPP puzzle: mean reversion

In the context of policy discussion, the finding of some of the SADC exchange rates to be mean-reverting means that any shocks are temporary and the exchange rate achieves equilibrium in the long-run. Thus, in the presence of a historically high volatility of exchange rates, authorities in those countries don't have to use limited reserves to influence the nominal level of the exchange rate. For countries whose exchange rates are non-mean-reverting, it is necessary to find policies that stabilise the currency because the exchange rate shocks on their economies take a long, long time to dissipate.

As far as econometric analysis is concerned, the PPP puzzle is beginning to be less of a puzzle due to the development of better tests that account for nonlinearities and structural change. In point of fact, there are extensions in the form of joint tests of nonstationarity and nonlinearity that have been developed by, among others, Kilic

(2004), Bec, Ben Salem and Carrasco (2004), Park and Shintani (2005) and Rothe and Sibbertsen (2006).

8.2.1   The PPP puzzle: Half-life deviations

As indicated, the main weakness of the Rossi (2005a) output is that confidence intervals of half-life deviations are too wide to be informative. The exchange rate half-life as a strand of research is in its infancy in terms of the robustness of the techniques produced and used. It is this author's judgement that the most robust methods have been developed by Pesavento and Rossi (2006) and Kim, Silvapulle and Hyndmand (2006). Kim, Silvapulle and Hyndman (2006) propose a bias-corrected bootstrap procedure for the estimation of half-life deviations from PPP by adopting Hyndman (1996) highest density region (HDR) approach to point and interval estimation. Pesavento and Rossi construct confidence bands for multivariate impulse response functions in the presence of highly persistent processes. They use local-to-unity asymptotic approximations. An alternative approach to the calculation of exchange rate half-lives in the context of nonlinearities is associated with the work of Norman (2007).

These new methods are left for future research.

8.2.2   Exchange rate determination puzzle

Chapter 7 relied on the autoregressive distributed lag (ARDL) model of Persaran, Shin and Smith (2001) and as explained in Persaran and Persaran (1997) to avoid the pre-testing problems mentioned above. We found that risk premia, and interest rate differentials are the main determinants of the ZAR/USD exchange rate.

8.3   Issues for future research

The Thesis has appraised the extent to which the puzzles of concern can be resolved. It was seen that some of the results were contradictory. One of the main

issues for future research is to compare the robustness of the results of various methods. For instance, can we make non-contradictory inferences using Rossi (2005b) and the highest density approach? The second issue is that economists need to develop a coherent econometric framework that provides reasonable certainty about the statistical properties of exchange rates and related highly persistent processes. For example, we should be able to know with confidence that we are dealing with a long memory nonlinear process.

References

Abhyankar A, L Sarno, G Valente. 2004. Exchange rates and fundamentals: Evidence on the economic value of predictability.
Online:http://www2.warwick.ac.uk/fac/soc/wbs/research/wfri/wpaperseries/
Accessed 1 May 2007.

Abuaf, N., and P. Jorion, 1990, Purchasing power parity in the long-run. *Journal of Finance*, Vol. 45, pp. 157–74.

Ahking, F. 1997. Testing long-run purchasing power parity with a Bayesian unit root approach: the experience of Canada in the 1950s. *Applied Economics*, 1997, 29, 813- 819.

Ahking, F. 2004. The power of the "objective" Bayesian unit root test. *University of Connecticut* Working Paper 2004-14.

Andrews, D.W.K. and Chen, H.-Y. 1994. Approximate median-unbiased estimation of autoregressive models. *Journal of Business and Economic Statistics,* 12, 187-204.

Andrews, D.W. K. and W. Ploberger. 1994. Optimal tests when a nuisance parameter is present only under the alternative. Econometrica 62, 1383–414.

Aron J and I John Muellbauer. 2000a. Inflation and Output Forecasting
for South Africa: Monetary Transmission Implications. *Centre for the Study of African Economies, Oxford University* WPS/2000-23.

Aron J and I John Muellbauer. 2000b. Monetary Transmission and Policy Rules in South Africa. *Centre for the Study of African Economies, Oxford University*

Ashley, R A and Patterson, D M. 2007. Apparent long memory in time series as an artifact of a time-varying mean: A "local mean" filtering alternative to the fractionally integrated model.
Online: ashleymac.econ.vt.edu/working_papers/**long_memory**.pdf.
Accessed: 17 July 2007.

