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# **An Econometric Model of the rand-US Dollar**

## **Nominal Exchange Rate**

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### **Abstract**

Modeling the nominal exchange rate has been one of the most difficult exercises in economics. This paper attempts to estimate the nominal rand-USD exchange rate under the Dornbusch(1980) and Frankel (1979) overshooting model using the Johansen cointegration technique. The overshooting model fits the data well and that commodity prices are sticky in South Africa. Thus any monetary policy strategy to strengthen or weaken the rand by means of raising or cutting interest rate does the opposite in the short-run.

*JEL Classification:* B23, C22, F31

*Key words:* Exchange rate, overshooting model, VECM

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## Introduction

South Africa has adopted various exchange rate management policies with a view to addressing major shocks in the form of significant gold price reductions and political crises (Aron *et al.* 1997). Until 1979, South Africa had a fixed exchange rate regime, which was pegged to a particular currency. Capital controls were quintessential in the exchange rate management policy.

In 1979 the Reserve Bank split the foreign exchange market into two sections. One market dealt with forex transactions related to trade in goods and services (commercial rand) while the other related to international capital movements (financial rand). The financial rand was abolished in 1983 before being re-introduced in September 1985 to provide some protection to the domestic economy from the adverse effects of large capital outflows at that time.

The dual exchange rate system remained in existence until the re-unification of the commercial and financial rand in March 1995. This led to the current unitary managed floating exchange rate in which the Reserve Bank intervenes in the foreign exchange market mainly to smooth out undue short-term fluctuations in the exchange rate. After 1994, South Africa followed a gradual approach to elimination of exchange controls rather than a “big-bang” approach.

South Africa's heightened integration into the trading and financial global market brought newer challenges to the exchange rate management. Indeed, in 2001, the rand depreciated substantially and led to the setting up of a commission of inquiry by the government to investigate the causes (South Africa, 2002). The commission of inquiry identified a number of factors which may have been responsible for the depreciation of the rand; high inflation differential, low export prices, low interest differentials, portfolio shifts and leads in payments for imports and lags in export receipts. These developments call for a need to understand the determinants of the nominal rand-dollar exchange rate.

Floating exchange rate models with fundamentals are classified into two categories; monetary exchange rate and portfolio balance models. The monetary exchange rate model is based on either flexible prices (Mussa, 1976) or sticky prices (Dornbusch, 1980 and Frankel, 1979).

However, existing exchange rate models perform dismally when confronted with actual data. Mussa (1979) found four stylised facts about the exchange rate. First, the log of the spot rate is approximately a random walk. Second, most changes in the exchange rates are unexpected. Third, countries with high inflation rates tend to depreciate at approximately the inflation differential in the long run. Finally, actual exchange rate movements tend to overshoot movements in smoothly adjusting equilibrium exchange rates. Meese and Rogoff (1983) found that no existing structural exchange rate model could reliably out-predict the naïve alternative of a random walk at short- and medium term horizons.

Given the current managed floating exchange rate supported by exchange controls in South Africa, the sticky price monetary model is the most appropriate. The sticky-price and overshooting model of exchange rate allow short-term overshooting of the nominal and real exchange rates above their long-run equilibrium levels. This emanates from the interaction of sluggishly adjusting goods markets and hyperactive asset markets.

There is a dearth of studies that test the validity of either the Dornbusch's or Frankel's approach in South Africa. Brink and Koekemoer (2000) estimated the Dornbusch's version of the monetary model for South Africa using the three-step Engle and Yoo cointegration procedure. Their model employed nominal money supply, real GDP, and inflation rate of South Africa relative to those of the US. The long run coefficients are consistent with the Dornbusch's sticky price theory and statistically significant. This paper therefore is an attempt to extend the work of Brink and Koekemoer (2000) by applying Johansen multivariate cointegration approach.

The rest of the paper is structured as follows. Section 2 attempts to shed some light on the general framework and identify the similarities and differences that exist between the Dornbusch sticky-price overshooting theoretical model and the one developed later by Frankel (1980). Section 3 deals with the estimation methodology and the data. Section 4 discusses the estimation results while section 5 presents the conclusions.

## Model specification

The monetary exchange rate model is predicated on the fact that since the exchange rate is the relative price of foreign and domestic money, it should be determined by the relative supply and demand of these moneys. The Dornbusch(1980) and Frankel (1979) models begin by expressing the function of real money demand in logarithmic notation.

$$\text{Home country: } p = m - \beta y + \delta i \quad (1)$$

$$\text{Foreign country: } p^* = m^* - \beta y^* + \delta i^* \quad (2)$$

Combining Equations 1 and 2 and assuming that the purchasing power parity condition holds in the long run generates;

$$e = p - p^* = (m - m^*) - \beta(y - y^*) + \delta(i - i^*) \quad (3)$$

The model estimated by Frankel (1979) is different to some extent from Equation 3 because of introducing two additional assumptions. The first assumption is that interest rate parity is associated with efficient markets in which the bonds of different countries are perfect substitutes;

$$d = i - i^* \quad (4)$$

The second fundamental assumption is that the expected rate of depreciation is a function of the gap between the current spot rate and an equilibrium rate, and of the expected long-run inflation differential between the domestic and foreign countries:

$$d = -\theta(e - \bar{e}) + \pi - \pi^* \quad (5)$$

Where  $e$  is the log of the spot rate;  $\pi$  and  $\pi^*$  are the current rates of expected long-run inflation at home and abroad, respectively.

