



# Price-Setting Behaviour in the Jamaican Foreign Exchange Market

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## Abstract

*We develop an exchange rate model by applying dynamic optimization to a small open economy operating under a flexible exchange rate regime. Building on the work of Kouri (1976) and Hirose (2001) which extended the model to include current account balances and capital accumulation, the paper empirically evaluates the impact of various shocks on the saddle path of changes in the exchange rate. Structural Vector Autoregression model estimates indicate that a positive shock to the cash flow balance causes the pace of exchange rate depreciation to decelerate.*

**JEL Classification numbers:** F31, C13, F32

**Keywords:** exchange rate, current account

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<sup>1</sup> The views expressed are those of the authors and not necessarily those of the Bank of Jamaica.

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## 1.0 Introduction

This paper has two objectives. Firstly, we are interested in evaluating the time path of changes in Jamaica Dollar/US dollar exchange rate when it temporarily deviates from equilibrium in the context of a shock to some macroeconomic variable. By way of explanation, if the trajectory of the exchange rate ( $\frac{\dot{e}_t}{e_t}$ ) is not at equilibrium because of some shock, this equilibrium (the steady state motion) is only attainable after a process of adjustment, resulting from changes in the rate of change in the exchange rate over time. This adjustment defines the (saddle) path that the rate takes as it converges to equilibrium. Secondly, we are interested in evaluating the usefulness of US Dollar cash flow information currently estimated by the Bank of Jamaica from the balance of payments in understanding current and future price setting behaviour in the Jamaican foreign exchange market.

The mainstream literature on exchange rate determination does not accord a significant role to balance of payments flows in the price setting mechanism for one currency relative to another. The central approaches to exchange rate determination in open economy macroeconomics have revolved around the Mundell-Fleming (or IS/LM/BP) and portfolio balance models (see for example Mundell (1963), Fleming (1962), Vines and Moutos (1987)). These traditional monetary theories discuss the role of income and prices in determining the exchange rate, with the balance of payments and trade flows representing underlying elements of the transmission process.

The development of models that assign a more explicit role to the current account has been pioneered by Kouri (1976), Dornbusch and Fischer (1980), Allen and Kenen (1980) Tobin and de Macedo (1981), Branson and Buiters (1983) and Branson and Henderson (1985). For Jamaica, very few papers have modelled and, or successfully explained exchange rate dynamics, and to our knowledge, none have attempted to use foreign currency flows in this context. We are also motivated by the fact that McFarlane (2002) found the exchange rate to be an important element in the monetary transmission process, with depreciation having a significant pass-through to domestic inflation. The impact of

balance of payments flows in the price setting mechanism for the exchange rate is therefore an important issue for Jamaica.

Building on the work of Hirose (2001), we revisit the issue of exchange rate determination in an intertemporal optimization framework, with a specific focus on the dynamic link between the changes in the exchange rate and the current account. The saddle path of the exchange rate is derived from the solution of the optimization efforts of rational agents - the household, the firm and government.

A major empirical innovation in this paper is the calculation of the current account balance. Following the work of Franklin (2006), which extracted the cash demand for foreign exchange from import transactions as recorded in the balance of payments (BOP), a time series of current account balances is constructed on a cash flow basis. This is then used as a proxy for the evolution of the countries net external assets/liabilities. The principal reasoning behind this framework is that the spot exchange rate is more likely to be influenced by actual demand and supply of foreign currency associated with people's transactions with the rest of the world, instead of the accrued transactions that are typically reported in standard BOP accounts.

The paper uses a Structural Vector Autoregression (SVAR) model to assess the determinants of the rate of change in the exchange rate. Our results indicate that, along the saddle path, the rate of depreciation in the exchange rate will fall when net foreign assets jump above their steady state i.e. when the cash flow current account balance is in surplus. Consistent with theory, a shock to the differential in the growth rate between domestic and the trading partners' money supply results in an acceleration of the rate of depreciation in the exchange rate. A positive shock to the capital stock results in an increase in the rate of depreciation in the exchange rate.

The remainder of the paper is organized as follows: Section 2 outlines the theoretical model while Section 3 presents the empirical model. Section 4 discusses the selection process of the data and some stylized facts regarding the variables used in the model is

presented in Section 5. Discussions of the results are captured in Section 6. Section 7 concludes.

## 2.0 The Model

Following Kouri (1976) and Obstfeld (1981), we develop an exchange rate model by applying dynamic optimization to a small open economy operating under a flexible exchange rate regime. The economy consists of three sectors/agents; consumers/household, firms and government. Agents have perfect foresight concerning all disturbances. Unlike Dornbusch's (1976) sticky-price monetary model, prices in this economy are assumed to adjust instantaneously, thereby ensuring that the economy is always at full employment.

### 2.1 The Household

This economy is comprised of an infinitely lived representative consumer who maximizes utility from a single commodity, which may be consumed or invested in domestic fiat money or interest bearing securities denominated in either local or foreign currency. The intertemporal utility function of the representative household is given as follows:

$$U_0 = \int_0^{\infty} u(c_t, m_t) e^{-\theta t} dt. \quad (1)$$

$c_t$  and  $m_t$  are real consumption and money holdings, respectively.  $e^{-\theta t}$  is the discount factor with the discount rate  $\theta$  taken to be strictly positive, such that  $\theta(c_t, m_t) > 0$ , both for consumption  $\theta(c_t) > 0$  and for money  $\theta(m_t) > 0$ . The utility function is assumed to be strictly increasing,  $u'(c_t, m_t) > 0$  and strictly concave  $u''(c_t, m_t) < 0$  in both  $c_t$  and  $m_t$ .

Maximization of this utility function is carried out over positive consumption levels subject to the following lifetime budget constraint:

$$\dot{a}_t = r_t a_{t-1} + w_t - \tau_t - c_t - (r_t + \pi_t) m_t. \quad (2)$$

The variable  $a_t$  is a portfolio of financial assets,  $w_t$  is real wages,  $\tau_t$  is a lump-sum tax,  $\pi_t$  is the inflation rate, and  $r_t$  is real interest rates.<sup>2</sup>

The household's portfolio demand is the sum of foreign assets ( $b_t$ ) and money holdings ( $m_t$ ):

$$a_t = b_t + m_t. \quad (3)$$

with initial conditions  $b(0) = B_0 / P_0$ ;  $m(0) = M_0 / P_0$ .

Equation 3 suggests that the change in the demand by the household for net foreign assets is given as follows:

$$\dot{b}_t = \dot{a}_t - \dot{m}_t. \quad (4)$$

Given equations (1) and (2), the present value Hamiltonian is as follows:

$$H = [u(c_t, m_t)] e^{-\theta t} + \lambda_t (r a_t + w_t - \tau_t - c_t - (r_t + \pi_t) m_t) \quad (5)$$

The variable  $\lambda$  can be interpreted as the marginal utility of the state variable  $a_t$ , which, given the presence of the discount factor, disappears over time.<sup>3</sup> To address this deficiency in the specification of the present value Hamiltonian, the alternative specification (in current value terms) can be derived by defining a shadow price as  $\mu_t = \lambda_t e^{\theta t}$ . The current value Hamiltonian can then be expressed as:

$$H_c = [u(c_t, m_t)] + \mu_t (r a_t + w_t - \tau_t - c_t - (r_t + \pi_t) m_t) = H e^{\theta t} \quad (6)$$

<sup>2</sup> The dot (·) represents the time derivative of the variable under consideration.

<sup>3</sup> The state variable is the variable upon which the decision-maker bases his or her choices in period  $t$ . An important characteristic of the state variable is that the choices made by the individual, in one period affects the value of the state variable in the next period.