Atanasova, C. 2003. Credit market imperfections and business cycle dynamics: A nonlinear approach. *Studies in Nonlinear Dynamics and Econometrics*, 7(4), Artl. 5.

Bacchetta, P. and E. van Wincoop. 2003. Can Information Heterogeneity Explain the Exchange Rate Determination Puzzle?
Online: www.nber.org/papers/W9498. Accessed on 15 January 2007.

Bacchetta, P. and E. van Wincoop. 2006. Can Information Heterogeneity Explain the Exchange Rate Determination Puzzle? American Economic Review, Vol. 96 (3), 552-576.

Baillie, R.T. 1996. Long memory processes and fractional integration in econometrics. *Journal of Econometrics,* Vol. 73, 5-59.

Baillie, R.T. and Kapetanios, G. 2006. Nonlinear models with strongly dependent processes and applications to forward premia and real exchange rates, *Queen Mary University of London, Working Paper* 570.

Baillie and Kapetanios, G. 2005. Testing for neglected nonlinearity in long memory models. *Queen Mary Working Paper number 528*, University of London.

Balke, N. S. and T. Fomby. 1997. Threshold cointegration. International Economic Review 38, 627–45.

Barnard, L and J N de Clerck. 2007. The structure and development of the foreign exchange market in South Africa. *South African Reserve Bank Discussion Paper* number 07/04.

Baxter, M and AC Stockman. 1989. Business cycles and the exchange-rate regime some international evidence. J*ournal of Monetary Economics.*

Beaudry, P and Koop, G. 1993. Do recessions permanently change output? Journal of Monetary Economics, vol. 31(2), pages 149-163, April.

Bec, F, Ben Salem, M, Carrasco, M. 2004.Tests for unit-root versus threshold specification with an application to the purchasing power parity relationship. *Journal of Business and Economic Statistics* 22, 382-395.

Berben, R. P. and van Dijk, D.1998. Unit root tests and asymmetric adjustment: A reassessment. Research Report EI-9902/A, Econometric Institute, Rotterdam.

Caner, M., Hansen, B. E.2001. Threshold autoregression with a unit root. *Econometrica* 69, 1555-1596.

CCBG. 2006. *SADC financial systems: Structures, policies and markets*. September.

Charfeddine, L and Guégan, D. 2007. Is it possible to discriminate between structural breaks model and long memory processes: Methodology approach and Empirical evidence?
Online: www.u-paris2.fr/ermes/**d**octrav/trav%200618.p**d**f
Accessed: 25 July 2007.

Chen, Yu-Chin.2003. Exchange Rates and Fundamentals: Evidence from Commodity Economies. University of Washington, mimeo.

Cheung, Y.W. 1993. Tests for fractional integration: A Monte Carlo investigation, *Journal of Time Series Analysis,* 14, 331-345.

Cheung Y, W. 1993. Long memory in foreign exchange rates. J*ournal of Business and Economic Statistics,* 11, 93-101.

Cheung, Y Wand K S Lai. 2000. On the purchasing power parity puzzle. J*ournal of International Economics,* 52, 321-330.

Cheung, Yin-Wong, K S Lai, and M Bergman. 2004. Dissecting the PPP puzzle: The unconventional roles of nominal exchange rate and price adjustments. *Journal of International Economics*, 64, 135-150.

Chen, Y-C, and Rogoff, K. 2003. Commodity currencies. *Journal of International Economics*, 60, 133-60.

Chortareas G, and Kapetanios, G. 2004. How puzzling is the PPP puzzle? An alternative half-life measure of convergence to PPP, Queen Mary Working Paper number 522, University of London.

Coleman, A.M.G. 1995. Arbitrage, Storage and the Law of One Price: New Theory for the Time Series Analysis of an Old Problem, *Discussion Paper,* Department of Economics, Princeton University.

Danielsson, J., Payne, R., and J. Luo .2002. Exchange rate determination and inter–market order flow effects. memeo, London School of Economics.

