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EXCHANGE RATE FUNDAMENTALS AND DYNAMICS IN A LIBERALIZED FOREIGN EXCCHANGE MARKET: EVIDENCE FROM UGANDA

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Abstract

This paper investigates exchange rate fundamentals and dynamics since the liberalization of the foreign exchange market in Uganda. The longrun behaviour of the exchange rate and the underlying fundamentals is investigated using both multivariate cointegration framework and dynamic ordinary least squares (DOLS). The DOLS elasticities are largely consistent with those derived from the Johansen and Juselius maximum likelihood approach, except in a few cases. In general both approaches indicate that the fundamentals determine the longrun behaviour of the exchange rate in Uganda are domestic money supply, price differential, terms of trade, and private transfers or remittances from abroad.

Having established the existence of a long run relationship, the shortrun dynamics are investigated using a vector error correction model. The results indicates that 2.7 percent of the adjustment towards the longrun equilibrium takes place in one month. In terms of shortrun dynamics, the significant lags are a one-period and a two-period lagged difference of the exchange rate; a two-period and a three-period lagged difference of money supply; a one-period, two-period and three-period lagged difference of the price differential; a two period lagged difference of the terms of trade; a one-period and four-period lagged difference of private transfers; and a two-period lagged difference of the foreign interest rate. It is thus evident that the exchange rate behaviour is influenced by monetary policy actions, current account dynamics, and to a limited extent, movements in foreign interest rates.

JEL Classification: F31, F37, F41

Key words: Exchange rate, Exchange rate fundamentals and dynamics, cointegration, dynamic ordinary least squares, vector error correction model.

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[1] The views expressed in this paper are those of the authors and do not in anyway represent the official position of the Bank of Uganda.

Table of contents

List of tables

List of figures

1. Introduction

The question of exchange rate volatility and predictability has been a subject of academic and policy debate since the collapse of the Bretton-Woods fixed exchange rate system in 1973. Many exchange rate determination models have been developed. These models usually emphasize the importance of different fundamentals in explaining exchange rate behaviour. Indeed, Dornbusch (1980) argues that these theories can be regarded as providing partial explanations of the exchange rate behaviour. Furthermore, the empirical evidence supporting these models remains elusive. In fact Meese and Rogoff (1983) demonstrate that the exchange rate is a random walk, since none of the fundamentals-based structural models could reliably out perform a simple random walk model.

In Uganda, since the liberalization of the foreign exchange market in 1993, exchange rate fluctuations have been a persistent feature of the economy. In this paper, we investigate the behaviour of the nominal exchange rate by augmenting standard macroeconomic models with additional economic fundamentals in the hope that we generate an empirical model that provides a more robust explanation of the exchange rate behaviour in Uganda. The longrun relationship is examined using cointegration analysis. In particular, we investigate the longrun relationship using both the Johansen and Juselius (1990) maximum likelihood approach and the dynamic ordinary least squares technique of Stock and Watson (1993), and the shortrun dynamics and speed of adjustment to equilibrium after a destabilizing shock using a vector error correction model.

The rest of the paper is structured as follows. Section 2 examines the evolution of exchange rate regimes in Uganda. An overview of traditional theories of exchange rate determination is provided in section 3 while the empirical model, data characteristics and estimation framework are discussed in section 4. The empirical findings are discussed in section 5, and finally, the concluding remarks are presented in section 6.

2. Exchange rate policy in Uganda

For most of the 1970s, the official exchange rate with the US dollar was held close to the original rate at which the East African shilling had been fixed, which the Uganda shilling inherited in 1966 after the dissolution of the East African Currency Board. Economic mismanagement of the time, and artificial shortages created by the fixed exchange rate regime led to the emergence of a parallel foreign exchange market. The premium on the parallel foreign exchange market increased dramatically and by 1981, the price of foreign currency in the parallel market was over 10 times higher than the official exchange rate (Atingi-Ego and Sebudde 2003).

In 1981, an adjustment program partly aimed at correcting the exchange rate distortion was initiated. Its centerpiece was a massive devaluation of the shilling, followed by a further devaluation in July 1982. In August 1982, a two-window system was introduced; with key transactions including exports of coffee, tea, tobacco and cotton; imports of petroleum; aid-financed projects; official loan and grant inflows; and the servicing of debts and arrears being carried out through Window I at the official exchange rate; and other transactions falling under Window II through an auction system. The two windows were subsequently merged in 1984 just before the collapse of the adjustment program.[2]

In 1986, there was a brief return to the two-window system before a fixed rate system was again established at the end the year. This further aggravated the external disequilibria in the economy. Consequently, a currency reform was undertaken in May 1987 in which one hundred shillings were exchanged for one new shilling, and the shilling devaluated by 77.0 percent, in an attempt to address external imbalances. This reduced the parallel market premium substantially. In addition, various schemes, such as the Open General Licence System, the Special Import Programs and the Dual Licensing schemes for exporters wishing to import crucial inputs, were put in place to assist import-dependent industries.

In October 1989, the policy of maintaining the real effective exchange rate constant (a 'crawling peg' system) was introduced. As a result, the nominal exchange rate was adjusted on a monthly basis. In July 1990 the parallel market was legalized, leading to the establishment of foreign exchange bureaux. The bureaux were permitted to conduct spot transactions at freely determined exchange rates. Limits, albeit liberal, were placed on invisible payments in a bid to address concerns about capital flight.

In a further move towards a market based exchange regime, a foreign exchange auction system for import support funds was introduced in January 1992. Initially, commercial banks, and later foreign exchange bureaux, were permitted to bid in the auction, provided they were in a good financial footing with the Bank of Uganda. The auction was held weekly under the Dutch auction system, whereby each successful bidder paid its bid price. Eligibility of imports was based on a short "negative" list of goods jointly set by the Government and the donor community.

The move to the auction system effectively ended the period of administered exchange rates. The private sector bought foreign exchange at market-

[2] The adjustment program almost achieved the unification of the exchange rates before it collapsed.

determined rates in the bureaux market or through the auction. Transactions through the official channel, including Government, were initially conducted at the auction rate and later at an average of the bureaux rates. However, while exchange rates were market determined, the foreign exchange market remained segmented. By end October 1993, there was still a premium of about 5.0 per cent between the auction and the bureau rate. Thus, in spite of the introduction of the auction system, exchange rate convergence remained elusive.

In order to eliminate the segmented nature of the foreign exchange market and to bring about convergence of the exchange rates, an inter-bank foreign exchange market system was introduced in November 1993. This was expected to provide a more efficient and reliable mechanism for determining the official exchange rate and allocating scarce foreign exchange resources. Authorized dealers, including bureaux were free to set their exchange rates while trading among themselves. Subsequently, on fifth April 1994, the government accepted the obligations of Article VIII, Sections 2,3 and 4 of the IMF's Articles of Agreement, expressing its commitment to a free and open exchange rate system.

The floating exchange rate system has, nonetheless, presented certain difficulties for the country. First, it has heightened the risk of exchange rate volatility, which is synonymous with the flexible exchange rate system. Second, the adoption of a flexible exchange rate system meant the loss of the exchange rate as a nominal anchor for domestic prices. Finally, the operation of an efficient foreign exchange market may not be technically feasible in a situation where financial markets are underdeveloped.[3] This is where Uganda finds its self today. In order to have a better understanding of the exchange rate fundamentals and dynamics, the next section highlights some theoretical and empirical insights of the theories of exchange rate determination.

3. Models of exchange rate determination

This section presents an overview of theories of exchange rate determination. In particular, the purchasing power parity model, the monetary model and the portfolio balance model are discussed. In addition, given the empirical failures of the theoretical models of exchange rate determination, the random walk hypothesis is discussed. Finally, an overview of empirical issues is presented.

[3] In view of the linkages between different financial operations, some degree of development in other financial markets is necessary to support the operation of a smoothly functioning foreign exchange market with a floating rate.