The first order conditions of the household are therefore given as follows:<sup>4</sup>

$$u'(c_t) = \mu_t \quad (7)$$

$$u'(m_t) = \mu_t(r_t + \pi_t) \quad (8)$$

$$\mu_t r_t = \theta \mu_t - \dot{\mu}_t \quad (9)$$

$$\dot{a}_t = r a_t + w_t - \tau_t - c_t - (r_t + \pi_t) m_t \quad (10)$$

$$\lim_{t \rightarrow \infty} \mu_t e^{-\theta t} a_t = 0 \quad (11)$$

## 2.2 The Firm

The objective of the firm is to maximize the present value of shareholders' wealth or the value of the firm. The firm is assumed to be capital intensive and, as such, labour supply is not varied in the short run. The firm therefore maximizes profits on the basis of the rate of its capital accumulation. The firm's maximisation problem can therefore be expressed as

$$\max v_0 = \int_0^{\infty} [F(K_t, L_t) - w_t L_t - I_t] e^{-\theta t} dt \quad (12)$$

subject to the capital accumulation equation

$$\dot{K}_t = I_t - \delta K_t \quad (13)$$

$F(K_t, L_t) = f(k_t)L_t$  is the production function, which is assumed to be linearly homogenous and concave in both capital ( $K_t$ ) and labour ( $L_t$ ) and  $K_t / L_t$  is the capital to labour ratio. Based on the assumption of constant labour supply,  $L_t = \bar{L}_t$ .  $I$  represents investment and  $\delta \geq 0$  is the rate of capital depreciation. The discount rate is represented by  $\theta_t$  and is taken to be strictly positive.  $[F(K_t, L_t) - w_t L_t - I_t]$ , is the neoclassical representation of profits.

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<sup>4</sup> The derivation of these conditions is given in Appendix 1.

The present value Hamiltonian is expressed as

$$H = [f(k_t)L_t - w_tL_t - I_t] + \lambda(I_t - \delta K_t)$$

while the current value Hamiltonian is as follows:

$$H_c = [f(k_t)L_t - w_tL_t - I_t] + \mu_t(I_t - \delta K_t) = He^\theta \quad (14)$$

The first order conditions of the firm are thus:

$$w_t = f(k_t) + f'(k_t) \quad (15)$$

$$\dot{\mu}_t = (\delta + \theta)\mu_t - f'(k_t) \quad (16)$$

$$\dot{K}_t = I_t - \delta K_t \quad (17)$$

$$\lim_{t \rightarrow \infty} \mu_t e^{-\theta t} K_t = 0 \quad (18)$$

Equation (15) describes the condition for the representative firm's profit to be maximized, which indicates that real wages must equate the marginal product of capital. With respect to equation (16), the instantaneous change in  $\mu_t$  is capital gain or the change in the price of capital. This is determined by the costate variable  $\mu_t$  which represents the price of capital in terms of current profits and  $f'(k_t)$ , which represents the marginal contribution of capital to profits. Equation (17) is the state equation, which defines the economy's accumulation of capital through the optimization behaviour of the firm while (18) is the usual transversality condition.



### 2.3 The Government

The budget constraint of the government is expressed as

$$\tau_t + \phi m_t = g_t \quad (19)$$

Equation (19) indicates that government expenditure must be financed by taxes  $\tau_t$ , and seignorage  $\phi m_t$ . We also assume that the government sets real expenditure exogenously while the constant nominal money growth  $\eta$  is set by the monetary authorities. On these premises, the rate of growth of the real money stock is:

$$\dot{m}_t = (\eta - \pi_t)m_t \quad (20)$$

Given that the economy acquires foreign assets through the household, we may express the rate of accumulation of foreign assets as being equal to the current account in the balance of payments. This relationship is given by equation (4)

$$\dot{b}_t = \dot{a}_t - \dot{m}_t$$

We expand by substituting the budget constraints of  $\dot{a}_t$  and  $\dot{m}_t$  from (2) and (20)

$$\begin{aligned} \dot{b}_t &= r_t a_t + w_t - \tau_t - c_t - r_t m_t - \pi_t m_t - \eta m_t + \pi_t m_t \\ \dot{b}_t &= r_t b_t + f(k_t) + f'(k_t) - c_t - g + m_t(\phi - \eta) \end{aligned} \quad (21)$$

To ensure that the economy does not accumulate debt with the rest of the world indefinitely, we impose an intertemporal budget constraint. Therefore, the transversality condition is expressed as:

$$\lim_{t \rightarrow \infty} \mu_t e^{-\theta t} b_t = 0 \quad (22)$$

In this economy, securities denominated in either domestic or foreign currency are perfect substitutes and there are no capital controls.<sup>5</sup> This implies that uncovered interest parity (UIP) holds

$$R_t = R_t^* + \dot{e}_t / e_t \quad (23)$$

To close the model, we also assume that purchasing power parity holds

$$p_t = p_t^* e_t,$$

or alternatively

$$\pi_t = \pi_t^* + \dot{e}_t / e_t \quad (24)$$

Combining equations (23) and (24), the domestic real interest rate ( $r_t$ ) is equivalent to the real interest rate of the foreign country:

$$r_t = r_t^* \quad (25)$$

#### 2.4 *Perfect Foresight Equilibrium*

The economy is in equilibrium when the demand for output, labour, capital and other assets equals their respective supply and all expectations are fully realized. Under these conditions, the maximization of the household's objective function yields a set of demand functions for consumption together with a supply function for financial assets invested. The firm's optimization problem yields a set of demand functions for capital and

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<sup>5</sup> Therefore, under the assumption of perfect foresight, should  $R_t \neq R_t^*$ , arbitrageurs will move funds from one country to the next, as long as the change in the exchange rate is smaller (greater) than the interest rate differential.

investment, and a supply function for output. Thirdly, the government policy decisions generate a growth rate for the money supply and a demand for goods.

Combining the optimality conditions for the consumer/household, the firm and government yields the following:

$$\mu_t = u'(c_t) \quad (26)$$

$$u'(m_t) = \mu_t(r_t + \pi_t) \quad (27)$$

$$w_t = f(k_t) + f'(k_t) \quad (28)$$

$$\dot{c}_t = -(r_t - \theta)v(c_t) \quad (29)^6$$

$$\dot{\mu}_t = (\delta + r_t)\mu_t - f'(k_t) \quad (30)$$

$$\dot{K}_t = I_t - \delta K_t \quad (31)$$

$$\dot{m}_t = (\eta - \pi_t)m_t \quad (32)$$

$$\dot{b}_t = r_t b_t + f(k_t) + f'(k_t) - c_t - g + m_t(\phi - \eta) \quad (33)$$

Equations (26) and (27) are the Euler equations corresponding to  $c_t$  and  $m_t$ , respectively. Equation (28) describes the optimality condition for the maximization of the firm's profit. Equations (29) to (32) represent the differential equations that correspond to the saddle path behaviour of the variables that affect the exchange rate, while equation (33) incorporates all the agents and how they interact in the economy, through the rate of accumulation of net foreign assets or liabilities

## 2.5 *Steady State Equilibrium*

The steady state or the long-run equilibrium values of variables in the system are those after all dynamic adjustment has taken place. Therefore, the time path of a stable differential equation asymptotically approaches its steady state when

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<sup>6</sup> See Appendix 1 for derivation.

