# Monetary Policy in a Low Exchange Rate Pass-Through Environment: The case of Botswana

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## ABSTRACT

This paper constructs a small open economy New Keynesian Dynamic Stochastic General Equilibrium (DSGE) model, to examine monetary policy conduct and the extent of exchange rate pass-through in Botswana. Thus, I apply a three-step procedure. In the first step, I estimate the degree of exchange rate pass-through to Consumer Price Index (CPI) and import prices using a Vector Error Correction model (VECM). Secondly, I carry out simulations using trade openness parameter value suggested by the imports and exports to GDP ratio for Botswana and using parameter values consistent with Justiniano and Preston (2010). The simulations allow me to establish the impact of different economic disturbances on Botswana's business cycle fluctuations and the extent to which these economic disturbances influence Botswana's business cycle fluctuations. Following this set-up, using time series data for Botswana's macro-economic variables for the period 2004:Q1-2017:Q4 obtained from Bank of Botswana I use Bayesian methods to estimate the DSGE model. I find that in the short-run, exchange rate pass-through to CPI and imports prices is low, at 12 percent and 5 percent, respectively. Secondly, the simulations show that imports cost-push shock leads to a decrease in consumption by a higher magnitude than the decrease in output. The estimation results show that the central bank allocates the largest weight towards price stability as compared to other target variables such as the output gap, in its monetary policy rule. Moreover, the monetary policy shock, import cost-push shock and risk premium are responsible for majority of the business cycle fluctuations in Botswana. These findings may be useful for policy makers and in particular in guiding their policy decision making because of the suggested variables that may influence business cycle fluctuations in Botswana.

## 1. INTRODUCTION

Monetary authorities face a trade-off between output and inflation in their monetary policy conduct. This is because an increase in aggregate demand leads to an increase in output and a decline in unemployment. As the economy expands towards its full employment, this triggers a rise in inflation which in-turn affects the stability of the economy. In an open economy set-up, this becomes even more complicated as the central bank must consider the impact of foreign policy actions on the domestic economy and the exchange rate. In addition, openness gives rise to international trade which in turn implies that the domestic economy's inflation is affected by foreign inflation. The extent to which domestic inflation is affected by foreign inflation depends on the degree of exchange rate pass-through. When the pass-through is perfect a central bank should target domestic inflation. Meanwhile, when the pass-through is incomplete, then it is best to augment its reaction function to both foreign and domestic inflation (Gali, et al., 2002). This is mainly because the exchange rate transmits the impact of any shock on the economy through its effect on import prices and relative prices (Buyandelger, 2014). Under this circumstance, the exchange rate channel plays a role as either shock absorber or amplifier in implementing the monetary policy, but how much it can absorb (or amplify) depends on the exchange rate pass-through. In most cases, if not all pass-through is incomplete (Monacelli, 2005). Therefore, the exchange rate pass-through is an important consideration with respect to the effectiveness of monetary policy.[1]

In the recent past, there has been a growing interest from both academia and central banks in macroeconomics for small-scale New Keynesian applied to the analysis of monetary policy. These models have been termed "the New Keynesian synthesis" for which both theoretical and methodical contributions have so far converged to the use of Dynamic Stochastic General Equilibrium (DSGE) models. Major examples include the closed economy case of Gali et al. (1999) and the small open economy model by Gali (2002). These models incorporate optimising behaviour of agents as well as very realistic aspects such as monopolistic competition and sticky prices. Hence, because of these features monetary policy has been found to have a non-trival effect on real variables, i.e monetary policy can be used as a stabilisation tool as well as a source of fluctuations in the economy (Gali and Monacelli, 2005).

[1] Exchange rate pass-through (ERPT) can be defined as the percentage change in local currency import prices resulting from a one percent change in the exchange rate between the exporting and importing economies, see Bada et al. (2016).