3.1 Purchasing Power Parity

The simplest model of exchange rate determination is based on the concept of purchasing power parity (PPP). Whether reflecting the notion that the law of one price holds in traded goods or the Casselian view that the value of a currency should reflect its relative purchasing power, the notion of PPP is central in international macroeconomics.[4] The Casselian view of PPP theory relates the exchange rate to relative price levels. It states that the exchange rate between two currencies over any period of time is determined by the change in the two countries price levels. This theory is also called the 'inflation theory' of exchange rate determination, because it singles out price levels as the overriding factor in the determination of the exchange rate. The basic concept underlying PPP is that arbitrage forces will equalize prices of goods internationally if they are measured in the same currency. There are basically two forms of PPP, absolute and relative PPP.

The absolute version states that the nominal exchange rate (S), measured as the domestic currency price of the foreign currency, is determined by the ratio of domestic prices (P) and foreign prices (P^*).[5] That is:

$$S = P/P^* \tag{1}$$

By taking logarithms, equation (1) can be rewritten as:

$$s_t = p_t - p_t^* \tag{2}$$

Where the lower case letters denote natural logarithms of variables.

The relative version of PPP states that the percentage change in the nominal exchange rate is equal to the difference in inflation rates between the two countries. This relationship is expressed in equation (3).

$$\Delta s = \Delta p - \Delta p^* \tag{3}$$

Where Δ denotes a percentage change and all other variables as earlier on defined.

Empirical investigation on the validity of PPP in the short-run has yielded mixed results.[6] But, although there are disputes on the validity of the short-run

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[4] Since the objective of this paper is to examine exchange rate fundamentals, we focus on the Casselian view of PPP.

[5] It is very unlikely that the absolute version of PPP will hold because of the existence of transport costs, imperfect information and the distorting effect of tariffs and protections.

[6] There are several reasons that have been identified as the root causes of deviations from PPP, First, there may be restrictions on trade and capital movements or transfer pricing in a country, which distorts the relationship between the relative price levels. Second, productivity bias, manifested in faster productivity growth in the tradable goods sector relative to the non-tradable goods sector, may result in systematic divergence of internal prices (see Balassa, 1964).

relationship, there seems to be a general agreement that PPP will hold in the long-run.

3.2 Monetary model

The monetary models of exchange rate determination build on the PPP theory by imposing additional structural restrictions.[7] One such additional assumption is the money market equilibrium, which states that the log of the real money demand depends linearly on the log of real income and the nominal interest rate. This model emphasizes that the fundamentals that drive the exchange rate originate from the disequilibria in the money markets of the two countries. We discuss below three versions of the monetary model: the flexible-price model, the sticky-price model, and the currency substitution model.

3.2.1 The flexible-price model

This assumes that prices are flexible and PPP holds all the time. The basic tenet is that the demand for real balances is a stable function of real income. Assume identical specifications of domestic and foreign money demand functions as given in equations (4a) and (4b).

$$m_t^d - p_t = ky_t - \lambda i_t \tag{4a}$$

$$m_t^{*d} - p_t^* = ky_t^* - \lambda i_i^* \tag{4b}$$

where m_t^d, p_t, y_t denote demand for nominal balances, the price level, real income, all expressed in logarithms; i_t nominal interest rate; and the superscript " * " indicates a foreign variable. In equilibrium, the money market must clear. Accordingly, in the two countries, money market equilibrium conditions will be represented by equations (5a) and (5b).

$$m_t = p_t + \lambda_1 y_t - \lambda_2 i_t \tag{5a}$$

$$m_t^* = p_t^* + \lambda_1^* y_t^* - \lambda_2^* i_i^* \tag{5b}$$

Subtracting equation (5b) from (5a) yields the relative money market equilibrium condition given in equation (6).

$$(m_t - m_t^*) - (p_t - p_t^*) = (\lambda_1 y_t - \lambda_2 i_t) - (\lambda_1^* y_t^* - \lambda_2^* i_t^*) \tag{6}$$

Rearranging equation (6) and assuming that the income elasticities and interest rate semi-elasticities of demand for money do not differ significantly, that is, $\lambda_1 = \lambda_1^*$ and $\lambda_2 = \lambda_2^*$, yields the relationship depicted in equation (7).

[7] These restrictions, if true, should lead to better asymptotic performance. In fact, Mark and Sul (2001) provide evidence that suggests that the linkage between nominal exchange rates and monetary fundamental is stronger than that between nominal exchange rates and purchasing power parities.

$$p_t - p_t^* = (m_t - m_t^*) - \lambda_1 (y_t - y_t^*) + \lambda_2 (i_t - i_t^*) \quad (7)$$

If PPP holds continuously, then equation (7) can be expressed in terms of the exchange rate as given in equation (8).

$$s_t = (m_t - m_t^*) - \lambda_1 (y_t - y_t^*) + \lambda_2 (i_t - i_i^*) \quad (8)$$

Equation (8) expresses the exchange rate as a function of the relative money stocks, relative real income and the interest rate differential. Substituting the efficient market hypothesis condition, that is, $i_t - i_t^* = \pi_{t+1}^e - \pi_{t+1}^{e^*}$, into equation (8) yields:

$$s_t = (m_t - m_t^*) - \lambda_1 (y_t - y_t^*) + \lambda_2 (\pi_{t+1}^e - \pi_{t+1}^{e^*}), \quad (9)$$

where π_{t+1}^e is the expected rate of inflation. The term $\lambda_1 (y_t - y_t^*)$ captures the transactions demand for money while $\lambda_2 (\pi_{t+1}^e - \pi_{t+1}^{e^*})$ captures the influence of the value of money on the demand for money. Together, the two terms represent the relative demand for money in the two countries while $(m_t - m_t^*)$ represents the relative supply of money.

If y_t is growing faster than y_t^*, then the demand for domestic currency by domestic residents will be growing faster than the demand for foreign currency by foreign residents.[8] If the relative money supply, $(m_t - m_t^*)$, remains unchanged, then the value of the domestic currency relative to the foreign currency will increase, i.e., the domestic currency appreciates. In the case of inflation expectations, if expected inflation in the domestic economy increases, then the value of the domestic currency depreciates. On the other hand, an increase in foreign inflation expectations relative to domestic inflation expectations will lead to an appreciation of the domestic currency. On the relative money supply $(m_t - m_t^*)$ side, an increase in m_t relative to m_t^* leads to a depreciation of the domestic currency since the liquidity conditions in the domestic country have eased relative to the foreign country.

If the uncovered interest parity (UIP) condition, that is, $\Delta s_{t+1}^e = i_t - i_t^*$, holds, where $\Delta s_{t+1}^e = s_{t+1}^e - s_t$ then incorporating this condition into equation (8) yields an exchange rate determination equation that integrates exchange rate expectations as given in equation (10).

$$s_t = (m_t - m_t^*) - \lambda_1 (y - y_t^*) + \lambda_2 (s_{t+1}^e - s_t) \quad (10)$$

Solving equation (10) for s_t and re-arranging the resultant equation yields:

[8] This follows from the transactions demand for money.

$$s_t = \frac{1}{1+\lambda_2}\left[(m_t - m_t^*) - \lambda_1 (y - y_t^*) + \lambda_2 \tilde{s}_{t+1} \right] \quad (11)$$

Equation (11) expresses the exchange rate as a discounted present value of the fundamentals and expectations. Equation (11) further shows that even if the fundamentals are constant, expectations can generate exchange rate volatility. Specifically, the nominal exchange rate is positively related to the relative money supply and the expected exchange rate and negatively related to income differential.

3.2.2 The sticky-price (overshooting) model

In contrast to the flexible-price model, the sticky-price model (also called the overshooting model) developed by Dornbusch (1976) and Frankel (1979) incorporates short-term rigidities. It assumes that nominal output prices are sticky, and consequently the goods markets are not always in equilibrium. Furthermore, it assumes that PPP holds only in the long-run.[9] Consequently, the exchange rate may in the shortrun deviate from its longrun equilibrium value. MacDonald (1988) and Obstfeld and Rogoff (1996) argue that this model is basically an extension of the Mundell-Fleming model. Consequently, this model is also known as the Mundell-Fleming-Dornbusch (MFD) model.

The sticky-price model, incorporates short-term interest rates to capture the liquidity effect. It assumes that the expected rate of exchange rate depreciation is a function of the gap between the current exchange rate and the longrun equilibrium rate, and the expected longrun inflation differential between the domestic and foreign countries.

$$\Delta s_{t+1}^{e} = -\delta(s_t - \bar{s}_t) + \pi_t^{e} - \pi_t^{e^*} \quad (12)$$

From equation (12) it can be argued that the exchange rate can deviate from its longrun equilibrium level in the shortrun and convergence to a new longterm equilibrium depends on the speed of adjustment parameter (δ).