Davies, R. B. 1987. Hypothesis testing when a nuisance parameter is present under the alternative. Biometrika 74, 33–43.

Devereux, M. and Engel, C.2002. Exchange rate pass-through, exchange rate volatility and exchange rate disconnect. *Journal of Monetary Economics*, 49:913-940.

Diebold, F X, S Husted, and M Rush. 1991. Real exchange rates under the Gold Standard. *Journal of Political Economy*, Vol. 99, pp. 1252-71.

Diebold, F. X. and Inoue, A. 2000. Long memory and regime switching. *NBER* Working Paper No. 264.

Diebold, Francis X and Glenn D. Rudebusch 1991. On the power of Dickey-Fuller tests against fractional alternatives. *Economics Letters,* Volume 35, Issue 2, 155-160.

Diebold, F X, Killian L, and M Nerlove. 2008. Time Series Analysis forthcoming in: S. Durlauf and L. Blume (eds.), *The New Palgrave Dictionary of Economics*, 2nd ed., London: Macmillan.
Online: http://www-personal.umich.edu/~lkilian/publications.html
Accessed on 26 June 2007.

Dickey, D. A. and W. A. Fuller. 1979. Distribution of the estimators for autoregressive time series with a unit root. *Journal of the American Statistical Association* 74, 427–31.

Dornbusch, R. 1976. Exchange rate expectations and monetary policy. *Journal of International Economics,* vol. 6(3), pages 231-244, August.

Duarte, M. and Stockman A.C.2001. Rational speculation and exchange rates. *NBER Working Paper*, No. 8362.

Elliott, G and Stock, J. 2001. Confidence intervals for autoregressive coefficients near one. *Journal of Econometrics* 103, pp. 155-181.

Eklund, B. 2003. Testing the unit root hypothesis against the logistic smooth transition autoregressive model. SSE/EFI Working Paper Series in Economics and Finance, No. 546.

Enders, W., Granger, C. W. J. 1998. Unit root tests and asymmetric adjustment with an example using the term structure of interest rates, *Journal of Business and Economic Statistics* 16, 304-311.

Engel, C and J H. Rogers. 1996. How wide is the border? *The American Economic Review*, Vol. 86, No. 5, pp. 1112-1125.

Engle, R. and C. W. J. Granger. 1987. Cointegration and error correction: representation, estimation and testing. *Econometrica* 55, 251–76.

Engel, C, and James C. Morley. 2002. The adjustment of prices and the adjustment of the exchange rate. *University of Wisconsin and Washington University,* mimeo.

Escribano, A. and O. Jorda. 1999. Improved testing and specification of smooth transition autoregressive models, in P. Rothman (ed.), *Nonlinear Time Series Analysis of Economic and Financial Dat*a, pp. 289-319 (Boston: Kluver).

Escribano, A. and O. Jorda. 2004. Testing nonlinearity: decision rules for selecting between logistic and exponential STAR models. *Spanish Economic Review*, 3, 193-209.

Evans, M D D and R K Lyons. 2001. *The market microstructure approach to exchange rates.* Cambridge, The MIT Press.

Evans, M D D and R K Lyons. 2005. Exchange rate fundamentals and order flow. Online: http://www.ecb.int/events/conferences/html/jointbocecb-workshop2005.en.html Accessed: 22 June 2007

Evans, M D D and R K Lyons. 2005. Meese-Rogoff Redux: Micro-based exchange rate forecasting. American Economic Review, Papers and Proceedings, May.

Fedderke, J and Flamand P. 2005. Macroeconomic news "surprises" and the rand/dollar exchange rate. *Studies in economics and econometric*s, 29(3).

Flood R P and A K Rose. 1995. Fixing exchange rates a virtual quest for fundamentals. *Journal of Monetary Economics* 36 (1995), pp. 3–37.

Frankel, J. 1983. Monetary and Portfolio-Balance Models of Exchange Rate Determination, in *Economic Interdependence and Flexible Exchange Rates,* ed. By J.S. Bhandari, B.H. Putnam, and J.H. Levin (Cambridge, MA: MIT Press).