From an open economy perspective, early contributions to literature include Benigno and Benigno (2001), Gali et al. (2001 and 2002), Woodford (2003) and Gali and Monacelli (2005). These early contributions analysed monetary policy in a small open economy set-up by assuming perfect or complete exchange rate pass-through. They found solutions similar to a closed economy and concluded that optimal monetary policy should focus on domestic price stability. This suggests that in an open economy the exchange rate volatility does not have any direct impact on welfare, whereas only price volatility affects welfare. However, this poses a significant limitation since well established empirical literature has shown that the exchange rate pass-through is incomplete in the short-run for developing and developed economies, see for example, Marston (1990), Rogoff (1995), Goldberg and Knetter (1997) and Smets and Wouters (2002). As such, since it is well established that exchange rate pass-through is incomplete in the short-run, allowing for incomplete pass-through yields important implications for the design of monetary policy as it suggests a focus on not only domestic inflation developments but also on imported inflation. Incomplete pass-through means that there is some form of import price stickiness, i.e prices are not transmitted one for one between the exporting and importing country. This assumption of sticky import prices also implies that there may be deviations from the law of one price as import prices adjust gradually.

Consequently, because of the incomplete pass-through, neither the model proposed by Gali and Monacelli, (2005) nor the isomorphic solution for the interest rate rule argued by Clarida et al. (2001) hold in the presence of incomplete pass-through. Buyandelger (2014) emphasises this by stating that often a central bank follows an interest rate rule and the target variables are output gap and inflation, as such exchange rate movements have a direct effect on both target variables and in turn thus affect monetary policy indirectly. Papers by Corsetti and Pesenti (2001), Smets and Wouters (2002), Sutherland (2002), Monacelli (2005) and Adolfson (2005) have studied the impact of incomplete pass-through on monetary policy using different approaches though all within a dynamic New Keynesian framework. Their key result is that exchange rate volatility and exchange rate pass-through are important and are pivotal in the design and implementation of optimal monetary policy.

In this paper, I argue that allowing for incomplete pass-through yields important implications for the design for monetary policy in Botswana due to the country's structural set-up which makes it susceptible to exchange rate fluctuations originating from structural shocks. First, the country is largely open with imports accounting for about 57 percent of real GDP (as at December 2017, author's calculation). Moreover, 80 percent of total goods and services consumed locally are imported with majority of them coming from South Africa (Bank of Botswana report, 2016). Imports of food and beverages, fuel and machinery equipment account for 43.7 percent of the consumer basket of goods index (CPI). Meanwhile, tradable and non-tradable goods account for 20.4 percent and 35.83 percent of the CPI, respectively, (Statistics Botswana, 2018). Thus, when prices of imports increase, they will reflect on the overall domestic inflation. Jefferies et al. (1999) argues that the expectation is that since Botswana depends highly on imports from South Africa, local prices will be determined by the prices of imports from South Africa. In addition, the distribution business requires heavy load trucks which are expensive to acquire or rent thus leaving the domestic market at retail level dominated by few players who keep domestic prices above foreign prices of the imported goods thus contributing to the local currency pricing of imports.

Secondly, foreign shocks such as the world commodity prices increase exchange rate fluctuations in exporting economies and Botswana is susceptible to these external shocks. Botswana is a core exporter of unprocessed minerals (mainly diamonds) to markets in Europe and Asia. Diamonds contribute about 88.6 percent to aggregate exports as at December 2017 (Bank of Botswana report, 2017). In addition, the second major export commodity is beef, which is exported to the European market. Thus, exchange rate movements are expected to affect the performance and or competitiveness of these sectors.

To examine the conduct of monetary policy and exchange rate pass-through for the Botswana economy this paper develops a small-scale microfounded New Keynesian DSGE model following the works of Monacelli (2005) and Justiniano and Preston (2010). As in Monacelli (2005) and Preston (2010), imports are subject to local currency pricing given the deviations from the law of one price. The model incorporates nominal rigidities by assuming monopolistic competition in the import and export goods markets. Moreover, the domestic and imported goods sectors are assumed to face staggered price setting. The model's dynamics are enriched by allowing for habit formation in the household utility function as in Justiniano and Preston (2010). To do so: (i) I first test the hypothesis that exchange rate pass-through (ERPT) is incomplete in Botswana using aVector Autoregressive Error Correction model (VECM), something which most authors have assumed given emprical evidence from ERPT analysis; (ii) I derive model solutions and calibrate a model using parameter values consistent with Justiniano and Preston (2010) for a small open economy and as well as based on Botswana data; (iii) I simulate the impluse response functions (IRFs) using Dynare Toolbox in Matlab software; (iv) lastly, I estimate a few parameters using Bayesian estimation techniques and discuss the key parameters for the study i.e the monetary policy parameters, habits, the calvo parameters and magnitude of the imported inflation/cost-push shock.