In the longrun, $s_t = \tilde{s}_t$, thus the expected rate of currency depreciation will be equal to the difference between expected domestic and foreign inflation rates. Combining the UIP condition with equation (12) results in equation (13).

$$s_t - \bar{s}_t = -\frac{1}{\delta}[(i_t - \pi_t^e) - (i_t^* - \pi_t^{e^*})] \quad (13)$$

Equation (13) shows that the gap between the current exchange rate and its longrun level is proportional to the real interest rate differential between the

[9] In the presence of short-term price stickiness, the PPP condition would be violated temporarily and the relation between interest rates and exchange rate needs to capture this short-term liquidity effects of monetary policy.

domestic and foreign country. If the domestic real interest rate is higher than the foreign real interest rate, then there will be a portfolio shift from foreign to domestic bonds. In the longrun, interest rate differential is equal to the longrun expected inflation differential, that is, $\bar{i}_t - \bar{i}_t^* = \pi_t^e - \pi_t^{e^*}$. Incorporating this relationship into equation (13) results in equation (14).

$$s_t - \bar{s}_t = -\frac{1}{\delta}[(i_t - \bar{i}_t) - (i_t^* - \bar{i}_t^*)] \tag{14}$$

In the longrun, PPP holds and can be written as: $\bar{s}_t = \bar{p}_t + \bar{p}_t^*$. Thus, from the flexible model, the expression for the longrun exchange rate is by equation (15).

$$\bar{s}_t = (\bar{m}_t - \bar{m}_t^*) - \lambda_1(\bar{y}_t - \bar{y}_t^*) + \lambda_2(\pi_t^e - \pi_t^{*^*}) \tag{15}$$

The shortrun sticky-price equation of Dornbusch (1976) is arrived at by substituting equation (15) into equation (14). The resultant expression is given in equation (16).

$$s_t = (\bar{m}_t - \bar{m}_t^*) - (\bar{y}_t - \bar{y}_t^*) + (\pi_t^e - \pi_t^{*^*}) - \frac{1}{\delta}\left[(i_t - \bar{i}_t) - (i_t^* - \bar{i}_t^*)\right] \tag{17}$$

Equation (17) is the Dornbusch (1976) overshooting exchange rate model. From equation (17), it is evident that the flexible-price model is nested in the sticky-price model, which shows that the exchange rate is excessively volatile when compared with the fundamentals in the flexible-price model.

3.2.3 Currency substitution model

In addition to the assumptions of flexible-price monetary model, this model assumes that the demand for money is influenced by the availability of another form of means of exchange and that both domestic and foreign currencies provide monetary services in the economy. From the viewpoint of the currency substitution model, the money demand function is given by equation (18).

$$m_t^d - p_t = \gamma + ky_t - \lambda i_t, \tag{18}$$

where γ is the currency substitution parameter, which depends on the expected change in the exchange rate. Since in the flexible-price model, exchange rate expectations are a function of expected changes in money supply[10], γ can also be modeled as a function of both the expected change in money supply and its variance as given in equation (19).

$$\gamma = f(E_t \Delta M_{t+1}, Var(E_t \Delta M_{t+1})) \tag{19}$$

[10] Expected increase in the money supply would fuel depreciation expectations.

Expected depreciation of the exchange rate will reduce the demand for domestic currency. Since there is a positive relationship between money supply and exchange rate depreciation expectations, $E_t \Delta M_{t+1}$ will be negatively related to the currency substitution parameter (γ). As for the variance of the expected change in money supply, $Var(E_t \Delta M_{t+1})$, high variance reduces the demand for domestic currency, so the sign of the variance is also expected to be negative.

If γ takes a log linear form given in equation (20),

$$\gamma = \gamma_1 E_t \Delta M_{t+1} + \gamma_2 Var(E_t \Delta M_{t+1}), \tag{20}$$

where $\gamma_1 \ \& \ \gamma_2 < 0$, substituting equation (20) into equation (18) yields:

$$m_t^d - p_t = \gamma_1 E_t \Delta M_{t+1} + \gamma_2 Var(E_t \Delta M_{t+1}) + ky_t - \lambda i_t, \tag{21}$$

If we subtract p* from both sides of equation (21) and assume that PPP holds, by rearranging the resultant equation we obtain equation (22).

$$s_t = m_t^d - \gamma_0 E_t \Delta M_{t+1} - \gamma_1 Var(E_t \Delta M_{t+1}) - ky_t + \lambda i_t - p_t^* \tag{22}$$

If $i_t = i_t^* + E_t \Delta s_{t+1}$ then substituting this condition into equation (22) yields the relationship depicted in equation (23).

$$s_t = m_t^d - \gamma_0 E_t \Delta M_{t+1} - \gamma_1 Var(E_t \Delta M_{t+1}) - ky_t + \lambda(i_t^* + E_t \Delta s_{t+1}) - p_t^*, \tag{23}$$

and since $E_t \Delta s_{t+1} = E_t \Delta M_{t+1}$, equation (23) can be expressed as:

$$s_t = m_t^d - ky_t + [(\lambda - \gamma_0) E_t \Delta M_{t+1} - \gamma_1 Var(E_t \Delta M_{t+1})] + \lambda(i_t^* \frac{p_t^*}{\lambda}), \tag{24}$$

where the term $[(\lambda - \gamma_0) E_t \Delta M_{t+1} - \gamma_1 Var(E_t \Delta M_{t+1})]$ represents the currency substitution effect.

3.3 Portfolio balance model

This views exchange rates and interest rates as being determined simultaneously by the portfolio equilibrium conditions for wealthholders in each country. Economic agents in each country are assumed to allocate their net financial wealth among three assets: the domestic monetary base, domestic bonds and foreign bonds denominated in foreign currency.[11] An increase in foreign (domestic) interest rates causes investors to increase the desired proportions of foreign (domestic) bonds, which reduces the desired proportion of money in the wealth portfolio. In this model, the wealth constraint is given by equation (25).

[11] The desired proportions of these assets are assumed to depend on their respective returns, with domestic and foreign bonds considered imperfect substitutes.

$$W = M + B + sF\ , \qquad (25)$$

where M, B, s and F denote money balance, domestic bonds, the nominal exchange rate and foreign bonds denominated in foreign currency, respectively. The proportion of wealth held in any of the three forms on the other hand is determined by equation (26a) – (26c).

$$M_t = m[\, i_t , i_t^* , E_t(\Delta s_{t+1}), W_t\,] \qquad (26a)$$

$$B_t = b[\, i_t , i_t^* , E_t(\Delta s_{t+1}), W_t\,] \qquad (26b)$$

$$s_t F_t = f\,[\, i_t , i_t^* , E_t(\Delta s_{t+1}), W_t\,] \qquad (26c)$$

The outstanding stocks of these assets are fixed at any point in time so that the exchange rate and the two interest rates equal the values at which the wealthholders are just willing to hold existing assets.[12] Stocks of financial assets change[13] over time causing corresponding changes in interest rates and exchange rates. From the wealth constraint, it is apparent an increase in the monetary base and domestic bonds should lead to exchange rate depreciation while and increase in net holdings of foreign bonds denominated in foreign currency will lead to exchange rate appreciation. [14]

4 Methodology

4.1 Specification of the empirical model

We postulate a hybrid model that combines the features of the theoretical models discussed above and the salient features of the Ugandan economy. Consistent with the assumptions of the sticky-price model, assume that the expected rate of exchange rate depreciation is a function of the gap between the current exchange rate and the longrun equilibrium rate, and the expected longrun inflation differential between the domestic and foreign countries. Invoking the UIP condition, and assuming that PPP holds in the longrun leads to the exchange rate determination equation given in equation (27)

$$s_t = (\bar{p}_t - \bar{p}_t^*) + \frac{1}{\delta}(i_t^* - i) + \frac{1}{\delta}(\pi_t^e - \pi_t^{e^*}) \qquad (27)$$

Where the variables in lower case indicate that the variable is transformed into logarithmic form and a bar over a variable reflects its longrun value. Given the

[12] This assumes that asset markets clear continuously.