Frankel, J. and A. Rose.1995. A Survey of empirical research on nominal exchange Rates, in E. Grossman and K. Rogoff (eds),_*The Handbook of International Economics*, Vol. 3, Amsterdam: North Holland.

Frankel, J. 1995. A Panel project on purchasing power parity: Mean reversion within and between countries, *NBER Working Paper* No. 5006.

Frankel, J. A. 1999. No single currency regime is right for all countries or at all times, Princeton University, International Finance Section, *Essays in International Finance,* No. 215 (August).

Fung, H G and W C Lo. 1992. Deviations from purchasing power parity. *Financial Review,* pp. 553-570.

Granger CWJ, and Hyung N. 1999. Occasional structural breaks and long memory. *University of California, San Diego Discussion Paper* 99-14.

Granger, CW.J and Joyeux, R. 1980. An introduction to long-range time series models and fractional differencing. *Journal of Time Series Analysis,* 15-29*.*

Granger, C. W. J., Terasvirta, T. 1993. *Modelling nonlinear economic relationships*, Oxford University Press, Oxford.

Gonzalez-Rivera, G. 1998. Smooth-transition GARCH models. *Studies in nonlinear dynamics and econometrics* 3, 61-78.

Groen, J J 2000. New multi-country evidence on purchasing power parity. *Econometric Institute Report* 188, Erasmus University Rotterdam.

Grilli, V and G Kaminsky. 1991. Nominal exchange rate regimes and the real exchange rate: Evidence from the United States and Great Britain, 1885-1986. *Journal of Monetary Economics*, Vol. 27, pp. 191-212.
Diebold, F. X and Rudebusch, G.D. 1991. On the power of Dickey-Fuller tests against fractional alternatives, *Economics Letters*, Vol. 35: 2, 155-160.

Guégan, D. 2005. How can we define the concept of long memory An econometric survey. *Econometric Reviews*, 24(2), 113-149.

Guégan, D and Rioublanc, S. 2005. Regime Switching Models: Real or Spurious Long Memory? Research Note, IDHE-MORA n*o* 02-2005, Cachan, France.

Hansen, B. 1996. Inference When a nuisance Parameter is not identified under the null Hypothesis, *Econometrica* 64, 413-430.

Hansen, B 1999. Bootstrapping the autoregressive model. *Review of Economics and Statistics* 81(4), pp.594-607.

Hassler U and Wolters, J. Autoregressive distributed lag models and cointegration. Online: www.wiwi.uni-frankfurt.de/~hassler/ha-wo-revision.pdf Accessed on 5 February 2007.

He, C and R Sandberg. 2005. Dickey-Fuller type of tests against nonlinear dynamic models. *SSE/EFI Working Paper Series in Economics and Finance No. 580,* Stockholm School of Economics.

Hill, J. 2004. LM-tests for linearity against smooth transition alternatives: A bootstrap simulation study. Online: www.fiu.edu/~economic/wp2004/04-12.pdf. Accessed 17 June 2007.

Hill, J. 2006. Consistent and non-degenerate model specification tests against smooth transition and neural networks alternatives.
Online: http://www.fiu.edu/~hilljona/working%20papers.htm
Accessed on 19 June 2007.

Hinich, M.J and Chong T.L. 2007. A class test for fractional integration, *Studies in Nonlinear Dynamics and Econometric*s, Vol. 11, Issue 2, Article 5.

Hosking, J.R.M. 1996. Asymptotic distributions of the sample mean, autocovariances, and autocorrelations of long-memory time series. *Journal of Econometrics*, 73, 261-284.

Hualde, J and Velasco C. 2006. Distribution-free tests of fractional cointegration. Working Paper 08/06, Universidad de Navarra.

Hyndman, R. J. 1996. Computing and graphing highest density regions. *The American Statistician* 50, 120–126.

Imbs, Jean; Haroon Mumtaz, Morten Ravn, and Helen Rey. 2005a. PPP strikes back: Aggregation and the real exchange rate. Quarterly Journal of Economics, 120(1): 1-43.

Imbs, Jean; Haroon Mumtaz, Morten Ravn, O Morten, and Helen Rey. 2005b. "Aggregation bias" does explain the PPP Puzzle, NBER Working Paper number 11607.