$\dot{b} = \dot{m} = \dot{\mu} = \dot{K} = \dot{c} = 0$ . Imposing this condition on the optimality conditions for the economy above yields the following equations:

$$\bar{b} = \frac{\bar{c} + g - f(\bar{k}) - f'(\bar{k}) - \bar{m}(\phi - \eta)}{\bar{r}} \quad (34)^7$$

$$\bar{\pi} = \eta \quad (35)$$

$$(\delta + \bar{r})\bar{\mu} = f'(\bar{k}) \quad (36)$$

$$\bar{I} = \delta\bar{K} \quad (37)$$

$$\bar{r} = \theta \quad (38)$$

Equation (34) shows that net foreign assets in the steady state depend on the steady state level of household consumption, government expenditure, capital utilized by the firm and real money holdings. All these factors are discounted by the real rate of interest. In equation (35) the inflation rate is equivalent to the growth in money, while, in (36), the marginal contribution of capital to profits in the steady state is equal to the long-run price of capital given the rate of depreciation and the market interest rate. Equations (37) and (38) indicate that, in the steady state, the level of investment is determined by the amount by which capital has depreciated; and the market rate must equal the subjective discount rate, respectively.

## 2.6 Saddle Path Dynamics

Of interest is the observation of the variables around the steady state equilibrium. In this context, saddle path dynamics determine the nature and persistence of these deviations from equilibrium. For saddle path analysis to be valid the system must be stable. This can be achieved through the imposition of terminal conditions and the embodiment of the optimizing behaviour of economic agents (Brock, 1974).<sup>8</sup>

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<sup>7</sup> A bar denotes a steady state value.

<sup>8</sup> Typically, some transversality conditions are also imposed to limit the effects of explosive roots.

To prove that the system is saddle path stable, it is necessary to estimate its characteristic roots (or eigenvalues) by linearizing differential equations (29) through (32) in the neighbourhood of the steady state equilibrium. This is done by conducting a Taylor series expansion of the equations which produces first order partial derivatives in the Jacobian matrix. The eigenvalues are calculated by finding the values of  $\lambda$  such that  $|A - \lambda I| = 0$ , where the  $A$  matrix consists of the coefficients of the Jacobian matrix; and the diagonal matrix  $\Lambda$  is a  $5 \times 5$  diagonal matrix containing the characteristic roots; and  $I$ , the identity matrix. This produces the system below:

$$\begin{array}{ccc} & A & \Lambda \\ \begin{bmatrix} \dot{K}_t \\ \dot{m}_t \\ \dot{b}_t \\ \dot{\mu}_t \\ \dot{c}_t \end{bmatrix} = \begin{bmatrix} -\delta_K & 0 & 0 & 0 & 0 \\ 0 & -\pi & 0 & 0 & 0 \\ f'(k) & 0 & r & 0 & -1 \\ -f''(k) & 0 & 0 & \delta+r & 0 \\ 0 & 0 & 0 & 0 & -v'(c) \end{bmatrix} \begin{bmatrix} K_t - \bar{K} \\ m_t - \bar{m} \\ b_t - \bar{b} \\ \mu_t - \bar{\mu} \\ c_t - \bar{c} \end{bmatrix} & \begin{bmatrix} \lambda_1 & 0 & 0 & 0 & 0 \\ 0 & \lambda_2 & 0 & 0 & 0 \\ 0 & 0 & \lambda_3 & 0 & 0 \\ 0 & 0 & 0 & \lambda_4 & 0 \\ 0 & 0 & 0 & 0 & \lambda_5 \end{bmatrix} & \end{array}$$

If the eigenvalues are positive then the system is globally unstable, and the variables approach either positive or negative infinity. However, if the roots are all negative, then the system is globally stable irrespective of the initial values, and the system eventually returns to its steady state. In the case of perfect foresight, it generally holds that the characteristic roots have mixed signs (Klein, 2002). This produces a system that is saddle path stable and the steady state equilibrium is known as the saddle point.

The behaviour of the variables around their steady state values is written as:

$$K_t = \bar{K} + (\hat{K}_t + \hat{b}_t)e^{\lambda_1 t} \quad (39)$$

$$m_t = \bar{m} + (\hat{K}_t + \hat{b}_t)e^{\lambda_2 t} \quad (40)$$

$$b_t = \bar{b} + (\hat{K}_t + \hat{b}_t)e^{\lambda_3 t} \quad (41)$$

$$\mu_t = \bar{\mu} + (\hat{K}_t + \hat{b}_t)e^{\lambda_4 t} \quad (42)$$

$$c_t = \bar{c} + (\hat{K}_t + \hat{b}_t)e^{\lambda_5 t} \quad (43)$$

where  $\lambda_1$  is a negative characteristic root and the variables with “hats” represent deviations around their steady state values.<sup>9</sup>

The matrix algorithm in EVIEWS is used to solve the 5×5 system which produced the following

$$\Lambda = \begin{bmatrix} -9.9 & 0 & 0 & 0 & 0 \\ 0 & -3.5 & 0 & 0 & 0 \\ 0 & 0 & -1.1 & 0 & 0 \\ 0 & 0 & 0 & 15.6 & 0 \\ 0 & 0 & 0 & 0 & 25.6 \end{bmatrix}.$$

which suggests that the system has a saddle point. The parameters in the  $A$  matrix were picked on the basis of Jamaican data. The average Treasury bill yield was used as the interest rate variable ( $r$ ), while the ratio of gross fixed capital formation to GDP was employed as a proxy for the marginal product of capital ( $f'(k)$ ). The measure of marginal utility of consumption  $v'(c)$  was based on an estimate of private consumption by households in Jamaica. The average rate of depreciation ( $\delta$ ) was assumed to be 10.0 per cent per year.

## 2.7 Exchange Rate Dynamics

Given that the system is saddle path stable, we can now analyze how it behaves when the variables are disturbed. Based on the purchasing power parity theory (PPP), changes in the exchange rate equilibrate domestic and foreign inflation

$$\frac{\dot{e}_t}{e_t} = \pi_t - \pi_t^* \quad (44)$$

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<sup>9</sup>  $\hat{K}_t = K_t - \bar{K}$  and  $\hat{b}_t = b_t - \bar{b}$

which further implies that  $\frac{\dot{e}_t}{e_t}$  is determined by the difference in monetary growth rates  $(\eta - \eta^*)$ . By combining equations (32) and (44), the path of exchange rate changes is given by:

$$\frac{\dot{e}_t}{e_t} = (\eta - \eta^*) - \frac{\dot{m}_t}{m_t} \quad (45)^{10}$$

By substitution and simplification, our final reduced form model is

$$\frac{\dot{e}_t}{e_t} = (\eta - \eta^*) + \frac{\lambda_1 t \{ (K_t - \bar{K}) + (b_t - \bar{b}) \} e^{-\lambda_1 t}}{\bar{m} + \{ (K_t - \bar{K}) + (b_t - \bar{b}) \} e^{-\lambda_1 t}} \quad (46)$$

From equation (46), it is clear that an increase in the monetary growth differential increases the rate of exchange rate depreciation. This is consistent with theory. However, with respect to changes in  $K_t$  and  $b_t$ , the rate of exchange rate depreciation depends on the relative magnitudes of the steady state values for  $\bar{m}$  and  $\bar{K}$  as well as on the location of both  $K_t$  and  $b_t$ , relative to their steady state values. This cannot be determined aprior.<sup>11</sup>

### 3.0 Empirical Model

This paper uses a Structural Vector Autoregression (SVAR) model to estimate (46). A simple VAR for a  $k$ -dimensional vector of variables,  $Z_t$ , is given by the following:

$$X_t = B_1 X_{t-1} + \dots + B_q X_{t-q} + \varepsilon_t, \quad E \varepsilon_t \varepsilon_t' = V \quad (47)$$

<sup>10</sup> To obtain  $\dot{m}_t$  we take the partial derivative of  $m_t$  to obtain  $\dot{m}_t = \lambda_1 \{ (K_t - \bar{K}) + (b_t - \bar{b}) \} e^{\lambda_1 t}$

<sup>11</sup> In other words, the sign of  $\frac{\partial \left( \frac{\dot{e}_t}{e_t} \right)}{\partial b_t} = \frac{-\lambda_1 t e^{-\lambda_1 t} \bar{m} + 2e^{-\lambda_1 t} \bar{K}}{[\bar{m} + e^{-\lambda_1 t} \{ (K_t - \bar{K}) + (b_t - \bar{b}) \}]^2}$  cannot be evaluated theoretically with reference to the data.