[13] Bond-financed government deficits (surpluses) increase (decrease) the private holdings of government bonds while money-financed deficits (surpluses) increase (decrease) the monetary base. On the other hand, current-account deficits (surpluses) decrease (increase) the net holding of foreign debt instruments.

[14] In this model, being a relative price of money, the exchange rate is viewed as one of the prices that equilibrates the international markets for various financial assets. The substitutability of assets and the nature of expectation formation are critical determinants of stability.

efficient market hypothesis, the longrun relative money market equilibrium can be expressed as:

$$\overline{p}_t + \overline{p}_t^* = \lambda_1(\pi_t^e - \pi_t^{e*}) + \lambda_2(\overline{y}_t + \overline{y}_t^*) + (\overline{m}_t - \overline{m}_t^*) \quad (28)$$

Assuming that equilibrium money supply and income levels are defined by their current levels, equation (28) can be substituted into equation (27) to yield equation (29).

$$s_t = (m_t - m_t^*) + \frac{1}{\delta}(i_t^* - i) + (\frac{1}{\delta} + \lambda_1)(\pi_t^e - \pi_t^{e*}) + \lambda_2(y_t + y_t^*) \quad (29)$$

If the quantity theory of money holds, then at full employment level of income and constant velocity, the price level is directly proportional to the level of money supply. Thus equation (29) can be modified to:

$$s_t = (p_t - p_t^*) + \frac{1}{\delta}(i_t^* - i) + (\frac{1}{\delta} + \lambda_1)(\pi_t^e - \pi_t^{e*}) \quad (30)$$

Meese and Rogoff (1983)[15] among others, incorporate several variants and determinants of the current account balance, such as exports, imports, and terms of trade) into equation (30). Following this tradition, we incorporate the terms of trade, donor inflows to government and Non-governmental organizations (NGOs) and private transfers. Finally, incorporating stochastic elements yields the estimable version of our model, as given in equation (31).

$$s_t = \beta_0 + \beta_1(p_t - p_t^*) + \beta_2(i_t - i_t^*) + \beta_3(\pi_t^e - \pi_t^{e*}) + \beta_4 tot_t + \beta_5 govinf_t + \beta_6 ptrans_t + \varepsilon_t \quad (31)$$

Where

$p_t - p_t^*$ = price differential measured as the difference between the domestic price level and a weighted whole sale price index of major trading partners[16]

$i_t - i_t^*$ = interest rate differential measured as the difference between the 91-day treasury bill rate and the short-term London Interbank Offer rate (LIBOR)

$\pi_t^e - \pi_t^{e*}$ = expected inflation differential proxied by changes in money supply

tot = terms of trade

$govinf$ = donor grants to government and inflows to NGOs

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15 They argued that the cumulative trade balance and current account balance are important fundamentals in the determination of the longrun exchange rate.

16 In cases where the wholesale price index was not available, the consumer price index was used.

ptrans = private transfers

4.2 Empirical framework

We investigate the longrun relationship between the exchange rate and the underlying fundamentals using two approaches. First, we employ the Johansen (1988) and the Johansen and Juselius (1990) maximum likelihood approach, which allows for multiple cointegrating vectors. Second, if the maximum likelihood approach establishes the existence of one cointegrating vector, we proceed and apply the dynamic ordinary least squares (DOLS) estimator of Stock and Watson (1993). We use both estimators for exploring the longrun relationship to increase our comfort since the popularly used Johansen and Juselius procedure is known for producing widely dispersed estimates. Having established the existence of a cointegrating vector, we then examine the shortrun dynamics using a Vector error correction model (VECM).

4.2.1 Johansen and Juselius (1990) maximum likelihood approach

This systems approach sets up a non-stationary time series as a vector autoregressive process of order k in a re-parameterized form as given in equation (32).

$$X_t = \alpha + \prod_1 X_{t-1} + \ . \ . \ . + \prod_{k-1} X_{t-k+1} + \prod_k X_{t-k} + \varepsilon_t \qquad (32)$$

where $X_t = \left(s_t, m2, p_t - p_t^*, i_t - i_t^*, \pi_t^e - \pi_t^{e^*}, tot_t, gov\,inf_t, ptrans_t \right)$ is a vector of first order integrated variables of nominal exchange rate, broad money, interest rate differential, price differential, terms of trade, donor inflows to government and NGOs and private transfers. α is a *nx1* vector of constant terms that capture time series trend characteristics, $\prod_t$ is a $n\,x\,k$ coefficient matrix, and ε_t is a vector of normally and independently distributed error terms. From Granger's representation theorem, if the coefficient matrix $\prod$ has reduced rank $r < k$, then there exists $k\,x\,r$ matrices α and β, each with rank r, such that $\prod = \alpha\beta'$ and $\beta' X_t$ is $I(0)$[17].

4.2.2 Dynamic ordinary least squares (DOLS)

DOLS introduced by Stock and Watson (1993) is a parametric approach for estimating long-run equilibria in systems, which may involve variables integrated of different orders but still conitergrated. DOLS procedure basically involves regressing any $I(1)$ variables on other $I(1)$ variables, any $I(0)$ variables and leads and lags of the first differences of any $I(1)$ variables. The DOLS estimator has desirable properties when the system is triangular and if there is only one cointegrating relationship.

[17] Where β is the cointegrating vector and r is the number of cointegrating relations.

DOLS corrects for possible simultaneity bias among regressors. The potential of simultaneity bias and small-sample bias amongst the regressors is dealt with by the inclusion of lagged and led values of the change in the regressors.[18] Thus, we estimate the cointegrating vector β between the nominal exchange rate and a set of fundamentals using the DOLS specification given in equation (33).

$$s_t = \beta X_t + \sum_{j=-K}^{j=k} \eta_j \Delta X_{t-j} + \varepsilon_t \quad , \qquad (33)$$

where s_t is the nominal exchange rate, X_t is a vector of exchange rate fundamentals as defined above, and ε_t is a stochastic disturbance term. Since we treat the leads and lags of the first differences as nuisance parameters, the DOLS estimator does not represent the shortrun dynamics of the relationship between the nominal exchange rate and its fundamentals.

4.2.3 Shortrun dynamics

To estimate the short-run dynamics, we specify a vector error correction model (VECM), which specifies the short-run dynamics of each variable in the system, and in a framework that anchors the dynamics to long-run equilibrium relationships suggested by economic theory.

4.3 Data characteristics and time series properties

4.3.1 Data and variables

We use monthly for the period 1995:01 - 2006:12, for empirical investigation. This corresponds to the period of a floating exchange rate regime as discussed in section 2. All data are transformed to logarithmic form and are seasonally adjusted, unless otherwise stated.

The nominal exchange rate is the bilateral Uganda shilling/United States dollar rate. The foreign price level is calculated as a weighted average of the wholesale price index of Uganda's major trading partners, while the 3-months LIBOR dollar rate is used as a proxy for the foreign interest rate. Broad money (M2) growth is used as a proxy for expected domestic inflation. We drop expected foreign inflation from the model because of the empirical difficulties of quantifying the equivalent in terms of money supply. The terms of trade, private transfers (remittances), donor inflows are obtained from bank of Uganda's balance of payments database.

[18] This procedure is similar to estimators proposed by Phillips and Loretan (1991), Phillips and Hansen (1990), Saikkonen (1991) and Park (1992), but much more practically convenient to implement and estimate

4.3.2 Time series properties of the data

We investigate the time series properties of the data using the Elliot-Rothenberg and Stock (1996), hereinafter referred to as ERS (1996)[19], unit root test and Kwiatkowski, Phillips, Schmidt and Shin (1992)[20], hereinafter referred to as KPSS (1992), stationarity test.[21] A detailed discussion of these test is provided in appendix A and B. The ERS (1996) unit root tests show that there is some evidence of stationarity in interest rate differential, donor inflows to government and NGOs, 91-day treasury bill rate and private transfers in levels. However, the KPSS test rejects the null of stationarity for the government grants and NGO inflows and private transfers.[22] To arrive at conclusive results, we also examine the evolution of these variables graphically as shown in figure 1. A close examination of these graphs reveals that in levels, there is evidence of a trend in data in most cases, save for interest rate differential and the 91-day treasury bill rate. In first differences, both tests suggest that all variables are stationary as shown in table 1. The evolution of the variables in first differences also confirms stationarity. This evidence leads us to conclude that all other variables I(1) while interest rate differential and the 91-day treasury bill rate are I(0).