Jorion, Philippe. 2001. Value at Risk: The new benchmark for managing financial risk. London and New York: McGraw-Hill.

Kapetanios, G. and Shin Y. 2003a. Testing for nonstationary long memory against nonlinear ergodic models, *Queen Mary University of London Working Paper* number 500.

Kapetanios, G. and Y. Shin. 2003b. GLS detrending-based unit root tests in non-linear STAR and SETAR framework. Unpublished Manuscript, *Queen Mary, University of London.*

Kapetanios, G., Y. Shin and A. Snell. 2003c. Testing for a unit root in the nonlinear STAR framework. *Journal of Econometrics* 112, 359–79.

Keenan, D.M. 1985. A Tukey nonadditivity-type test for time series nonlinearity, Biometrika 72, 39-44.

Kilic, R. 2004. Linearity Tests and Stationarity. *Econometrics Journal,* 7 (1), 55-62, June.

Killeen, W., R. Lyons and M. Moore. 2004. Fixed versus Flexible: Lessons from EMS order flow, NBER Working Paper 8491.

Kilian, L. 1998. Small sample confidence intervals for impulse response functions. *The Review of Economics and Statistics* 80, 218–230.

Kim, J H, P Silvapulle and R J. Hyndman.2007. Half-life estimation based on the bias-corrected bootstrap: A highest density region approach. *Monash University* working paper number 11/06.

Koop, G. 1992. Objective, Bayesian unit root tests. *Journal of Applied Econometrics*, 7, 65- 82.

Koop, G, Pesaran, M H and Potter, S M. 1996. Impulse response analysis in non-linear multivariate models. *Journal of Econometrics* 74, 119–47.

Krugman. 1989. Currencies and Crisis. Cambridge: MIT Press.

Levin, A, and C-F Lin. 1992. Unit root tests in panel data: asymptotic and finite sample properties. (Unpublished; Washington: Federal Reserve Board of Governors)

Lothian, J. 1997. Multi-country evidence on the behaviour of purchasing power Parity under the current float. *Journal of International Money and Finance.*

Lothian, J., and M. Taylor. 1995. Real exchange rate behaviour: the recent float from the behaviour of the past two centuries. *Journal of Political Economy*.

Lyons, Richard. 2002. Foreign exchange: macro puzzles, micro tools. *Economic Review.* Federal Reserve Bank of San Francisco, 51-69.

Lyons R K. 2001. *The microstructure approach to exchange rates.* Cambridge Massachusetts: MIT Press.

Lyons, Richard K. 2002. The failure of empirical exchange rate models: Room for optimism? *Economic Policy*, Web Essay.

Love, R and R Payne. 2002. Macroeconomic news, order flows and exchange rates. Online:www.faculty.haas.berkeley.edu/lyons/Love%20Payne%20**news**%20**order**%20flow.pdf. Accessed: 25 January 2007

Lo, M. C. and Zivot, E. 2001. Threshold cointegration and nonlinear adjustment to the low of one price. *Macroeconomic Dynamics* 5, 533-576

Luukkonen, R., Saikkonen, P. and Terasvirta, T. 1988. Testing linearity against Smooth Transition Autoregressive Models, Biometrika, 75, 491–99.

Macdonald R and J Nagayasu. 2000. The long-run relationship between real exchange rates and real interest rate differentials: A panel study. *IMF Staff Papers*, Vol. 47, No. 1

Maddala G.S and Kim, In-Moo. 1998. Unit roots, cointegration, and structural change. Cambridge University Press.

Mark, N C. 1990. Real and nominal exchange rates in the long-run: An empirical investigation. *Journal of International Economics,* 28, 115-36.

Mark, N C. 1995. Exchange rates and fundamentals: Evidence on long-horizon predictability. *American Economic Review,* 85, 201-18.

Mark, N C and D Sul. 2001. Nominal exchange rates and monetary fundamentals: Evidence from a small post-Bretton Woods panel. *Journal of International Economics,* 53 (2001) 29–52.

Manzur, M. 1990. An international comparison of prices and exchange rates: A new test of purchansing power parity. *Journal of international money and finance,* 9(1),75-91.