To compute the dynamic response function of  $X_t$  to fundamental shocks, we follow Amisano and Giannini (1997) by assuming that the relationship between the VAR disturbances,  $\varepsilon_t$  and these fundamental shocks,  $\zeta_t$ , is given by

$$Ae_t = Bu_t \quad (48)$$

where  $e_t$  and  $u_t$  are vectors of length  $k$ .  $e_t$  is the observed (or reduced form) residuals, while  $u_t$  is the unobserved structural innovations.  $A$  and  $B$  are  $k \times k$  matrices to be estimated. The structural innovations  $u_t$  are assumed to be orthonormal, which imposes the following identifying restrictions on  $A$  and  $B$ :

$$A \Sigma A' = BB' \quad (49)$$

Since the expressions on either side of (49) are symmetric, this imposes  $k(k+1)/2$  restrictions on the  $2k^2$  unknown elements in  $A$  and  $B$ , which implies that we need to supply  $2k^2 - k(k+1)/2 = k(3k-1)/2$  additional restrictions.

Our reduced form model from (46) indicates that  $X_t = \left[ \frac{\dot{e}_t}{e_t}, \eta_t - \eta^*, \hat{k}_t, \hat{b}_t, \bar{m} \right]'$ .

To identify this system, we impose the following restrictions:

$$A = \begin{bmatrix} 1 & a_{12} & a_{13} & a_{14} & a_{15} \\ a_{21} & 1 & 0 & 0 & 0 \\ a_{31} & 0 & 1 & a_{34} & 0 \\ a_{41} & a_{42} & a_{43} & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 \end{bmatrix} \quad B = \begin{bmatrix} 1 & b_{12} & b_{13} & b_{14} & b_{15} \\ b_{21} & 1 & b_{23} & b_{24} & b_{25} \\ b_{31} & b_{32} & 1 & b_{34} & b_{35} \\ b_{41} & b_{42} & b_{43} & 1 & b_{45} \\ b_{51} & b_{52} & b_{53} & b_{54} & 1 \end{bmatrix}$$

The principal restriction is that the steady state does not change in response to temporary shocks (deviation of all the variables from their steady state values). In essence, this restriction imposes stable saddle points on our data and is achieved by setting  $a_{5j} = 0, \forall$



$j=1...4$ . For symmetry, we impose the restrictions  $a_{i5} = 0, \forall i=2...4$ , which ensures that shocks to the steady state variable ( $\bar{m}$ ) has no impact on the saddle path behaviour of the variables. We also choose to turn off the interactions between  $\eta_t - \eta^*$  and  $\hat{k}_t$ . In terms of the restrictions  $a_{32} = a_{23} = 0$ , the rationale is that domestic firms largely acquire external financing to pay for imported capital. Moreover, we assume that the time period for this analysis is sufficiently short so that second round multiplier effects will not materialise. This is not too far from the Jamaican reality.

#### 4.0 Data Selection

The paper uses monthly data to estimate equation (46). There were no clear candidate indicator variables for  $\hat{k}_t$ ,  $\hat{b}_t$  and, to a lesser extent,  $\bar{m}$ . Selecting the appropriate set of time series for use in this model therefore required some empirical evaluation.

Published Jamaican data on the capital stock does not exist. Our candidate indicators for investment include capital goods imports and FDI inflows. To derive the capital stock from these variables, we assume that the initial flow at the start of our sample corresponds to the initial capital stock and then update our view about the stock by adding the current period investment and assuming a straight line depreciation rule of the form  $K_t = 0.9K_{t-1} + I_t$ .<sup>12</sup>

The same broad approach applies to  $\hat{b}_t$ . Bank of Jamaica has only recently started to publish International Investment Positions (IIP) at the end of each calendar year. To derive monthly data from this limited dataset, we update the initial estimated IIP at the start of the sample with four candidate variables; the current account deficit from the balance of payments (BOP\_CAD), the derived cash flow estimate of the current account deficit (CAD\_CF), net private capital cash flow (NPC\_CF) and the net interaction of the BOJ with the private economy (BAL\_CF). In principle, net foreign assets should fall with

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<sup>12</sup> For simplicity, we assume that the capital stock depreciates fully over 10 years.

each realisation of the current account deficit (accrued or cash) and with each additional unit of private capital inflows.

This method of using the current account deficit to update the economy's net foreign asset position is justified by the accounting identity that the sum of the current account (CA) and the capital and financial accounts (KFA) must be equal to zero. That is  $CA_t + KFA_t = 0$ . If we assume that the capital account balance is negligible, and that there is an initial stock of net foreign assets (or liability) ( $B_0$ ), then  $\dot{b}_t \approx B_{t+1} - B_t = KFA_t$ .<sup>13</sup> In this context  $\dot{b}_t \approx CA_t$ .

The issue of cash flows versus the flows from the BOP which are based on accrued accounting also merits some discussion. The cash flow current account balance is estimated from BOP statistics and reflects the net foreign exchange flows into and out of the economy over a specified period. Non-cash transactions describe a situation where an entry is made in the BOP, but the corresponding flow of foreign currency through the domestic banking system does not take place. The reason for focusing on this distinction comes from the view that changes in the exchange rate, which react to disjuncture between the demand for and the supply of foreign exchange, should more reflect cash flows rather than accrued flows.

Balance of payments cash flow analysis, which is actively used by the BOJ in its policy dialogue, employs an inventory type accounting system that separates BOP transactions into cash and non-cash items. Cash transactions may differ from the recorded BOP transactions as the BOP does not account for trade arrangements (for example prepayments or credit lines). Rather, trade statistics are recorded on the basis of customs documents reflecting the physical movement of goods across the national or customs frontier of an economy.<sup>14</sup> Additionally, some transactions might be financed through

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<sup>13</sup> In Jamaica the capital account balance is very small averaging a deficit of US\$0.4 million over the past eight years.

<sup>14</sup> See the IMF 2003 BOP Manual.

grants, as well as, foreign direct investments, both of which would not immediately (if ever) result in a significant pull/addition of foreign currency in the domestic market.<sup>15</sup>

Given that  $\bar{m} = m_t - \dot{m}_t$  and  $\dot{m}_t = (\eta - \pi_t)m_t$  we can derive a time series for the steady state value of the real money stock by substituting for  $\dot{m}_t$  in the first expression with the variables in the right side of the second:

$$\begin{aligned}\bar{m} &= m_t - [(\eta - \pi_t)m_t] \\ &= m_t(1 - \eta + \pi_t)\end{aligned}$$

As an alternative candidate variable we also apply the Hodrick Prescott filter to the real money stock series. All the other steady state variables were also derived by applying the HP filter.

In terms of the other variables,  $\frac{\dot{e}_t}{e_t}$  is defined as the percentage change in the number of U.S. cents per Jamaica Dollar.<sup>16</sup> The money growth differential ( $\eta_t - \eta^*$ ) is the difference between the monthly growth rate of broad money supply (M3) between Jamaica and the U.S.<sup>17</sup>

All the data were obtained from the Bank of Jamaica's (BOJ's) database, some of which are computed from data made available by the Statistical Institute of Jamaica (STATIN). The sample ranges from April 2000 to June 2008.

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<sup>15</sup> Theoretical studies on changes in the timing of exchange transactions associated with international trade credit have been forwarded as a possible explanation of instability in exchange rates (Van Der Toorn, 1986).