Combining Equations 4 and 5 yields;

$$e - \bar{e} = -\frac{1}{\theta} [(i - \pi) - (i^* - \pi^*)] \quad (6)$$

Frankel (1979) argues that the expression in brackets can be described as the real interest differential. Using bars to denote equilibrium values, Frankel (1979) further argues that when  $e = \bar{e}$ ,  $\bar{i} - \bar{i}^* = \pi - \pi^*$  in the long run and expressed Equation 3 as follows.

$$\bar{e} = \bar{p} - \bar{p}^* = \bar{m} - \bar{m}^* - \beta(\bar{y} - \bar{y}^*) + \delta(\pi - \pi^*) \quad (7)$$

Furthermore, substituting Equation 7 into Equation 6 and assuming that the current equilibrium money supply and income levels are given by their current actual levels, a complete equation of spot rate determination given below.

$$e = m - m^* - \beta(y - y^*) - \frac{1}{\theta}(i - i^*) + \left(\frac{1}{\theta} + \delta\right)(\pi - \pi^*) \quad (8)$$

Equation 8 can be expressed with an error term as follows.

$$e = m - m^* - \beta(y - y^*) + \alpha(i - i^*) + \varphi(\pi - \pi^*) + u \quad (9)$$

Where  $\alpha$  ( $=-1/\theta$ ) is hypothesized negative and  $\varphi$  ( $=1/\theta + \delta$ ) is hypothesized positive and greater than  $\alpha$  in absolute value. The innovation that was introduced by Frankel (1979) aims at combining the Keynesian assumption of sticky price with the Chicago

assumption that there are secular rates of inflation. Unlike the original hypothesis concerning the relationship between the exchange rate and the nominal interest rate differential, it turns out that the exchange rate is negatively related to the nominal interest differential, but positively related to the expected long run-inflation differential.

The main difference between the models of Dornbusch and Frankel lie in the hypothesised sign of the coefficient of the nominal interest rate in their equations. Unlike the hypothesized negative sign in the Frankel model, Dornbusch argues that relatively higher domestic interest rates reduce the demand for real balances, raise prices, and therefore bring about an exchange depreciation, i.e., positive coefficient of the interest rate.

The estimable model is specified in equation 10. The expected sign of the coefficients are as hypothesized by Dornbusch (1980) and Frankel (1979).

$$\ln e_t = f \left( \ln \left( \frac{m}{m^*} \right)_t^{(+)}, \ln \left( \frac{y}{y^*} \right)_t^{(-)}, (i - i^*)_t^{-/+}, (\pi - \pi^*)_t^{+} \right) \quad (10)$$

$\ln e_t$  is the logarithm of nominal rand-US dollar exchange rate(rand/US dollar).

$\ln \left( \frac{m}{m^*} \right)_t$  is the difference between South Africa's nominal money supply (M3) to

US money supply(M3).  $\ln \left( \frac{y}{y^*} \right)_t$  is the difference between South African real GDP



and US real GDP in different currencies.  $(i - i^*)_t$  is the difference between nominal Treasury bill rate of South Africa and the US.  $(\pi - \pi^*)_t$  is the inflation differential between South Africa and the US.

In the standard monetary model, the coefficients have structural interpretations, which vary with underlying assumptions. The money supply coefficient is restricted to be unity since an increase in the relative money supply at home is hypothesized to lead to an equi-proportionate depreciation (Dornbusch, 1980 and Frankel, 1979). Consistent with the monetary approach, the coefficient for the real GDP differential is expected to be negative. A negative sign is expected on the difference of nominal interest rate differential under the Frankel (1979) but a positive relationship under the Dornbusch (1980) model. Inflation differential is expected to have a positive sign.

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#### Estimation methodology

In accordance with Johansen (1988), Equation 10 is re-specified as a reduced-form vector autoregression (VAR);

$$X_t = \beta_0 + \beta_1 X_{t-1} + \dots + \beta_j X_{t-j} + \varepsilon_t \quad (11)$$

Where  $X_t$  is a vector of variables;

$$X'_t = \left( \ln\left(\frac{y}{y^*}\right)_t, \ln\left(\frac{m}{m^*}\right)_t, (\pi - \pi^*)_t, (i - i^*)_t, \ln e_t \right)$$

The ordering of the variables is dictated by the need to have meaningful impulse-response functions from the VECM. Cholesky decomposition is utilised for orthogonalisation, which implies that the Cholesky factor is lower triangular. Thus the first variable is not affected contemporaneously by any other variable in the VAR. The last variable (exchange rate) is contemporaneously affected by all the other variables.

Along with the long-term relationship that is captured by the Dornbusch model specified in Equation 3, a VECM (Vector Error Correction Model) of the following form is estimated to see the short run exchange rate dynamics.

$$\Delta X_t = \pi X_{t-1} + \sum_{i=1}^{p-1} \pi_i \Delta X_{t-i} + \varepsilon_t \quad (12)$$

The estimation procedure is as follows. First, reduced-form VAR in Equation 11 is estimated and diagnostic tests performed. Second, Johansen cointegration test is performed. The cointegrating vectors and loading matrices are identified. Third, a VECM in Equation 12 is estimated and diagnostic tests performed. Finally, innovation accounting (impulse-responses and variance-decomposition analyses) is performed. In view of the extensive nature of the estimation procedure only selected results are presented in the main body and the appendix.