The main results from the study are as follows: (i) in the short-run, exchange rate pass-through to CPI and imports prices is low; (ii) imports cost-push shock leads to a decrease in consumption by a higher magnitude than the decrease in output; (iii) the central bank allocates the largest weight towards price stability as compared to other target variables such as the output gap, in its monetary policy rule; (iv) shocks responsible for majority of the business cycle fluctuations in Botswana are - the monetary policy shock, import cost-push shock and risk premium.

The rest of the paper is organised as follows: Section 2 provides an analysis on the exchange rate pass-through. Section 3 presents the DSGE model and provides derivations of the DSGE model along with presenting the calibration values. Section 4 describes the data and estimation techniques, section 5 discusses the results and section 6 provides the conclusion of the paper.

## 2. EXCHANGE RATE-PASS-THROUGH ANALYSIS

The theoretical literature on exchange rate pass-through draws their strength from the law of one price (LoP), the purchasing power parity (PPP) and the monetary theory to exchange rate determination (Bada et al., 2016). The LoP relates exchange rates to the relative prices of an individual good, meanwhile, PPP relates exchange rates to the relative prices of a basket of goods. Thus the principle of PPP is a macro concept while LoP is a micro concept. Both theories are assume frictionless trade thus implying zero arbitrage (Kotze, 2017). However, in reality, PPP does not hold in the short-run due to transaction costs, non-traded goods, price stickiness, imperfect competition and some legal obstacles (Feensta and Taylor, 2008). On the other hand, monetary theory of exchange rate determination states that in the long-run, all nominal variables are interlinked (this refers to money supply, interest rate, price level and exchange rate). Therefore, monetary policy choices can profoundly affect some important economic outcomes, notably prices and inflation (Bada et al., 2016).

This paper starts of by testing the hypothesis of incomplete ERPT to consumer prices and import prices in Botswana. According to economic theory, inflation is expressed as a function of variables which can be money supply (narrow or broad definition), output, foreign prices ($P_f$), nominal exchange rates (NER), and nominal lending interest rates ($r$) (Laryea and Sumaila, 2001). That is:

$$inflation = f(M, Y, P_f, NER, r)$$

Nonetheless, for testing this hypothesis, I will specify a simple model. The variables chosen for the study are Money supply, mainly the narrow definition of money, $M_1$.This is because $M_1$ is made up of currency in circulation and demand deposit which both create an inflationary pressure when in abundance because people's purchasing power would increase and thus increasing demand for goods. The increase in demand for goods will in turn lead to an increase in prices. Nominal GDP is chosen as the second variable used for analysis as it captures the level of income in the economy. Lastly nominal exchange rate (Rand/Pula) is included for analysis because Botswana heavily imports from South Africa hence this exchange rate becomes the most appropriate one for testing the ERPT hypothesis. As such the estimated equation is as follows:

$$ln(P_i) = \beta_0 + \beta_1 \ln(NER) + \beta_2 \ln(NGDP) + \beta_3 lnM_1 + \varepsilon_t$$

Where:

**Nominal Gross Domestic Product (NGDP):** represents total output of final goods and services produced in the country at current prices.

**Money Supply ($M_1$):** Is a narrow definition of money made up of currency in circulation and demand deposits.

**Nominal Exchange Rate (NER):** It is the unadjusted weighted average value of a local currency relative to that of its major trade partner(s). In this study the nominal exchange rate is the Pula/Rand exchange rate.

**Price Index ($P_i$): is the** CPI/imports index. The CPI is made of sub-indexes of consumer goods and services and used to measure changes in prices of goods and services purchased by households. Meanwhile, the imports price index represents the goods and services which a country (Botswana) imports from other countries (trading partners).

The a-priori expectations of the explanatory variables are as expressed below:

$$\beta_2, \beta_3 > 0 \ and \ \beta_1 < 0$$

Money supply and nominal GDP both impact positively on consumer price index. That is a one unit increase in $M_1$ or NGDP will lead to an increase in inflation. $M_1$ is made up of currency in circulation and demand deposits, as such an increase in the supply of $M_1$ in the economy means that people's purchasing power increases thus increasing their demand for goods and services which then leads to an increase in inflation, hence the positive relationship captured by $\beta_3$ .Meanwhile, an increase in GDP, or economic activity leads to an increase in income which in turn leads to an increase in aggregate demand. The increase in aggregate demand exerts inflationary pressure on overall prices thus resulting in a positive relationship between GDP and inflation. The nominal bilateral exchange rate on the other hand has a negative relationship with inflation that is a unit increase in the nominal exchange rate (Rand/Pula) /appreciation of the domestic currency will lead to a decrease in inflation by the magnitude of the coefficient. The appreciation of the domestic currency makes imports less expensive thus the country imports less of the foreign inflation and results in a decline in overall domestic inflation.