<sup>16</sup> Due to the shock that was experienced in 2003, a dummy variable (DUMXR) was included in the model.

<sup>17</sup> The Federal Reserve uses M2 as a measure of broad money.

## 5.0 Stylised Facts

This section briefly reviews the behaviour of the data under consideration, including those that were simulated. To decide the most appropriate set of indicator variables, we estimated different combinations of these models in the SVAR and selected the best set based on their in-sample forecasting ability. Table 1 (appendix) indicates that the group of SVARs that contains the measure of the economy's net foreign liabilities as indicated by the cash flow balance, the measure of the capital stock as indicated by capital goods imports and the smoothed series of the money stock perform best in-sample. This is represented by model thirteen (13).

In terms of the exchange rate, the Jamaican economy recorded an average monthly rate of depreciation of 0.5 per cent over the review period. This was heavily influenced by the period January to June 2003, when the value of the local currency lost approximately 19.0 per cent of its value (an average of 3.84 per cent per month).<sup>18</sup>

The average rate of growth of the Jamaican money supply is typically higher than that for the US so that the mean differential is 0.43 per cent. This positive differential appears to underpin the trend depreciation in the exchange rate over the sample. Interestingly, the volatility of the differential appears to have been higher prior to the large depreciation in 2003. The monthly growth in money supply is usually highest in December, which is consistent with the seasonal increase during the holiday period (see Figure 1, plot 1 Appendix 1).

For the relationship between changes in the exchange rate and shocks to the private sector's net foreign liabilities, as indicated by net private capital cash inflows, 2003 appears to define a watershed. Shocks were consistently positive between December 2001 and March 2003, but exchange rate depreciation became progressively larger over

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<sup>18</sup> This was attributed to a decline in market confidence triggered by a confluence of factors, including deterioration of the fiscal and balance of payments accounts, and the related downgrade of the outlook of Jamaica's sovereign debt by Standard and Poor's (S&P). This was facilitated by the high level of Jamaica dollar liquidity.

that same period. After 2003, periods of positive shocks were occasioned by exchange rate appreciation, or at least a period of slower depreciation. The same view of the relationship between the net foreign liabilities, as indicated by the current account deficit, calculated on the basis of both BOP and cash flow analysis, and exchange rate changes, is true. Positive shocks appear to be correlated with appreciation after 2003 and vice versa (figure 2 & 3).<sup>19</sup>

It is difficult to discern a relationship from the graph between the exchange rate and shocks to the capital stock (as indicated by capital goods imports). In most cases, positive shocks appear to coincide with reduced exchange rate depreciation, or with an appreciation in the exchange rate.

The contemporaneous correlations of the selected variables are presented in Table 1, depicting the expected signs. Notably, the negative correlation between  $\frac{\dot{e}_t}{e_t}$  and  $\hat{b}_t\_bal\_cf$  implies that an increase in the net foreign assets of the country leads to an appreciation of the exchange rate. Similarly, an increase in  $\eta_t - \eta^*$  and  $\hat{K}_t\_cap$ , generally leads to an increase in the rate of depreciation of the exchange rate.

**Table 1: Correlations**

	$\frac{\dot{e}_t}{e_t}$	$\eta_t - \eta^*$	$\hat{K}_t\_cap$	$\bar{m}\_hp$	$\hat{b}_t\_bal\_cf$
$\frac{\dot{e}_t}{e_t}$	1.0000				
$\eta_t - \eta^*$	0.0379	1.0000			
$\hat{K}_t\_cap$	0.0738	-0.0539	1.0000		
$\bar{m}\_hp$	0.1054	0.0514	0.0594	1.0000	
$\hat{b}_t\_bal\_cf$	-0.0432	-0.0194	0.0462	-0.0992	1.0000

<sup>19</sup> This relationship appeared to have broken down again in 2008, when the CAD based on the BOP was widening, even while the exchange rate was broadly appreciating. The increased deficit after the December 2007 quarter reflected the impact of higher international commodity prices which resulted in a higher value for fuel imports. At the same time that this was happening, confidence in international financial markets waned and there was the takeover of a local company by a foreign corporation, leading to an increase in net private capital inflows.

## 6.0 Unit Root Tests and Impulse Response Functions

To conduct a more rigorous econometric evaluation of the reduced form model, all the variables were first tested for the presence of unit roots using the Augmented Dickey-Fuller and Phillips-Perron tests. With the exception of  $\bar{m}_{calc}$  and  $\bar{m}_{hp}$ , all the variables were found to be stationary (see Table 2).

The impulse response functions from the structural VAR show the response of  $\frac{\dot{e}_t}{e_t}$  to a shock from the other variables (see Figure 2, appendix). The X-axis gives the duration of the shock, whilst the y-axis gives the direction and intensity of the impulse. In the case of steady state analysis however, we are basically interested in recovering the direction of the response and not necessarily the intensity/magnitude, nor the duration. In this context, the response of the rate of change in the exchange rate to shocks to the other variables meets *a priori* expectations. A positive shock to  $\eta_t - \eta^*$  leads to an acceleration in the rate of depreciation (+). The largest response is in the first month following the shock and dies out almost immediately thereafter. For the impact of  $\hat{b}_t_{bal\_cf}$ ,  $\frac{\dot{e}_t}{e_t}$  appreciates sharply, while a positive shock to  $\hat{K}_t_{cap}$  results in a decrease in the rate of depreciation of the exchange rate.<sup>20</sup>

The response of  $\hat{K}_t_{cap}$  from shocks to  $\frac{\dot{e}_t}{e_t}$  indicates that the desired capital stock falls relative to the steady state. Similarly,  $\hat{K}_t_{cap}$  falls below steady state in the context of a shock to  $\hat{b}_t_{bal\_cf}$  (see Figure 3, appendix 2). For the household's portfolio,  $\hat{b}_t_{bal\_cf}$  falls relative to the steady state in the context of a fall in the rate of exchange rate depreciation.

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<sup>20</sup> The impulse responses of all variables in the SVAR model may be observed in Figure 3, Appendix.

### 6.1 Robustness Tests

Various goodness-of-fit measures were employed to ensure that the model was stable to provide unbiased and consistent results. An autoregressive (AR) model was estimated to compare the in-sample forecasting properties of these competing specifications with our base model. In this context, Table 3 shows the results from the AR model while the various measures of goodness of fit are presented in Table 4. The goodness of fit tests indicate that the SVAR model outperforms the AR model based on all measures of goodness of fit.

**Table 3: Autoregressive Model**

	Coefficient	Std. Error	t-Statistic	Prob.
<b>DUMXR</b>	98.366	4.121	23.871	0.00
<b>AR(1)</b>	0.697	0.074	9.477	0.00
R-squared	0.834	Akaike info criterion		1.265
Adjusted R-squared	0.832	Schwarz criterion		1.317
S.E. of regression	0.451	H-Q criterion		1.286
Durbin-Watson stat	1.93	Inverted AR Roots		0.7

**Table 4: Goodness-of-fit Tests**

	<b>SVAR Model</b>	<b>AR Model</b>
RMSE	0.0525	0.6253
MAE	0.0053	0.4449
Theil-U	0.1968	0.2761
Bias Proportion	0.000016	0.3802
Variance Proportion	0.0061	0.0119

## **7.0 Conclusion**

In this paper, we analyze the effects of various disturbances on the path of exchange rate changes in Jamaica, based on the intertemporal optimizing behaviour of agents in the economy. We get no clear theoretical guidance from our theoretical augmented monetary model on the relationship between shocks to net foreign assets as well as the capital stock and changes in the exchange rate. Empirically, the estimated model suggests, as expected, that shocks to the differential between domestic and external monetary growth rate leads to an acceleration in the rate of exchange rate depreciation. If net foreign assets are higher than required by agents in the economy, the exchange rate appreciates, possibly reflecting the impact of portfolio readjustment on the domestic foreign exchange market. A shock to the capital stock leads to an acceleration in the rate of depreciation as agents in the economy exert more demand for foreign exchange to import the excess capital.