5 Empirical results

5.1 Longrun relationship

Having established the time series properties of the variables, the I(1) variables were entered into the cointegrating vector. The appropriate lag structure of the VAR was determined using the Akaike Information Criterion (AIC) and the Schwarz Bayesian Criterion (SBC). The Johansen and Juselius (1990) cointegration results are presented in table 2.

Both the trace statistic and the maximal eigen statistic reject the null of no cointegrating vector in favour of one cointegrating relationship at the 5% significance level. A unique cointegrating vector between the nominal exchange rate and its fundamentals suggests the existence of a single stochastic shared trend. The identified cointegrating vector can be interpreted as a typical longrun relationship. The estimated cointegrating vector normalized on the exchange rate is also reported in table 2. The elasticity of the exchange rate with respect to broad money and foreign interest rates is positive and statistically significant. Specifically, a one percent increase in M2 depreciates the exchange rate by 1.5 percent, while a one percent increase in the foreign interest rate depreciates the exchange rate by 0.01 percent.

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[19] The null hypothesis under the ERS (1996) unit root test is that the series is non-stationary (i.e. the series has a unit root)

[20] The null hypothesis under the KPSS (1992) stationarity test is that the series is stationary.

[21] We use both tests to increase our degree of comfort.

[22] For the other variables, the KPSS (1992) test results are largely consistent with the ERS (1996) test results.

For other variables, the exchange rate elasticity is negative and significant. A one percent increase in terms of trade, donor inflows and private transfers appreciates the exchange rate by 0.41 percent, 0.31 percent, and 0.43 percent, respectively. Indeed, this is consistent with theory. However, the price differential also has a negative elasticity, implying that a one percent increase in the price differential appreciates the exchange rate by 0.41 percent, which is not consistent with the purchasing power parity theory.

Having established the existence of a single cointegrating vector, we also examined the longrun relationship using dynamic OLS. In particular, we implement a DOLS (-2 2) specification. The DOLS elasticities are largely consistent with those derived from the Johansen and Juselius maximum likelihood approach, except in a few cases. As seen from table 5, the DOLS elasticities indicate that a one percent increase in broad money depreciates the exchange rate by 0.32 percent, and consistent with the purchasing power parity theory, a one percent increase in the price differential, depreciates the exchange rate by 0.07 percent. For terms of trade and private transfers, a one percent increase appreciates the exchange rate by 0.33 percent and 0.08 percent, respectively. However, in contrast to the Johansen and Juselius (1990) estimation results, the donor inflows were found to be insignificant while the foreign interest rate was only marginally significant. Furthermore, since the DOLS approach allows inclusion of I(0) variables, we also estimated the model with the interest rate differential as one of the dependent variables, but the interest rate differential was found to be insignificant.[23]

5.2 Shortrun dynamics

Following the Granger representation theorem, the above unit root tests and cointegration results also imply that the dynamic modelling of variables included in our exchange rate model has a valid error correction representation with a cointegrating constraint embedded in them. We then proceed to examine the shortrun dynamics using a vector error correction (VEC) framework.

We examined the statistical properties of the VEC that was estimated with four lags. The model is stable as the inverse roots of the characteristic polynomial lie inside the unit circle. However, the Jarque-Bera test rejects the null of normality of the residuals. Indeed, this is expected since from visual inspection, the residuals display a number of significant outliers. Since the non-normality is largely a result of excess kurtosis rather than skewness (see table 4), our cointegration results are still valid. To check whether the description of the data is consistent with the assumption of white noise errors, we tested for

[23] The results of this estimation are available from the authors on request.

multivariate serial correlation of the residuals. The Lagrange multiplier test cannot reject the null of no serial correlation as shown in table 4. We also tested for Granger causality and Block exogeneity[24] within the VECM framework. The Granger causality and Block exogeneity test results are presented in table 5. As can be seen from table 5, the null of "no Granger causality" from M2, the price differential, terms of trade, private transfers and foreign interest rates is rejected at the 5 percent significance level. Although the null of "non causality" cannot be rejected for donor inflows, the block exogeneity Wald statistic indicates that the exchange rate is indeed endogenous to the system as a whole.

As seen from the VECM results in table 6, the coefficient of the lagged error term is negative and significant, at the 1% significance level, thus vindicating the validity of the cointegrating relationship. The size of the coefficient of the error term (-0.027) shows that 2.7 percent of the adjustment towards the longrun equilibrium takes place in one month. In terms of shortrun dynamics, the significant lags are a one-period and a two-period lagged difference of the exchange rate; a two-period and a three-period lagged difference of money supply; a one-period, two-period and three-period lagged difference of the price differential; a two period lagged difference of the terms of trade; a one-period and four-period lagged difference of private transfers; and a two-period lagged difference of the foreign interest rate.

6 Concluding remarks

The empirical results in this paper provide some useful insights into the Ugandan experience under a floating exchange rate regime. From the results, it is apparent that the domestic liquidity conditions, price differentials between domestic and foreign prices, terms of trade and private transfers have a substantial impact on the exchange rate. Furthermore, the differential between domestic and foreign interest rates seems to have some minimal impact on the exchange rate. Thus the exchange rate behaviour is influenced by monetary policy actions, current account dynamics, and to a limited extent, movements in foreign interest rates.

[24] Block exogeneity tests are used to determine how these variables enter the model. They are a multivariate generalization of the Granger causality tests. It has as its null hypothesis, that the lags of a set or block of variables do not enter the equations of the other variables. The Granger causality/block exogeneity results indicate the wald statistic for the joint significance of each of the other lagged endogenous variables in each equation of the model and also for the joint significance of all other lagged endogenous variables in each equation of the model.

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Table 1: Time series properties of the data

Test↓ Variable↓	Levels		First differences	
	ERS (1996) Statistic	KPSS Statistic	ERS (1996) Statistic	KPSS Statistic
Nominal exchange rate (s_t)	-0.532501	0.895000**	-9.864248**	0.085295
Broad money, M2 (m_t)	-2.242605	0.641251*	-10.70839**	0.064098
Interest rate differential ($i_t - i_t^*$)	-3.153211***	0.249600	-4.673315**	0.057305
Price differential ($p_t - p_t^*$)	-1.239233	0.839000**	-3.583011**	0.450762
Terms of trade (tot)	-2.276367	0.984136**	-8.367951**	0.177067
Government grants and NGO inflows	-2.852132*	0.842256**	-4.582872**	0.187943
Private transfers (ptrans)	-2.50484*	0.970655**	-15.46295**	0.215293
91-Day Treasury bill rate (i_t)	-2.994162**	0.051707	-8.834601**	0.189840
LIBOR (i_t^*)	-0.994567	0.603098*	-5.346798**	0.261988

Note: ** and * denote rejection of the null at the critical values of 1% and 5%, respectively.

Source: Authors' computations

Table 2: Johansen maximum likelihood estimation results

Cointegration results							
Eigenvalue	0.326	0.177	0.162	0.092	0.063	0.042	0.006
Null hypothesis[2]	r = 0	r = 1	r = 2	r = 3	R = 4	r = 5	r = 6
λ_{max}[3]	54.7721	27.2297	24.5332	13.4072	9.0470	6.096	0.851
λ_{trace}[3]	135.936	81.164	53.934	29.401	15.994	6.947	0.851
95% critical value[4]	46.23(125.61)	40.08(95.75)	33.87(69.81)	27.58(47.85)	21.13(29.79)	14.26(15.49)	3.84
Standardized eigenvector β' with standard errors in parenthesis							
Variable→ Vector↓	s_t	m2	$p_t - p_t^*$	tot	govinf	ptrans	i_t^*
Vector	-1.0000	1.469**	-0.4036**	-0.3089**	-0.4340**	-1.0974**	0.01061*
		(7.471)	(-4.093)	(-1.655)	(-2.922)	(-7.563)	(1.844)