### Estimation results

The appropriate model is selected on the basis of the nature of the DGP of all the five variables, the original Dornbusch (1980) model and the results of the trace and maximum eigenvalue tests are presented in Table 1. On the basis of applying the Pantula principle to testing which version of the deterministic component should be used, the trace test identified two cointegrating vectors while the maximum eigenvalue test found no cointegration for a model with trend but no intercept in the cointegrating equation (CE).

**Table 1: Cointegration test results**

Trace Test				Maximum Eigenvalue Tests			
$H_0$	$H_1$	$\lambda$ -Trace Stat.	5% CV	$H_0$	$H_1$	$\lambda$ -max	5% CV
$r = 0$	$r \geq 1$	<b>109.22**</b>	<b>88.80</b>	$r = 0$	$r = 1$	<b>35.97</b>	<b>38.33</b>
$r \leq 1$	$r \geq 2$	<b>73.24**</b>	<b>63.87</b>	$r = 1$	$r = 2$	<b>31.25</b>	<b>32.12</b>
$r \leq 2$	$r \geq 3$	<b>41.99</b>	<b>42.92</b>	$r = 2$	$r = 3$	<b>22.36</b>	<b>25.82</b>
$r \leq 3$	$r \geq 4$	19.64	25.87	$r = 3$	$r = 4$	12.79	19.39
$r \leq 4$	$r \geq 5$	6.84	12.52	$r = 4$	$r = 5$	6.84	12.52

Equation 13 shows the long-run part of the VECM in Equation 12. The first long-run equation is the nominal exchange rate. The coefficient of the relative money supply is normalized to one in accordance with the original model of Dornbusch (1980).

$$\pi X_{t-1} = \alpha \beta' X_{t-1} = \begin{bmatrix} \alpha_{11} & \alpha_{12} \\ \alpha_{21} & \alpha_{22} \\ \alpha_{31} & \alpha_{32} \\ \alpha_{41} & \alpha_{42} \\ \alpha_{51} & \alpha_{52} \end{bmatrix} \begin{bmatrix} \beta_{11} & -1 & \beta_{31} & \beta_{41} & 1 \\ 0 & 0 & \beta_{32} & 1 & \beta_{52} \end{bmatrix} \begin{bmatrix} \ln\left(\frac{y}{y^*}\right)_{t-1} \\ \ln\left(\frac{m}{m^*}\right)_{t-1} \\ (\pi - \pi^*)_{t-1} \\ (i - i^*)_{t-1} \\ \ln e_{t-1} \end{bmatrix} \quad (13)$$

The second cointegrating vector identifies the interest rate differential equation. It relates interest rate differential with inflation differentials and the exchange rate.

The estimated nominal exchange rate equation is presented in equation 14 with t-values in parentheses;

$$\ln e_t = -6.33 - 2.39 \ln\left(\frac{y}{y^*}\right)_t + 1 \ln\left(\frac{m}{m^*}\right)_t + 1.49(\pi - \pi^*)_t - 0.72(i - i^*)_t + 0.06t \quad (14)$$

(-3.05)
(5.09)
(-18.74)
(3.19)

All the coefficients are statistically significant and consistent with what was hypothesized by Dornbusch-Frankel model (Equation 10).

Income elasticity of demand is consistent with Dornbusch model and implies that an increase in income differential would lead to an appreciation of the rand-dollar exchange rate. The coefficient for the money supply differential is restricted to unity. The coefficient on the inflation differential is consistent with the Dornbusch-Frankel monetary model. It is positive and greater than the coefficient for interest differential in absolute terms. Thus an increase in South Africa's inflation relative to the US leads to a depreciation of the rand in the long-run.

The value of the interest semi-elasticity of money demand is consistent with the Frankel(1979) model and not Dornbusch(1980) model. This means that relatively

higher interest rates in South Africa reduce prices and therefore bring about nominal appreciation of the rand. The magnitude of this parameter is positively related to price stickiness. The more rapid price adjustment is the smaller this coefficient is in absolute terms. The coefficient of  $-0.72$  shows that goods market prices in South Africa adjust sluggishly while the asset market is hyperactive.

The positive time trend means that the nominal exchange rate generally depreciated during the period 1994 to 2004.

The estimated second cointegrating vector is an equation for interest differential.

$$(i - i^*)_t = -1.22 + \underset{(5.12)}{2.57}(\pi - \pi^*)_t - \underset{(-7.92)}{1.45} \ln e_t + \underset{(3.56)}{0.11}t \quad (15)$$

First, an increase in inflation differential leads to an increase in interest rate differential. This may be rationalized by the fact that South Africa would increase interest rates to contain the inflation pressures. Second, a depreciation of the rand would lead to a reduction in interest rate differential. Since South Africa's interest rates are generally above those of the US (Figure 4 in the appendix), depreciation of the rand is consistent with high interest rates in the US i.e reduced nominal interest rate differential. Third, there is a general trend of the interest differential to increase as shown by the positive time trend.

Table 2 presents adjustment coefficients ( $\alpha$ -values or loading matrices) that play significant role in bringing back the system to equilibrium in case of discrepancy from the long run relationship. First, the  $\alpha$ -values are all within 0 to 2 range as expected.