The main policy implication of these findings is the confirmation that cash flow balances are important leading indicators of near term pressures in the foreign exchange market. Efforts to estimate and forecast this indicator represent an important effort by the Bank of Jamaica in ensuring stability in the foreign exchange market.



## APPENDIX 1

### Deriving the first order condition for the household:

The intertemporal utility function of the representative household is given as follows:

$$U_0 = \int_0^{\infty} u(c_t, m_t) e^{-\theta t} dt. \quad (50)$$

Maximization of this utility function is carried out over positive consumption levels subject to the following lifetime budget constraint:

$$\dot{a}_t = r_t a_{t-1} + w_t - \tau_t - c_t - (r_t + \pi_t) m_t. \quad (51)$$

Given equations (50) and (51), the present value Hamiltonian is as follows:

$$H = [u(c_t, m_t)] e^{-\theta t} + \lambda_t (r a_t + w_t - \tau_t - c_t - (r_t + \pi_t) m_t) \quad (52)$$

The current value Hamiltonian can then be expressed as:

$$H_c = [u(c_t, m_t)] + \mu_t (r a_t + w_t - \tau_t - c_t - (r_t + \pi_t) m_t) = H e^{\theta t}$$

To derive the first order conditions (FOCs), we differentiate  $H_c$  w.r.t.  $c_t$  and  $m_t$  and set to zero

$$\frac{\partial H_c}{\partial c_t} = u'(c_t) - \mu_t = 0$$

$$\frac{\partial H_c}{\partial m_t} = u'(m_t) - \mu_t (r_t + \pi_t) = 0$$

which implies that

$$\mu_t = u'(c_t) \quad (53)$$

and

$$u'(m_t) = \mu_t(r_t + \pi_t) \quad (54)$$

With respect to the FOC for the state variable, we follow the standard formulation by Klein (2002)

$$\frac{\partial H_c}{\partial a_t} = -e^{\theta t} \dot{\lambda}_t$$

or alternatively,

$$e^{-\theta t} \frac{\partial H_c}{\partial a_t} = -\dot{\lambda}_t \quad (55)$$

For the current value Hamiltonian, the left hand side (LHS) of the above expression is:

$$e^{-\theta t} \frac{\partial H_c}{\partial a_t} = e^{-\theta t} \mu_t r_t$$

Since the right hand side (RHS) is equal to  $-\dot{\lambda}_t$  and we know that  $\mu_t e^{-\theta t} = \lambda_t$ , this implies that

$$-\dot{\lambda}_t = \theta e^{-\theta t} \mu_t - \dot{\mu}_t e^{-\theta t} \quad (56)$$

Equating the LHS and the RHS produces:

$$e^{-\theta t} \mu_t r_t = \theta e^{-\theta t} \mu_t - \dot{\mu}_t e^{-\theta t}$$

Cancelling the  $e^{-\theta t}$  gives

$$\mu_t r_t = \theta \mu_t - \dot{\mu}_t$$

$$\dot{\mu}_t = \mu_t (\theta - r_t) \quad (57)$$

To show that the state equation holds, we differentiate w.r.t. the alternative shadow price

$$\frac{\partial Hc}{\partial \mu_t} = ra_t + w_t - \tau_t - c_t - (r_t + \pi_t)m_t = \dot{a}_t \quad (58)$$

The following transversality condition holds:

$$\lim_{t \rightarrow \infty} \mu_t e^{-\theta t} a_t = 0 \quad (59)$$

The first order conditions of the household are therefore given as follows:<sup>21</sup>

$$u'(c_t) = \mu_t \quad (60)$$

$$u'(m_t) = \mu_t (r_t + \pi_t) \quad (61)$$

$$\mu_t r_t = \theta \mu_t - \dot{\mu}_t \quad (62)$$

$$\dot{a}_t = ra_t + w_t - \tau_t - c_t - (r_t + \pi_t)m_t \quad (63)$$

$$\lim_{t \rightarrow \infty} \mu_t e^{-\theta t} a_t = 0 \quad (64)$$

The interpretation of these FOCs relate consumption growth to the elasticity of intertemporal substitution, the market discount rate,  $r$  and the subjective discount rate,  $\theta$ .

To show this we note that:

$$-(r_t - \theta)\mu_t = \dot{\mu}_t$$

and substitute (60) to obtain

$$-(r_t - \theta)u'(c_t) = \dot{\mu}_t$$

In order to get  $\dot{\mu}_t$  we differentiate (60) w.r.t time

$$\frac{d\mu_t}{dt} = u''(c_t)\dot{c}_t = \dot{\mu}_t$$

By equating both terms,

$$-(r_t - \theta)u'(c_t) = u''(c_t)\dot{c}_t \text{ such that}$$

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<sup>21</sup> The derivation of these conditions is given in Appendix 1.

$$\dot{c}_t = -(r_t - \theta) \frac{u'(c_t)}{u''(c_t)} \quad \text{or} \quad \dot{c}_t = -(r_t - \theta)v(c_t) \quad (65)$$

Where  $v(c_t) = \frac{u'(c_t)}{u''(c_t)}$

### Deriving the first order condition for the Firm:

The firm's maximisation problem can be expressed as

$$\max v_0 = \int_0^{\infty} [F(K_t, L_t) - w_t L_t - I_t] e^{-\theta t} dt \quad (66)$$

subject to the capital accumulation equation

$$\dot{K}_t = I_t - \delta K_t \quad (67)$$

The present value Hamiltonian is expressed as:

$$H = [f(k_t)L_t - w_t L_t - I_t] + \lambda(I_t - \delta K_t)$$

The current value Hamiltonian can then be expressed as:

$$H_c = [f(k_t)L_t - w_t L_t - I_t] + \mu_t(I_t - \delta K_t) = H e^{\theta t} \quad (68)$$

For the first order condition, we differentiate  $H_c$  w.r.t. the control variable  $L_t$

$$\frac{\partial H_c}{\partial L_t} = f(K_t L_t^{-1}) + L_t f'(K_t L_t^{-1}) - w_t = 0$$

Assuming  $L_t = \bar{L}_t K_t = k_t$ . As a result

$$f(k_t) + f'(k_t) - w_t = 0$$

$$w_t = f(k_t) + f'(k_t) \quad (69)$$

For the current value Hamiltonian, we use the derivation employed in equation (9) to obtain

$$\frac{\partial H}{\partial K_t} = e^{-\theta t} \frac{\partial H_c}{\partial K_t} = e^{-\theta t} f'(K_t L_t^{-1}) L_t - \mu_t \delta$$

Given that labour is constant, and  $K_t = k_t$  the expression reduces to

$$e^{-\theta t} \frac{\partial H_c}{\partial K_t} = e^{-\theta t} (f'(k_t) - \mu_t \delta) \quad (70)$$

Equating equations (23) and (10) yields

$$e^{-\theta t} (f'(k_t) - \mu_t \delta) = \theta e^{-\theta t} \mu_t - \dot{\mu}_t e^{-\theta t}$$