1. Cointegration with nominal exchange rate, broad money (M2), price differential, terms of trade, donor inflows, private transfers and foreign interest rates as endogenous variables.
2. r is the number of cointegrating vectors.
3. The statistics λ_{max} and λ_{trace} are respectively the Johansen maximal and trace eigenvalue statistics for testing cointegration. The null hypothesis is in terms of r (the number of cointegrating vectors), and rejection of r=0 is evidence in favour of at least one cointegrating vector.
4. The critical value in parenthesis is for the trace statistic. The critical values for both the maximal and trace statistics are taken from Osterwald-Lenum (1992).
5. ** and * denote 1% and 5% significance levels, respectively

Source: Authors' computations

Table 3: Dynamic OLS results

Variable	Coefficient	Std. Error	t-Statistic	Prob.
$m2_t$	0.3236	0.0361	8.9720	0.0000
$p_t - p_t^*$	0.0678	0.0215	3.1489	0.0022
tot_t	-0.3322	0.0361	-9.2131	0.0000
$govinf_t$	0.0114	0.0239	0.4769	0.6345
$ptrans_t$	-0.0759	0.0234	-3.2373	0.0017
i_t^*	0.0164	0.0138	1.1913	0.0935
R-squared	0.959747	Mean dependent var		7.316789
S.E. of regression	0.058255	S.D. dependent var		0.235300
Sum squared resid	0.298640	Akaike info criterion		-2.579619
Log likelihood	221.1243	Schwarz criterion		-1.568153
F-statistic	45.61249	Prob(F-statistic)		0.000000

Note: A constant and two leads and lags of changes in explanatory variables were used in the regression. However, for brevity, we do not report these estimates here.

Source: Authors' computations

Table 4: VECM diagnostic tests

Multivariate tests	1	2	3	4	5	6	7	8	9	10	11	12
LM test[1]	49.729	55.129	57.945	37.518	36.799	38.152	46.720	57.468	33.189	34.571	45.279	59.632
	(0.444)	(0.254)	(0.179)	(0.884)	(0.900)	(0.869)	(0.566)	(0.190)	(0.959)	(0.941)	(0.625)	(0.142)
Normality JB[2]				59.679								
				(0.000)								
Skewness[3]				10.659								
				(0.154)								
Kurtosis[3]				49.019								
				(0.000)								

Univariate tests	Δs_t	Δm2	$\Delta(p_t - p_t^*)$	Δtot	Δgovinf	Δptrans	Δi_t^*
Normality JB[2]	8.853	0.449	7.889	9.248	11.558	12.592	9.089
	(0.012)	(0.798)	(0.019)	(0.009)	(0.003)	(0.002)	(0.011)
Skewness[3]	0.511	0.417	0.086	0.264	0.639	0.153	8.588
	(0.475)	(0.518)	(0.769)	(0.607)	(0.424)	(0.696)	(0.004)
Kurtosis[3]	8.342	0.031	7.803	8.983	10.919	12.439	0.502
	(0.003)	(0.858)	(0.005)	(0.002)	(0.001)	(0.000)	(0.478)

[1] The LM test denotes the Breusch-Godfrey Lagrange Multiplier test for serial correlation test. The null hypothesis is there is no serial correlation at a specified lag length.

[2]The JB is the Jarque-Bera test statistic. The null hypothesis for the JB tests is normally distributed residuals.

[3]The null hypothesis is that of residuals with no skewness, no kurtosis. The test statistic is the χ^2.

Note. For normality, skewness and Kurtosis

Source: Authors' computations

Table 5: Granger causality and block exogeneity results

	Excluded variables							Block exogeneity
Dependent Variable ↓	Δs_t	**Δm2**	$\Delta(p_t - p_t^*)$	**Δtot**	**Δgovinf**	**Δptrans**	Δi_t^*	**All**
Δs_t		6.3295	6.8452	6.748800	1.6028	6.667	2.3181	24.0926
		(0.0422)	(0.032)	(0.034)	(0.161)	(0.035)	(0.049)	(0.006)
Δm2	6.0319		5.935117	3.21293	0.105635	1.82862	0.596942	16.71311
	(0.049)		(0.050)	(0.201)	(0.948)	(0.401)	(0.742)	(0.161)
$\Delta(p_t - p_t^*)$	0.669529	0.467510		2.053491	0.304742	0.714651	0.337181	4.160997
	(0.716)	(0.792)		(0.358)	(0.859)	(0.699)	(0.845)	(0.981)
Δtot	0.368793	1.866702	1.3075		2.902662	0.163796	0.382623	11.89105
	(0.832)	(0.393)	(0.520)		(0.234)	(0.921)	(0.826)	(0.456)
Δgovinf	0.356	6.109	0.073	1.497		2.6941	0.247	14.819
	(0.837)	(0.047)	(0.964)	(0.473)		(0.260)	(0.883)	(0.253)
Δptrans	4.498	0.356	0.856	0.972	15.873		3.969	25.847
	(0.106)	(0.837)	(0.652)	(0.615)	(0.000)		(0.137)	(0.011)
Δi_t^*	0.724721	8.862615	0.477887	0.024657	1.101025	1.042455		11.88209
	(0.696)	(0.012)	(0.788)	(0.988)	(0.577)	(0.594)		(0.455)

Note: The reported statistic is the block exogeneity Wald-type causality tests from the estimated VECM. The p-values are reported in parenthesis. The null hypothesis is "no Granger causality". "All" refers to the exclusion of all the endogenous variables from the VECM other than the lags of the dependent variable. Significant test statistics (at 5 percent level) are in bold. P-values are χ^2.

Source: Authors' computations

Table 6: Vector error correction model results

	Δs_t	Δm2	$\Delta(p_t - p_t^*)$	Δtot	Δgovinf	Δptrans	Δi_t^*
CointEq1	-0.027143	0.018159	-0.128658	0.016463	-0.055199	-0.867273	-0.020801
	[-5.53857]***	[1.63522]	[-1.52331]	[0.53124]	[-0.22983]	[-6.56222]	[-1.12398]
C	0.002288	0.025656	-0.024312	-0.006693	-0.010869	-0.006430	0.004175
	[2.79716]***	[6.48179]	[-0.80764]	[-0.60600]	[-0.12697]	[-0.13651]	[0.63293]
Δs_t **(-1)**	0.203184	-0.305829	0.032152	-0.014398	-0.185697	-2.608792	-0.050382
	[2.17712] **	[-2.37655]	[0.03285]	[-0.04010]	[-0.06672]	[-1.70345]	[-0.23493]
Δs_t **(-2)**	0.128738	0.040059	1.278204	0.522601	2.673696	1.467807	-0.194127
	[1.74709] *	[0.31077]	[1.30381]	[1.45285]	[0.95909]	[0.95681]	[-0.90369]
Δm2 (-2)	0.198553	-0.413826	1.262823	0.037155	-3.213970	0.271688	0.106259
	[2.75480] ***	[-4.16396]	[1.67075]	[0.13397]	[-1.49535]	[0.22971]	[0.64158]
Δm2 (-3)	0.261844	-0.084700	0.942821	0.516495	0.178191	-0.493458	0.071523
	[3.88860] ***	[-0.88260]	[1.29179]	[1.92869]	[0.08586]	[-0.43207]	[0.44722]
$\Delta((p_t - p_t^*)$ **(-1))**	0.021755	-0.013616	0.122422	0.023585	-0.022851	0.256446	0.000721
	[2.31442] **	[-1.05056]	[1.24192]	[0.65209]	[-0.08152]	[1.66254]	[0.03337]
$\Delta((p_t - p_t^*)$ **(-3))**	-0.033991	0.007757	-0.128757	0.002579	0.039844	0.072855	-0.003937
	[-3.35066***	[0.55451]	[-1.21029]	[0.06606]	[0.13171]	[0.43764]	[-0.16888]
$\Delta((p_t - p_t^*)$ **(-4))**	0.012674	0.008319	-0.139649	-0.031704	0.112546	-0.190853	-0.002995
	[1.60093] *	[0.76206]	[-1.68211]	[-1.04080]	[0.47674]	[-1.46913]	[-0.16465]
Δtot (-2)	-0.308998	0.029002	0.360390	0.042103	-0.344513	0.140410	0.012740
	[-2.39011] **	[0.91193]	[1.49001]	[0.47443]	[-0.50090]	[0.37099]	[0.24038]
Δptrans (-1)	-0.05401	-0.024059	0.043730	-0.000930	0.030631	0.341086	0.018569
	[-2.16598**]	[-2.43340]	[0.58157]	[-0.03369]	[0.14326]	[2.89884]	[1.12699]
Δptrans (-4)	0.009616	-0.010133	0.079682	0.005476	0.031438	-0.004209	-0.009288
	[1.80163] *	[-1.37689]	[1.42361]	[0.26666]	[0.19753]	[-0.04805]	[-0.75730]
Δi_t^* **(-2)**	-0.062410	0.033249	-0.060277	0.108008	-0.449244	1.592993	-0.066497
	[-1.73201] *	[0.51464]	[-0.12268]	[0.59911]	[-0.32153]	[2.07189]	[-0.61764]
R-squared	0.336591	0.427062	0.203434	0.345096	0.478169	0.534811	0.570092
S.E. equation	0.017391	0.023980	0.182375	0.066916	0.518601	0.285380	0.039962

Notes: For brevity, we do not report the insignificant in the exchange rate equation since our focus of interest is exchange rate dynamics. Figures in parenthesis are t ratios. **, ** and * imply significance at 1%, 5% and 10% levels, respectively. SE is the standard error of the estimation.