Meese, R A., and K Rogoff.1983. Empirical Exchange Rate Models of the Seventies: Do They Fit Out of Sample? *Journal of International Economics,* 14, 3-24.

Meridith, G and Y Ma. 2002. The forward premium puzzle revisited. International Monetary Fund, Working paper 02/08.

Merrill Lynch. 2003. Modelling the rand. SA Economics. Global Fundamental Equity Research Department. September.

Merrill Lynch. 2004. The rand: A look at valuation. *SA Economics.* Global Fundamental equity research department. August.

Medeiros, O. 2005. Exchange rate and market microstructure in Brazil. Academic open internet journal, volume 14, 1-9.

Michael, P, Nobay, R A Nobay and Peel, D A. 1997. Transactions costs and non-linear adjustment in real exchange rates: an empirical investigation. *Journal of Political Economy* 105, 862–79.

Mokoena, T M. 2006. Smooth transition autoregressive modelling and related nonlinear tests of nonstationarity: A theoretical analysis related to international macroeconomics. Unpublished manuscript.

Mokoena T. M. 2007. Taking the puzzle out of the purchasing power parity puzzle: an application in respect of South Africa. *South African Journal of Economics,* Vol. 75:1 March.

Murray, C J., and D H Papell. 2002. The purchasing power parity persistence paradigm. *Journal of International Economics* 56, 2002, pp. 1-19.

Mussa, M.1986. Nominal exchange rates regimes and the behavior of real exchange rates: Evidence and implications. *Carnegie-Rochester Conference Series on Public Policy* 25, 117-216.

Neely, C J., and L Sarno. 2002. How well do monetary fundamentals forecast exchange rates? *Federal Reserve Bank of St. Louis Review*, 84, 51-74.

Nelson, C. and C Plosser C. 1982.Trends and random walks in macroeconomics time series: some evidence and implications. Journal of Monetary Economics, 10, 139-162.

Newey, W K and West, K. 1987. A simple, positive semi-definite. heteroskedasticity and autocorrelation consistent covariance matrix. *Econometrica* 55, 703– 708.

Ng, S and P Perron. 2001. Lag length selection and the construction of unit root tests with good size and power. *Econometrica,* 69(6), 1519-1554.

Norman, S. 2006.Testing for a unit root against ESTAR nonlinearity with a delay parameter greater than one. *Brigham Young University Working Paper.*

Norman, S. 2007. How well does nonlinear mean reversion solve the PPP Puzzle. Online: *http://stephen.e.norman.googlepages.com/research.* Accessed on 25 June 2007.

Obstfeld, M., and Rogoff, K. 1999. Foundations of international macroeconomics. Cambridge: The MIT Press.

Obstfeld, M., and Rogoff, K. 2000. The six major puzzles in international macroeconomics: Is there a common cause? in Bernanke, B. and Rogoff, K. (eds.) NBER Macroeconomics Annual, Cambridge: MIT Press, 339-390.

Obstfeld, M. 2002. Exchange rates and adjustment: Perspectives from the new open economy macroeconomics. manuscript, University of California, Berkeley.

O'Connell, Paul G.J. 1998. The overvaluation of purchasing power parity. *Journal of International Economics,* 44, 1-19.

Oh, K-Y. 1996. Purchasing power parity and unit root test using panel data. *Journal of International Money and Finance,* 15, 405-418.

Rapach, D.E. and Wohar, M.E. 2002 .Testing the monetary model of exchange rate determination: New evidence from a century of data. *Journal of International Economics,* 58, 359-85.

Papell, David H. 1998. Searching for stationarity: Purchasing power parity under the current float. *Journal of International Economics,* 43, 313-332.

Parsley, D C and S J Wei.1996. Convergence to the law of one price without trade barriers or currency fluctuations - The Quarterly Journal of Economics.

Parzen, E. 1981. Time series model identification and prediction variance horizon, In: Findley, ed. *Applied Time Series Analysis II.* New York: Academic Press, pp. 415–447.

Payne, R. 2003. Informed trade in spot foreign exchange markets: An empirical investigation. *Journal of International Economics*, 61, 307–329.

Payne, R and P. Vitale, 2003. A transaction level study of the effects of central bank intervention on exchange rates. *Journal of International Economics,* 61, 331–352.