Cancelling the  $e^{-\theta t}$  gives

$$f'(k_t) - \mu_t \delta = \theta \mu_t - \dot{\mu}_t \quad (71)$$

To show that the state equation holds, we differentiate w.r.t. the alternative shadow price

$$\frac{\partial H}{\partial \mu_t} = I_t - \delta K_t = \dot{K}_t \quad (72)$$

The following transversality condition holds:

$$\lim_{t \rightarrow \infty} \mu_t e^{-\theta t} K_t = 0 \quad (73)$$

The FOCs of the firm are thus:

$$w_t = f(k_t) + f'(k_t) \quad (74)$$

$$\dot{\mu}_t = (\delta + \theta)\mu_t - f'(k_t) \quad (75)$$

$$\dot{K}_t = I_t - \delta K_t \quad (76)$$

$$\lim_{t \rightarrow \infty} \mu_t e^{-\theta t} K_t = 0 \quad (77)$$

## APPENDIX 2

**Table 1: Comparative Model Structures and In-Sample Forecasting Assessment**

Model	et	n- n*	bhat			Khat		mbar		Theil U statistics	Rank
			bt_bal- cf	bt_CAD_BOP	bt_cad_cf	bt_NPC_cf	kt_cap	kt_fdi	mbar_hp		
1	☐	☐	☐					☐	☐	0.1995	5
2	☐	☐		☐				☐	☐	0.2035	11
3	☐	☐			☐			☐	☐	0.2040	15
4	☐	☐				☐		☐	☐	0.1998	6
5	☐	☐	☐				☐		☐	0.1969	2
6	☐	☐		☐			☐		☐	0.2006	8
7	☐	☐			☐		☐		☐	0.2038	14
8	☐	☐				☐	☐		☐	0.1987	3
9	☐	☐	☐					☐	☐	0.1988	4
10	☐	☐		☐				☐	☐	0.2036	12
11	☐	☐			☐			☐	☐	0.2037	13
12	☐	☐				☐		☐	☐	0.3670	16
<b>13</b>	☐	☐	☐				☐		☐	<b>0.1968</b>	1
14	☐	☐		☐			☐		☐	0.2011	9
15	☐	☐			☐		☐		☐	0.2029	10
16	☐	☐				☐	☐		☐	0.1999	7
Average Theil U's			<b>0.1980</b>	0.2022	0.2036	0.2414	<b>0.2001</b>	0.2225	0.2217	<b>0.2009</b>	

Table 2: Unit Root Tests				
Variables	ADF <sup>1</sup>		Philips Perron	
	Level	First diff.	Level	First diff.
$\eta_t - \eta^*$	-14.25	-10.79	-15.43	-85.89
$\bar{m}_{hp}$	-1.58	-2.15	-1.82	-0.67
$\bar{m}_{calc}$	-1.70	-12.23	-1.55	-12.17
$\hat{K}_{t\_fdi}$	-3.36	-2.86	-3.33	-9.77
$\hat{K}_{t\_cap}$	-3.66	-8.2	-3.77	-8.24
$\hat{b}_{t\_cad\_cf}$	-7.86*	-10.56*	-7.97	-23.24
$\hat{b}_{t\_cad\_bop}$	-5.60*	-9.26*	3.41	-6.85
$\hat{b}_{t\_npc\_cf}$	-3.02	-7.56	-2.97	-7.57
$\hat{b}_{t\_bal\_cf}$	-3.64	-7.15	-3.03	-7.19
$\hat{e}_t$				
$e_t$	-7.56	-16.29	-7.66	-32.52

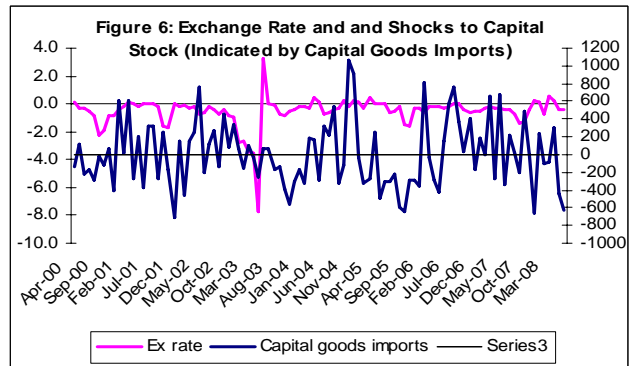
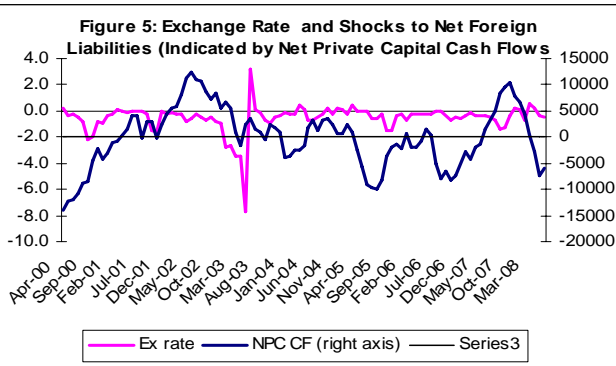
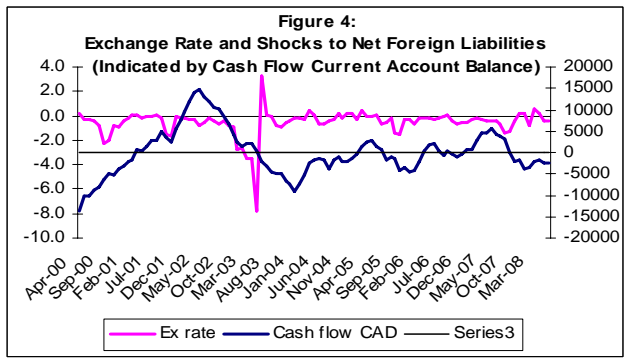
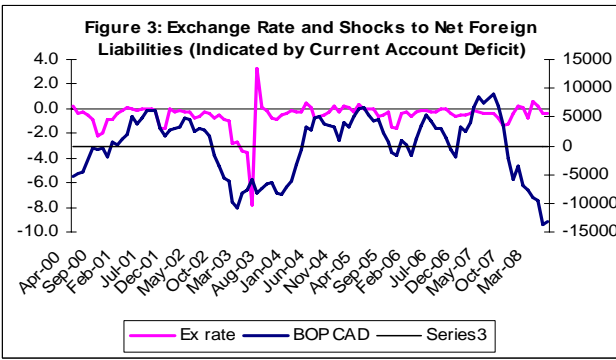
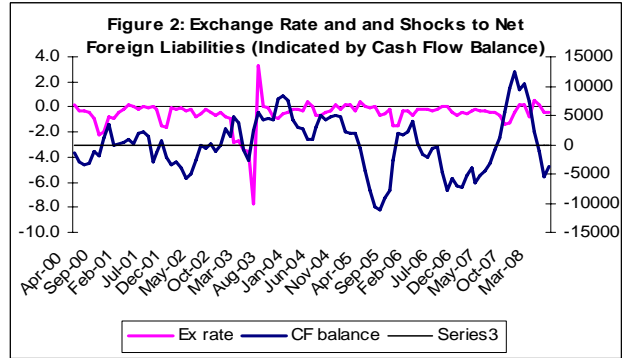
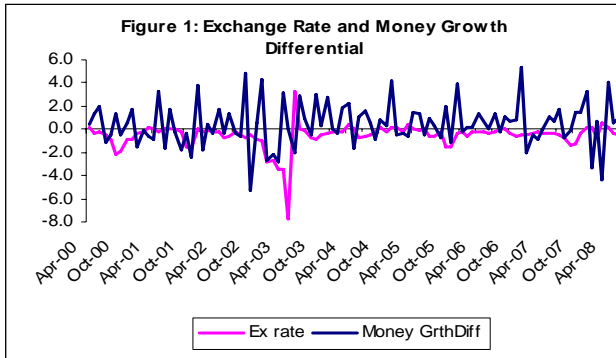
1. Without Trend