Source: Authors' computations

Figure 1: Evolution of Variables in levels

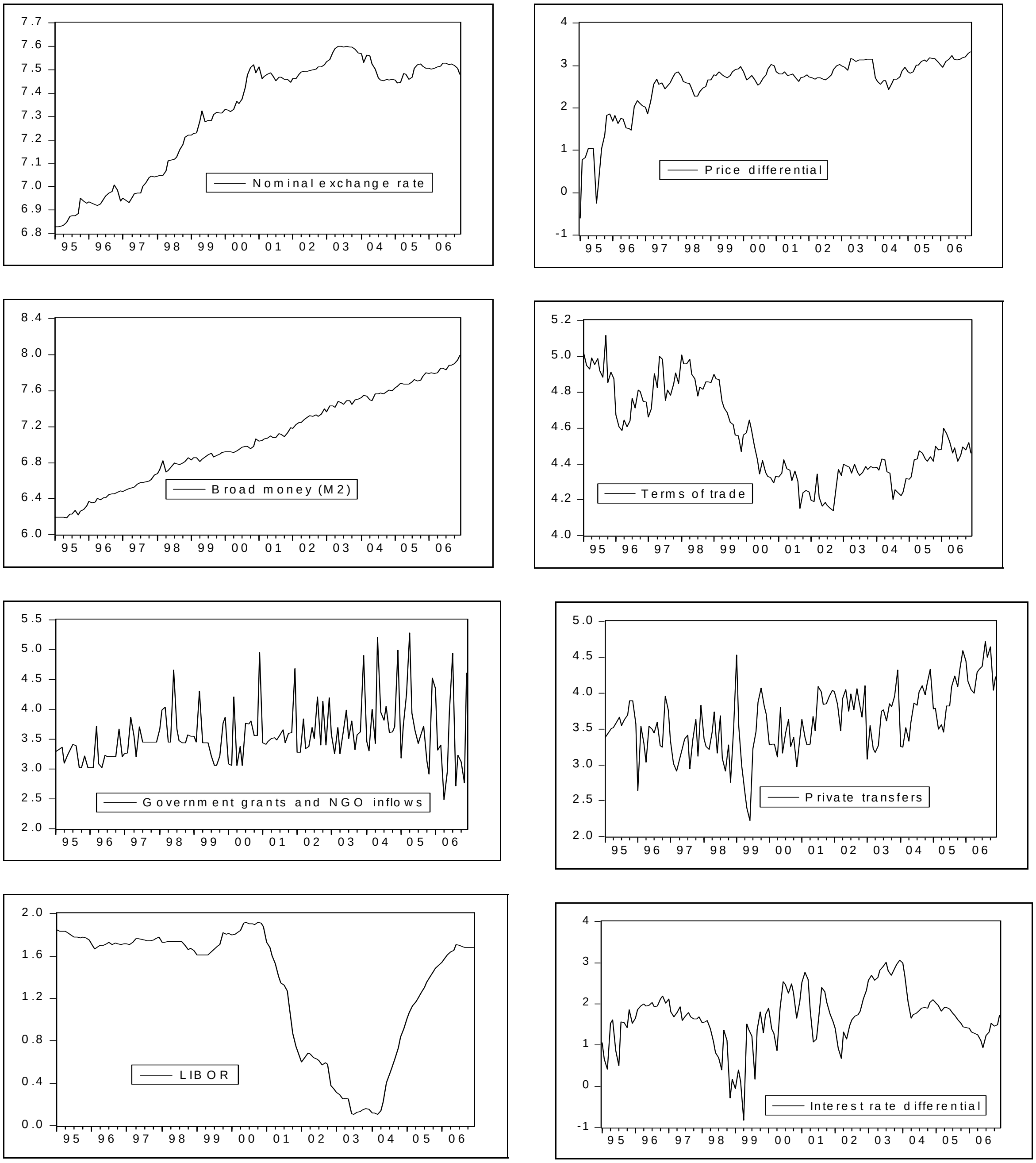


Figure 2: Evolution of Variables in first differences

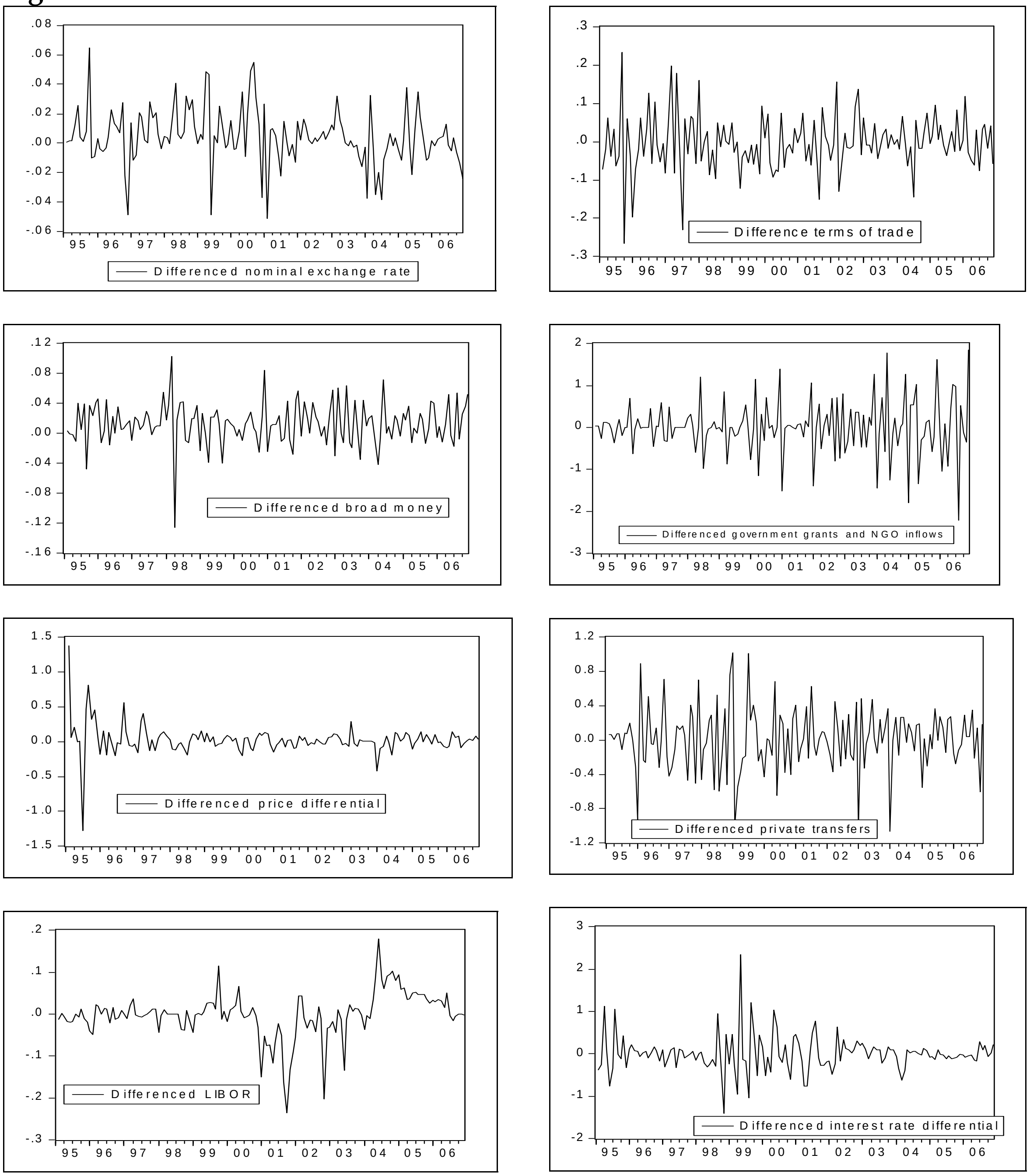


Figure 3: Inverse Roots of AR Characteristic Polynomial

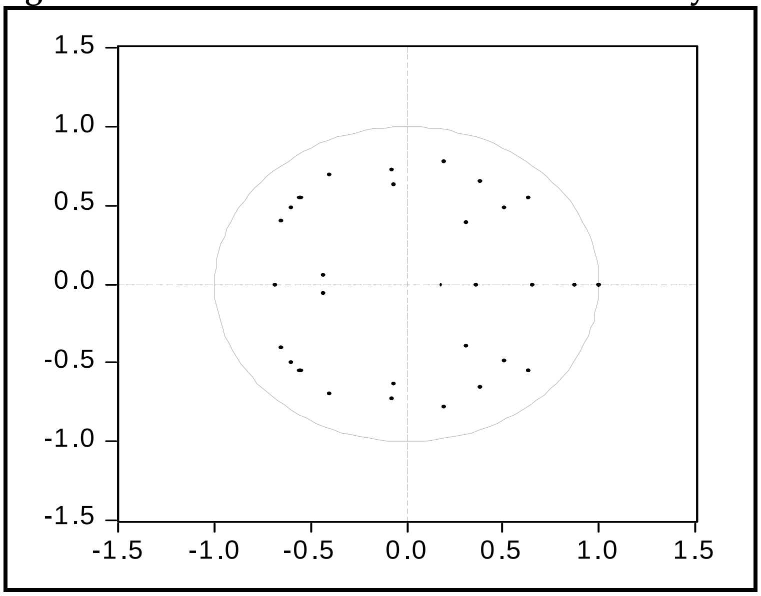
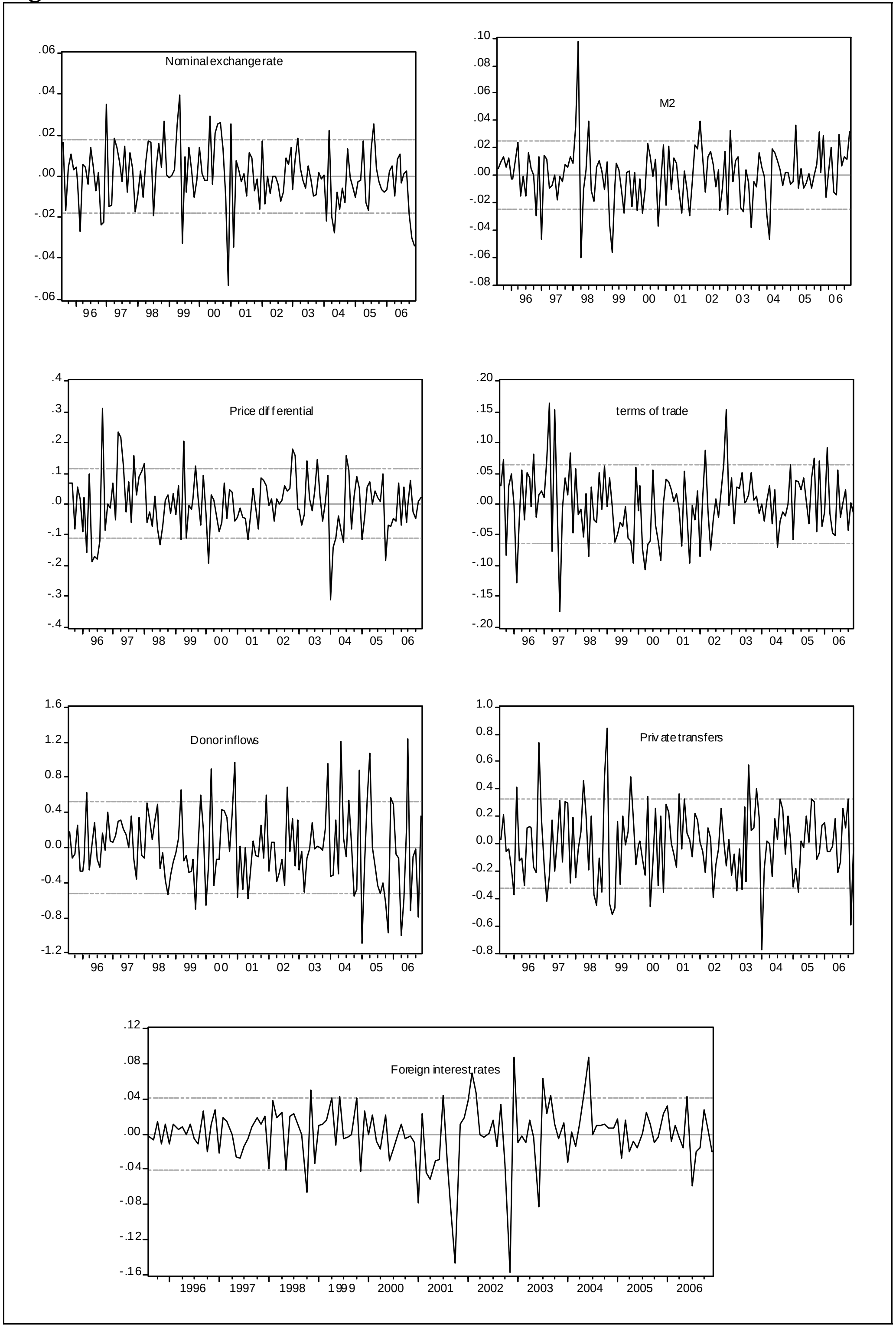


Figure 4: VEC Residuals



Appendix A: Elliot, Rothenberg and Stock (1996) Unit root test

The Elliot, Rothenberg and Stock (1996) test is an asymptotically efficient test of the unit root hypothesis based on the regression.

$$\Delta \tilde{x}_t = \alpha \tilde{x}_{t-1} + \sum_{k=1}^{k} \beta_i \Delta \tilde{x}_{t-i} + \mu_t \,, \tag{A1}$$

where $\tilde{x}_t$ represents the quasi-differenced data obtained from a GLS regression given in equation (A2).

$$\tilde{x}_t = x_t + z_t' \xi(\overline{c}) \tag{A2}$$

where c is the local-to-unity parameter. Following ERS (1996), $\bar{c}$ is selected as:

$$\bar{c} = \begin{cases} 1-7/T \,, if \ z_t = \{1\} \\ 1-13.5/T \,, if \ z_t = \{1,t\} \end{cases} \tag{A3}$$

Since $\tilde{x}_t$ has already been detrended, the elements of z_t need not be included in equation (A1). The results presented in ERS (1996) suggest that GLS local detrending yields substantial power gains over the standard ADF unit root tests.

Appendix B: Kwiatkowski, Phillips, Schmidt and Shin Unit root test

The KPSS (1992) test is a mean stationery test. The null hypothesis is that the time series is stationary. This test is based on the statistic:

$$\eta(u) = (1/N^2)\sum_{t=1}^{N} S_t^2 / \sigma_k^2 \,; \ where \quad S_t = \sum_{t=1}^{t} \nu_{i,} t = 1, \ldots\ldots N \tag{B1}$$

where $\nu_{i,}$ is the residual term from a regression of y_t on a intercept, and σ_k^2 is a consistent long-run variance estimate of y_t, and N represent the sample size. Kwiatkowski et al (1992) show that the statistic $\eta(u)$ has a non-standard distribution and critical values have been provided therein. If the calculated value of $\eta(u)$ is larger than the critical value, then the null of stationarity for the KPSS test is rejected.