Park, J. Y and Shintani, M. 2005. Testing for a unit root test against transitional autoregressive models, *Working paper, Vanderbilt University.*

Pesaran, M H, Shin, Y and Smith, R J. 2001. Bounds testing approaches to the analyses of level relationships. *Journal of Applied Econometrics*, No. 16, pp. 289-326.

Persaran, H. and Persaran B. 1997. *Working with Microfit 4.0.* Oxford University Press.

Pesavento, E and B Rossi. 2006. Small sample confidence intervals for multivariate iIRFs at long horizons. *Journal of Applied Econometric*s, 21(8), December, 1135-1155.

Pesavento, E and B Rossi. 2007. Impulse response confidence intervals for persistent data: What have we learned? *Journal of Economic Dynamics and Control* 31, 2398-2412.

Phillips, P.C.B. and Ploberger, W. 1996. Posterior odds testing for a unit root with data based model selection. *Econometrica,* 64, 381-412.

Pippenger, M. K. and G. E. Goering.1993. A note on the empirical power of unit root tests under threshold processes. Oxford Bulletin of Economics and Statistics 55, 473–81.

Potter, S. 1995, A nonlinear approach to US GNP. *Journal of Applied Econometrics*, I0, 109-125.

Potter, S M. 1999. *Nonlinear time series modelling: an introduction. Journal of Economic Surveys*, 13, 505–528.

Potter, S M. 2000. Nonlinear impulse response functions. *Journal of Economic Dynamics and Control*, 24, 1425–1446.

Ramsey, J B and P Schmidt. 1976. Some further results on the use of OLS and BLUS residuals in specification error tests. *Journal of the American Statistical Association,* 1976.

Robinson, P. M. 2003. *Time series with long memory,* Oxford: Oxford University Press.

Rogoff, K. 1996.The purchasing power parity puzzle. Journal of Economic Literature. Vol. 34, 647-668.

Rogoff, K. 2002. The failure of empirical exchange rate models: No longer new, but still true. *Economic Policy,* Web Essay.

Rossi, B. 2005a. Confidence intervals for half-life deviations from the purchasing power parity. *Journal of Business and Economic Statistics 23(4), October 2005, 432-442.*

Rossi, B. 2005b. Testing long-horizon predictive ability with high persistence, and the Meese-Rogoff puzzle. *International Economic Review*, 46(1), 61-92.

Saikkonen, P.; Luukkonen, R. 1988. Lagrange multiplier tests for testing nonlinearities in time series models. *Scandinavian Journal of Statistics,* 1988, 15, 55–68.

Sarno, L. 2001. Nonlinear exchange rate models: a selective overview. IMF Working Paper 03/111.

Sarno, L and C Ibrahim. 2003. The behaviour of the real exchange rate: Evidence from an alternative price index. *Economic Notes,* 32, 295-333.

Sarno, L and M P Taylor. 1998. Real exchange rates under the recent float: unequivocal evidence of mean reversion. *Economics Letters,* 60, 131-37.

Sarno, L and M P Taylor. 2002. Purchasing power parity and the real exchange rate. *International Monetary Fund Staff Paper*s, 49, 65-105.

Sarno, L, and M P. Taylor. 2003. *The economics of exchange rates*, Cambridge: Cambridge University Press.

Sarno, L, and G Valente. 2004. Deviations from purchasing power parity under different exchange rate regimes: do they revert and, if so, how? *University of Warwick,* mimeo.

Satchell, S, and A Timmermann. 1995. An assessment of the economic value of non-linear foreign exchange rates forecasts, *Journal of forecasting*, 14, 477-97.

Sarno, L, Taylor, M and Peel, D. 2001. Nonlinear mean-reversion in real exchange rates: toward a solution to the purchasing power parity puzzles. *International Economic Review*, 42, pp. 1015-1042.

Sarno, L and M Taylor. 2002. Purchasing power parity and the real exchange rate. *International Monetary Fund* Staff Papers, 49, 65-105.