Critical Values (1%) -3.50

(5%) -2.89

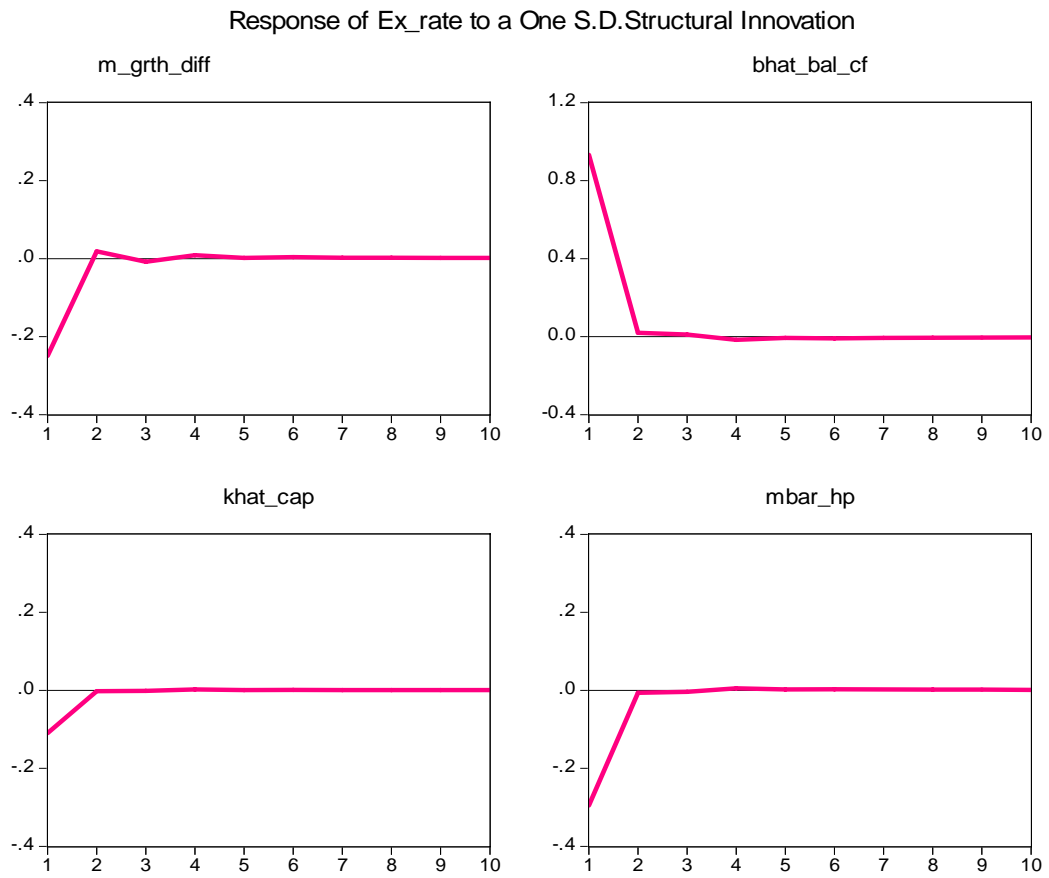
\* Restricted sample

**Figure 1: Plots of Variables and the Exchange Rate**

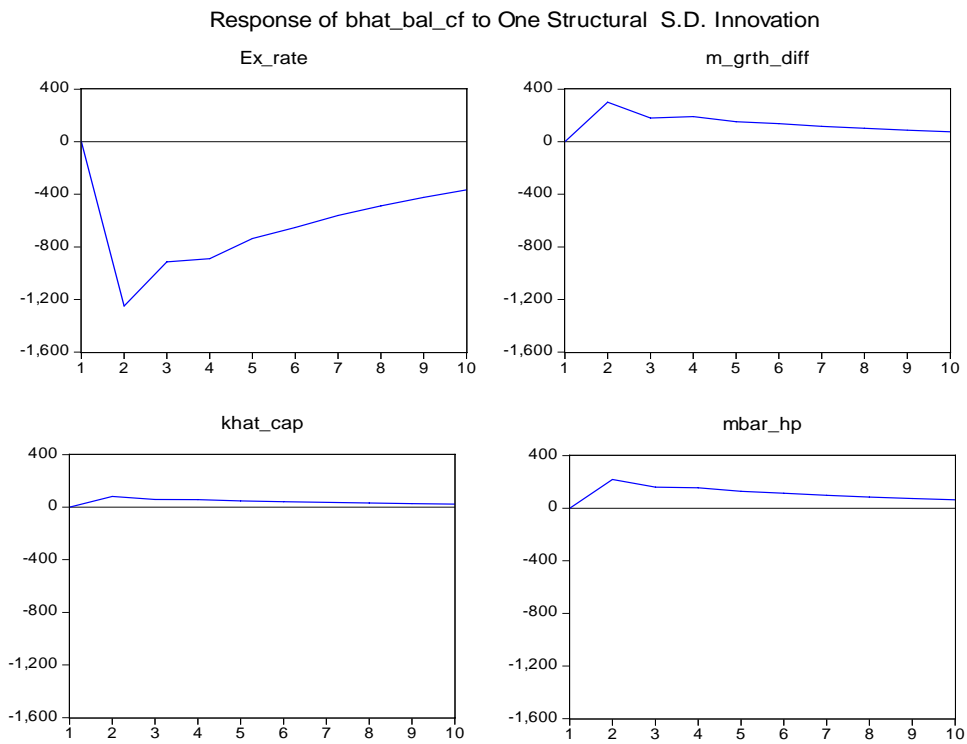
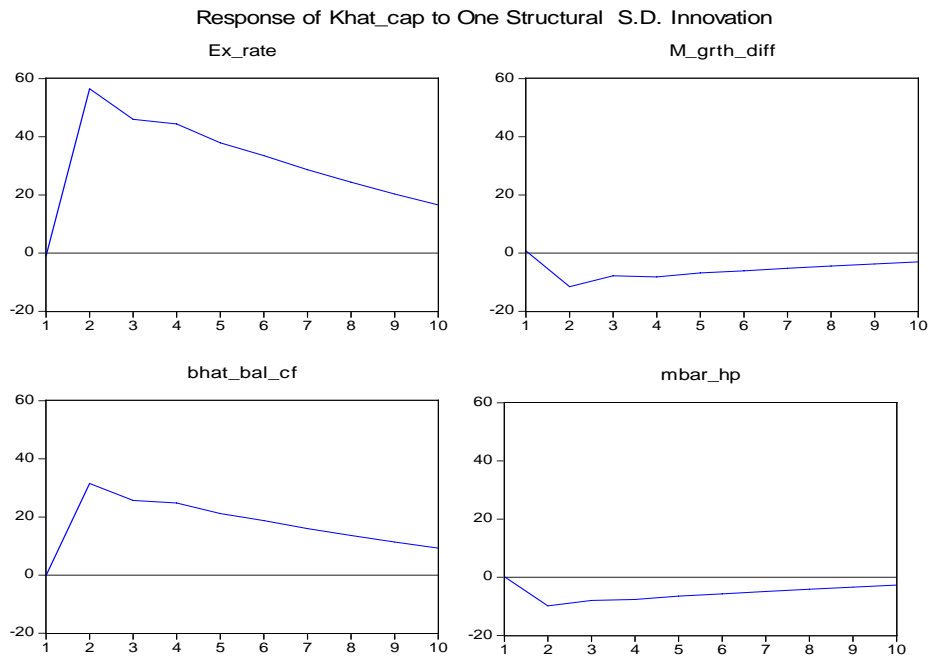




**Figure 2: Impulse Responses from SVAR (Response of Ex\_rate only)**



**Figure 3: Impulse Responses from SVAR (Response of all variables)<sup>22</sup>**



<sup>22</sup> This excludes Mbar\_hp.

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