Second those variables with 0 loading factors (speed of adjustment) mean that the cointegrating vector does not enter into the short-run determination for that variable. This means that those variables are weakly exogenous. For instance, income differential is weakly exogenous in the exchange rate and interest rate differential equations. Thus, if there is a shock that pushes exchange rate away from the equilibrium in Equation 14, income differential would not adjust immediately to correct the discrepancy. This is expected given the fact that real GDP takes time to adjust as opposed to financial variables.

**Table 2: Estimated Loading Matrices and Weak Exogeneity Tests**

Variables	$\ln e_t$ equation	$(i - i^*)_t$ equation
$\Delta \ln \left( \frac{y}{y^*} \right)_t$	0.00	0.00
$\Delta \ln \left( \frac{m}{m^*} \right)_t$	0.21 (4.81)	-0.12 (-4.71)
$\Delta (\pi - \pi^*)_t$	0.59 (4.50)	0.00
$\Delta (i - i^*)_t$	0.00	0.00
$\Delta \ln e_t$	-0.23 (-1.42)	0.15 (1.59)

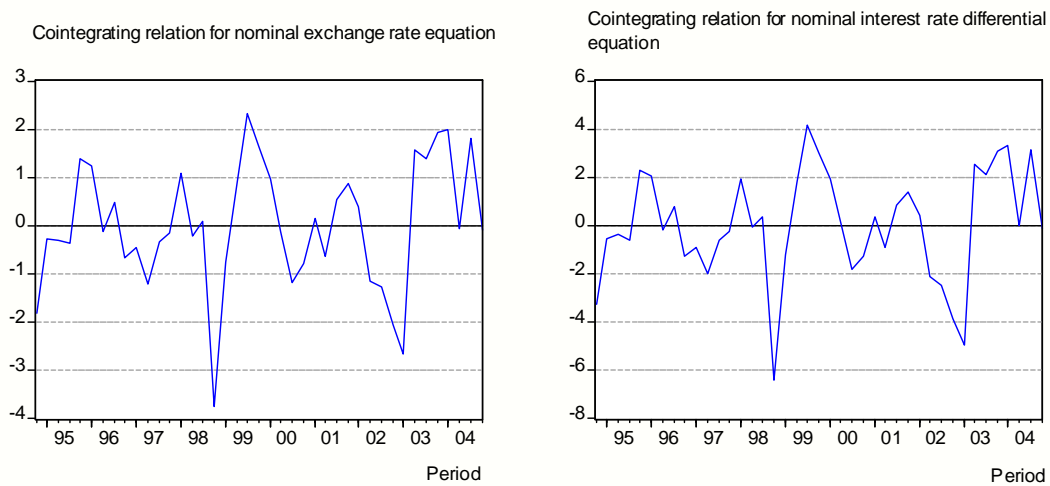
*Notes:* t-statistics are given in square brackets.

: The likelihood ratio test for binding restrictions is  $LR = 10.09784(0.120592)$ . The probability of committing Type I error in the parenthesis. This test refer to both long-run and the above loading matrix restrictions.

Third, the fact that some loading factors are positive in the exchange rate equation implies that they tend to push the system away from equilibrium. The nominal exchange rate, although negative, is insignificant implying that it does not play a pivotal role in returning the exchange rate (Equation 14) back to equilibrium.

Figure 1 shows the graphs of the estimated cointegrating relations in Equations 14 and 15 from the VECM. Since the graphs revert to the equilibrium (zero), the cointegrating relations are appropriate.