Seo, M.2005. Unit root test in a threshold autoregression: Asymptotic theory and residual-based block bootstrap. Discussion paper, No.EM/05/484, *London School of Economics and Political Science.*

Sercu, P., R. Uppal, and C. Van Hulle. 1995. The exchange rate in the presence of transactions costs: implications for tests of purchasing power parity. *Journal of Finance*, Vol. 50, pp. 1309–19.

Sheather, S. J. and Jones, M. C., 1991. A reliable data-based bandwidth selection method for kernel density estimation. *Journal of the Royal Statistical Society* B53, 683-690.

Shin, D. W. and O. Lee. 2001. Test for asymmetry in possibly non-stationary time series data. *Journal of Business and Economic Statistics,* 19, 233–44.

Smal M M and S de Jager. 2002. The monetary transmission mechanism in South Africa. South African Reserve Bank Occasional Paper number 16.

Smallwood, A. 2005. Joint tests for non-linearity and long memory: The case of purchasing power parity. *Studies in nonlinear dynamics and econometrics,* 9(2), Article 7.

Stock, J. 1991. Confidence intervals for the largest autoregressive root in U.S. macroeconomic time series. *Journal of Monetary Economics* 28, 1991, pp. 435-59.

Taylor, A M. 2000. Potential pitfalls for the purchasing-power-parity puzzle? Sampling and specification biases in mean-reversion tests of the law of one price. NBER Working Paper 7577.

Taylor, M P and D A. Peel. 2000. Nonlinear adjustment, long-run equilibrium and exchange rate fundamentals. *Journal of International Money and Finance*, Vol. 19, pp. 33–53.

Terasvirta, T. 1994. Specification, estimation, and evaluation of smooth transition autoregressive models. *Journal of the American Statistical Association* 1994, 89, 208–218.

Terasvirta, T. and Anderson, H.M.1992. Characterizing nonlinearities in business cycles using smooth transition autoregressive models. *Journal of Applied Econometrics* 1992, 7,S119–S136.

Tobin, J.1978. A proposal for international monetary reform. *Eastern Economic Journal.* 4:153-159.

Todani K R and T V Munyama. 2006. Exchange rate volatility and exports in South Africa. *South African Reserve Bank Discussion Paper* number 06/02.

Tong, H.1983. *Threshold models in non-linear time series analysis*, New York, Springer-Verlag.

Tong, H. 1990. *Nonlinear time series: a dynamical system approach*, Oxford University Press.

Wand, M. P., Marron J.S. and Ruppert, D. 1991. Transformation in density estimation. *Journal of the American Statistical Association* 86, 343-353.

West, K.D. 1996. Asymptotic inference about predictive ability. *Econometrica* 64, 1067–1084.

West, K.D., McCracken, M.W., 1998. Regression-based tests of predictive ability. *International Economic Review* 39, 817– 840.

West, K.D., Edison, H.J., Cho, D., 1993. A utility-based comparison of some models of exchange rate volatility. *Journal of International Economics* 35, 23– 45.

Wu, Y. 1996. Are real exchange rates nonstationary? evidence from a panel data set. *Journal of Money Credit and Banking*, 28, 54-63.

van Dijk, D, P H Franses, and R. Paap, 2002, A nonlinear long memory model for US unemployment. *Journal of Econometrics*, 110, 135-165.

van Dijk, D.and Franses, P.H. 1997. Nonlinear error-correction models for interest rates in the Netherlands. *In Nonlinear Econometric Modeling in Time Series Analysis*; Barnett, W.A., Hendry, D.F., Hyllebe

van Dijk D., Terasvirta, T., Franses, P. H. 2002. Smooth transition autoregressive models - survey of recent developments. *Econometric Reviews* 21, 1-47.

Vitale, P. 2006. A guided tour of the market micro structure approach to exchange rate determination.
Online: www.unich.it/~vitale/NewFXSurvey1bis.pdf. Accessed on 15 January 2007.

Xu, J. 2005. Noise traders, exchange rate disconnect puzzle and Tobin tax. Department of Economics, *Simon Fraser University   Working Paper.*

Zellner, A. and Siow, A. 1986. Posterior odds for selected regressions hypotheses, in *Baynesian Statistics*, edited by J. M. Bernardo, M. H. De Groot, D. V. Lindley and A. F. M. Smith (University Press, Valencia).