Many empirical studies apply the cointegration and VAR methodology to analyse ERPT in many countries. This paper follows suit by employing the VECM. The general VAR model from which the VECM evolves is stated as follows:

$$Y_t = c + \sum_{i=0}^{p} \Phi_i Y_{t-1} + \epsilon_t$$

where $Y_t$ represents a vector of endogenous variables, c is a vector of constants, $\Phi_i$ represents a vector of autoregressive coefficients and $\varepsilon t$ is a vector of white noise processes. The empirical analysis starts by checking the time series properties of the variables using the time line graphs and Augmented Dickey Fuller (ADF) test to establish the order of integration of the series, before embarking on Johansen and Juselius (1990) cointegration tests in a multivariate form. To validate the model, diagnostic checks for stability, autocorrelation and heteroscedasticity are carried out.

## 3. THE DSGE MODEL[2]

The model has two asymmetric countries, a small open economy and a large approximately closed one. Following Monacelli (2005), I model the foreign economy as a closed version of the small economy with identical structural parametrisation. Therefore, I introduce only the description of the domestic economy and the way the economies are linked together. In order to distinguish foreign and domestic variables in the text, the variables originating in the domestic economy are denoted by subscript H and variables originating abroad by subscript F. The foreign sector variables are denoted by '*'. The domestic economy is influenced by the foreign economy in two ways: First, the foreign interest rate and exchange rate influence the domestic interest rate through the Uncovered Interest rate Parity (UIP) condition. Second, foreign goods are imported into the domestic economy and constitute a part of the domestic consumption, thus also affecting the price dynamics.

### *3.1 Domestic households*

The domestic open economy is populated by infinitely-lived households. The representative households seek to maximise the following intertemporal sum of utility:

$$E_0 \sum_{t=0}^{\infty} \beta^t \left[ \frac{(C_t - H_t)^{1-\sigma}}{1-\sigma} - \frac{N_t^{1+\varphi}}{1+\varphi} \right] \tag{1}$$

where $\beta$ is the rate of time preference, $\sigma$ is the inverse elasticity of intertemporal substitution, and $\varphi$ is the inverse elasticity of labour supply. $N_t$ denotes hours of labour, and $H_t = hC_{t-1}$ represents external habit formation for the optimising household, for $h \in (0,1)$. $C_t$ is a composite consumption index of foreign and domestically produced goods defined as:

$$\left( C_t \equiv (1-\alpha)^{\frac{1}{\eta}} C_{H,t}^{\frac{\eta-1}{\eta}} + \alpha^{\frac{1}{\eta}} C_{F,t}^{\frac{\eta-1}{\eta}} \right)^{\frac{\eta}{\eta-1}} \tag{2}$$

Where $\alpha \in [0,1]$ corresponds to a measure of degree of openness which is the share of domestic consumption allocated to imported goods and $\eta > 0$ is the elasticity of substitution

[2] As mentioned above, the DSGE model in this paper follows that of Monacelli (2005) with innovations in the household utility function similar to that of Justiniano and Preston (2010). Overall, for derivations and explanation of thought the paper was guided by that of (Buyandelger, 2014), Gali (2008) and (Liu, 2006).

between domestic and foreign goods. The aggregate consumption indices of foreign $(C_{F,t})$ and locally $(C_{H,t})$ produced goods are given by the constant elasticity of substitution (CES) aggregators as follows:

$$C_{F,t} = \left(\int_0^1 C_{F,t}^{\frac{\varepsilon-1}{\varepsilon}} di\right)^{\frac{\varepsilon}{\varepsilon-1}} \quad \text{and} \quad C_{H,t} = \left(\int_0^1 C_{H,t}^{\frac{\varepsilon-1}{\varepsilon}} di\right)^{\frac{\varepsilon}{\varepsilon-1}}. \tag{3}$$