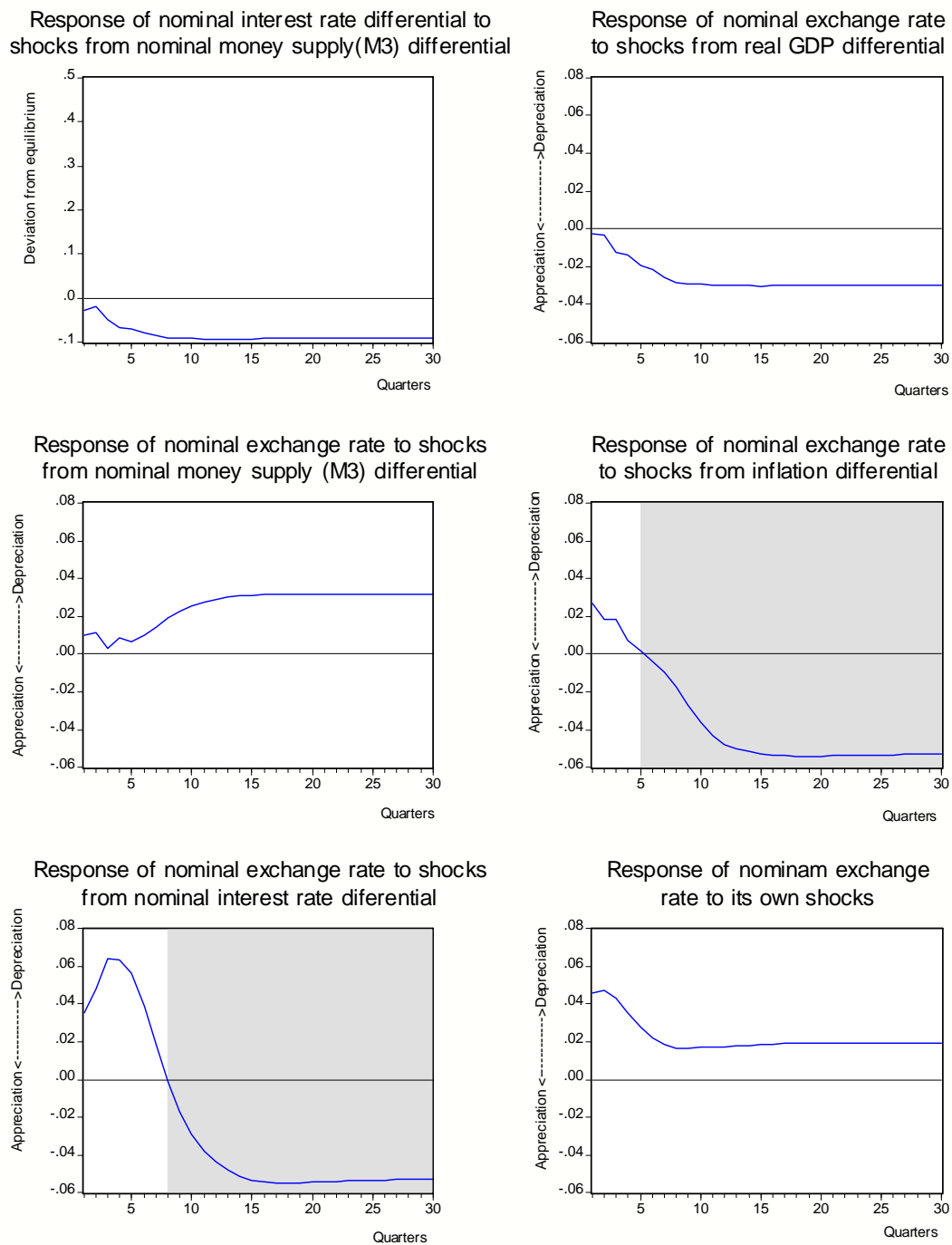
**Figure 1: Cointegrating relations from VECM**



### Impulse-response functions

A shock to the  $i$ -th variable not only directly affects the  $i$ -th variable but is also transmitted to all of the other endogenous variables through the dynamic (lag) structure of the VAR. An impulse response function traces the effect of a one-time shock to one of the innovations on current and future values of the endogenous variables. The impulse responses are derived from the VECM, which is orthogonalised using Cholesky (lower triangular) decomposition. Figure 2 shows the impulse-responses.

**Figure 2: Response to one standard deviation shock over 30-quarter horizon**



First, the expectation is that the expansion in money supply lowers interest rates. This can be seen in the impulse-response graph (row 1-column 1 of Figure 2). A one standard deviation Cholesky positive innovation of nominal money supply differential



causes a revision downwards of the forecast of interest rate differential over the 30 - quarters period.

Second, once the public observe the increase in the money supply they would form an immediate rational expectation that ultimately the rand will depreciate proportionately. There will be potential flight of capital out of South Africa, which puts pressure on the rand to depreciate. The potential capital flight from South Africa, would only cease when the rand overshoots its long-run level i.e.  $\frac{\Delta \ln e}{\Delta(\ln m - \ln m^*)} > 0$ .

This can be seen in the impulse-response (row 2-first column 1 of Figure 2).

Third, a one standard deviation positive innovation in nominal interest rate differential leads to a depreciation of the rand in the first 8 quarters and appreciation thereafter (row 3-column 1 in Figure 2). This means that the results are consistent with Dornbusch(1980) only in the first 8 quarters but in line with Frankel(1979) model thereafter. This is quite important for the Monetary Policy Committee (MPC) of the Reserve Bank. A relatively higher nominal interest rates in South Africa leads to a depreciation of the rand in the first 8 quarters and only deliver the intended results thereafter.

Fourth, one standard deviation positive shock from real GDP differential causes nominal exchange rate to appreciate over the 30 quarters horizon (row 1-column 2 of Figure 2). This is in line with the Dornbusch-Frankel sticky prices model.

Fifth, one standard deviation positive shock from inflation differential leads to a depreciation of the rand in the first 5 quarters (row 2-column2 in Figure 2). Thereafter, the rand appreciates. This means that the response is in accordance to with the monetary model of the exchange rate in the first 5 quarters only.

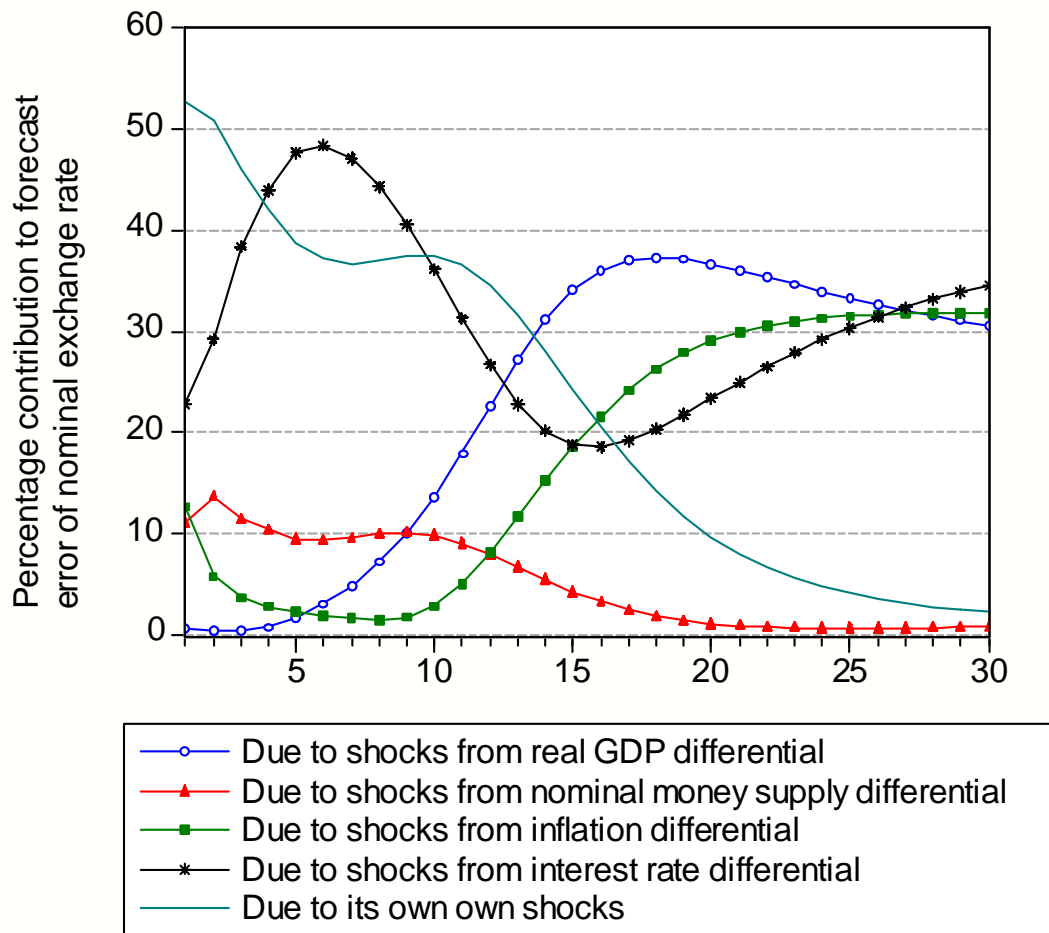
Finally, exchange rate depreciating shocks that originate outside the VECM cause the rand to depreciate over the 30-quarter horizon.

Figure 3 shows the forecast error variance decomposition (FEVD) of the nominal exchange rate. The FEVD provides information about the relative importance of each random innovation in affecting the nominal exchange rate over the 30-quarter period.

Since VECM is orthogonalised using the Cholesky (lower triangular) decomposition, the nominal exchange rate (ordered last in the VAR) is affected by all the other variables in the VECM. In the beginning, much of the errors made in forecasting exchange rate are attributed to its own shocks. Thereafter the errors are increasingly attributed to shocks from interest rate differential, real GDP differential and inflation differential. The nominal money supply differential plays limited role in explaining the forecast errors in nominal exchange rate.

Thus the variables included in the VECM are important in explaining the movement of nominal exchange rate.

**Figure 3: Forecast Error Variance Decomposition of Nominal Exchange Rate**



**5**

**Conclusion**

The Dornbusch-Frankel sticky-price overshooting monetary model appears to underlie the movement of the nominal rand-USD exchange rate in the period 1994 to 2004. Notwithstanding the conventional wisdom concerning the futility of structural exchange rate modeling attributed to Meese and Rogoff (1983), the model has some lessons for the MPC in the short-run and long-run. First, prices in South Africa are sticky as shown by the high-income elasticity of demand. Second, increasing interest

rates with a view to strengthening the rand does the opposite in the short-run i.e. depreciate the rand in the first 8 quarters.

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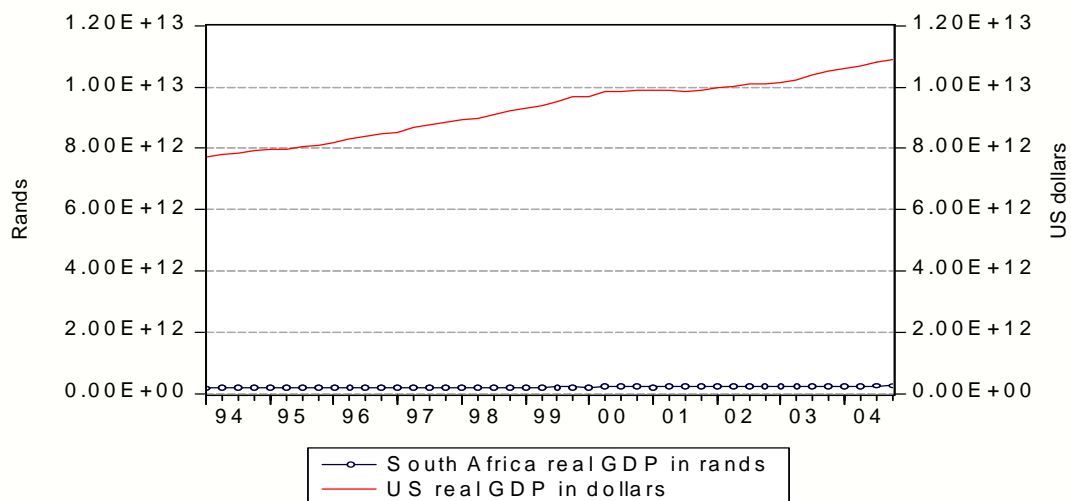
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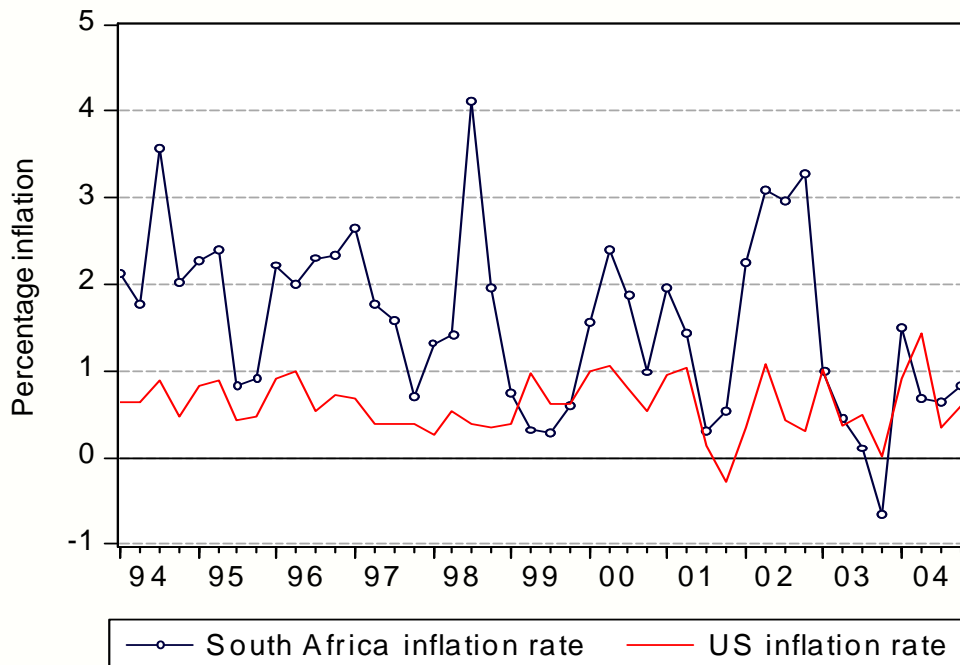
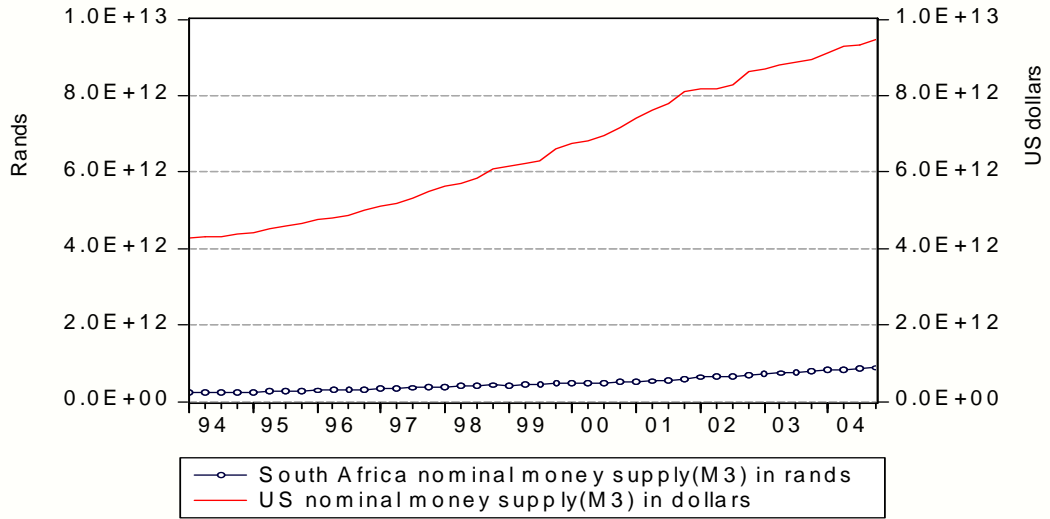
## Appendix

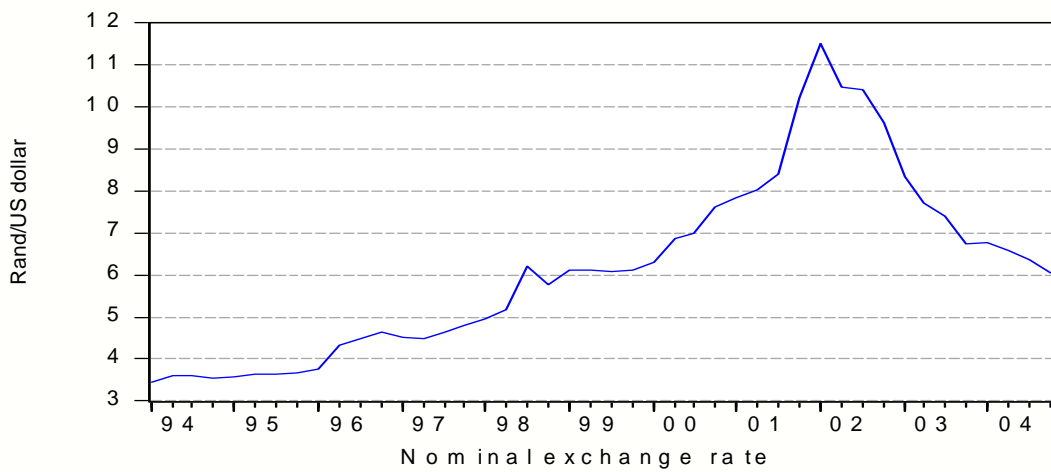
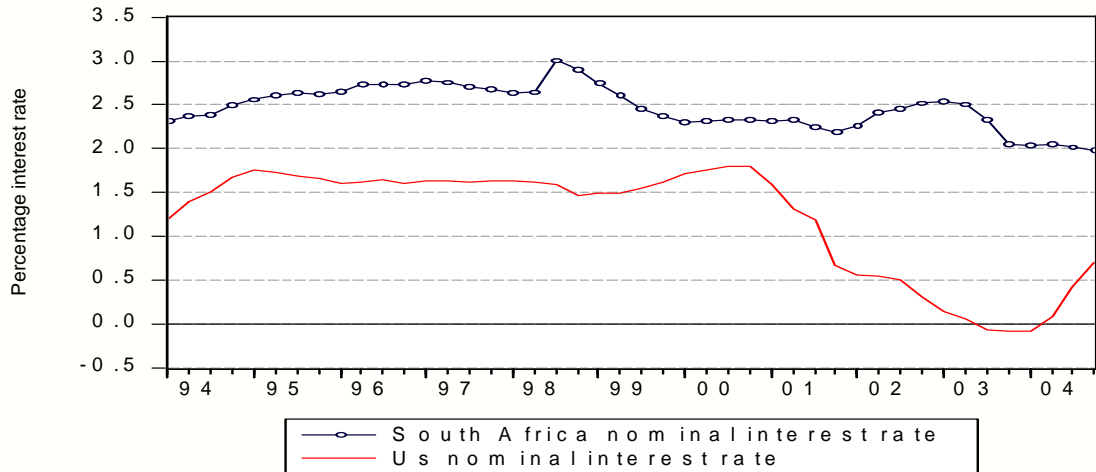
### Data

Quarterly data are collected for all the variables from IMF's international financial statistics, the South African Reserve Bank, and Bureau of Economic Analysis of the U.S. Department of Commerce. Data is seasonally adjusted data on all the variables. The study is limited to the period covering 1994Q1 to 2004Q4 since variability in the exchange rate of the Rand was restricted via the dual exchange rate regime.

**Figure 4: Graphical Representation of all the Variables**







### Tests for unit root

All the variables included in the model are tested for unit root. The Augmented Dickey Fuller test of unit root is performed on each of the variables using an iterative procedure highlighted in Enders (2004:213). All the variables are found to be I(1).



**Table 3: The ADF test for unit root**

Variable	Model specification	ADF-statistic	Joint test (F-statistic)	Conclusion
$e$	Intercept & Trend (random walk with drift and time trend)	0.311	$\Phi_3=2.0011$	
	Intercept (random walk with drift)	-1.575	$\Phi_1=2.0578$	
	None (pure random walk)	0.436		I(1)
$m - m^*$	Intercept & Trend (random walk with drift and time trend)	-1.358	$\Phi_3=0.9544$	
	Intercept (random walk with drift)	-0.109	$\Phi_1=3.820^{**}$	I(1)
$y - y^*$	Intercept & Trend (random walk with drift and time trend)	-1.853	$\Phi_3=2.1056$	
	Intercept (random walk with drift)	-2.076	$\Phi_1=2.1802$	
	None (pure random walk)	0.192		I(1)
$i - i^*$	Intercept & Trend (random walk with drift and time trend)	-3.082	$\Phi_3= 5.4907$	
	Intercept (random walk with drift)	-2.027	$\Phi_1=2.0565$	
	None (pure random walk)	-0.731		I(1)
$p - p^*$	Intercept & Trend (random walk with drift and time trend)	-2.406	$\Phi_3=4.1403$	
	Intercept (random walk with drift)	-1.873	$\Phi_1=4.7681$	
	None (pure random walk)	-1.789*		I(1)

Notes : \* (\*\*) [\*\*\*] Significant at 10 (5), [1] percent level

Critical values for the  $\Phi_3$ , and  $\Phi_1$  are from Dickey and Fuller (1981)

“General to specific model ” iterative procedure in Enders (2004:213) is used

### Reduced-Form VAR Diagnostic Tests

All the roots have modulus less than one and lie inside the unit circle. Other diagnostics tests for the VAR are presented in Table 4. the error term is white noise despite the lack of normality of the distribution of the error terms. However, the results of the Johansen (1988) tests will not be affected because of the lack of normality as long as the skewness of the distribution of the error terms is fine (Paruolo, 1997).

**Table 4: Diagnostics on the reduced-form VAR**

	<b>H<sub>0</sub></b>	<b>Test</b>	<b>Statistic</b>	<b>Prob.</b>
Serial correlation	No serial correlation	LM-Test – $\chi^2$ (lag. 3)	26.76	0.37
Normality	Normally distributed error terms	JB – Joint	21.92	0.02
		Kurtosis – Joint	13.69	0.02
		Skewness – Joint	8.23	0.14
Heteroscedasticity	No heteroscedasticity	$\chi^2$	603.64	0.45