The representative household's utility maximisation is subject to a budget constraint of the form:

$$P_{H,t}C_{H,t} + P_{F,t}C_{F,t} + D_t + e_t B_t = R_{t-1}D_{t-1} + e_t B_{t-1}R_{t-1}^{*}\phi_{t-1} + W_t N_t + \Pi_{H,t} + \Pi_{F,t} \tag{4}$$

Where $D_t$ is the household's holding of one-period domestic bonds, and $B_t$ denotes holdings of one-period foreign bonds with corresponding interest rates $R_t$ and $R_t^{*}$. The price indices $P_t$, $P_{H,t}(i)$ and $P_{F,t}(i)$ correspond to the domestic CPI, prices of domestic and foreign good $(i)$ respectively. $W_t$ is the nominal wage rate. In the model, the households are assumed to own the firms, thus profits serve as a resource for households. The combined variable $\phi_t(.)$ refers to the debt elastic interest rate premium given by:

$$\phi_t = exp\left[-\mathrm{X}(FD_t) - \varepsilon_t^{\phi}\right] \quad \text{where} \quad FD_t = \frac{e_{ss}B_t}{Y_{ss}P_t}$$

$FD_t$ is the real quantity of outstanding foreign debt expressed in terms of domestic currency as a fraction of steady-state output and $\varepsilon_t^{\phi}$ is the risk premium shock. The adopted functional form ensures stationarity of foreign debt level in a log-linear approximation to the model.

Solving the minimisation problem of the expenditure of each category of goods subject to the constraint of the CES aggregators' consumption of each category of goods and using the definition of the price indices for domestic $(P_{H,t})$ and imported goods $(.P_{F,t})$ the optimal allocation for good $i$ is given by the following demand functions:

$$C_{H,t}(i) = \left(\frac{P_{H,t}(i)}{P_t}\right)^{-\varepsilon} C_{H,t}\,, C_{F,t}(i) = \left(\frac{P_{F,t}(i)}{P_t}\right)^{-\varepsilon} C_{F,t} \tag{5}$$

In addition, assuming symmetry across all $i$ goods, the optimal allocation of expenditure between domestic and imported goods is given by:

$$C_{H,t} = (1-\alpha)\left(\frac{P_{H,t}}{P_t}\right)^{-\eta} C_t \quad \text{and} \quad C_{F,t} = \alpha\left(\frac{P_{F,t}}{P_t}\right)^{-\eta} C_t \tag{6}$$

where $P_t \equiv \left\{(1-\alpha)P_{H,t}^{1-\eta} + \alpha P_{F,t}^{1-\eta}\right\}^{\frac{1}{1-\eta}}$ is the overall consumer price index (CPI). Consequently, total consumption expenditure for the domestic household is given by $P_{H,t}C_{H,t} + P_{F,t}C_{F,t} = P_t C_t$.Using this relationship, the budget constraint in equation (4) can be rewritten as:

$$P_t C_t + D_t + e_t B_t = R_{t-1}D_{t-1} + e_t B_{t-1}R^*_{t-1}\phi_{t-1} + W_t N_t + \Pi_{H,t} + \Pi_{F,t}\ . \tag{7}$$

Finally, in order to define the optimal condition for the households, I solve the utility maximisation problem. The problem entails dividing the budget constraint through by $P_t$, then maximising the utility equation (1) subject to equation (7). As a result, the optimality conditions for the household's problem are determined as follows:

$$(C_t - hC_{t-1})^{-\sigma}\frac{W_t}{P_t} = N_t^{\varphi} \tag{8}$$

$$\left(\frac{C_{t+1}-hC_t}{C_t-hC_{t-1}}\right)^{-\sigma} = \frac{\beta R_t}{\pi_{t+1}} \tag{9}$$

The intra-temporal optimality condition in equation (8) states that the marginal utility of consumption is equal to the marginal value of labour at any one point of time; equation (9) gives the Euler equation for inter-temporal consumption. Log-linear approximations of equation 6 and the two optimal conditions yield:

$$c_{H,t} = -(1-\alpha)\{\eta(p_{H,t} - p_t) + c_t\} \tag{10}$$

$$c_{F,t} = -\alpha\{\eta(p_{F,t} - p_t) + c_t\} \tag{11}$$

$$w_t - p_t = \varphi n_t + \frac{\sigma}{1-h}c_t \tag{12}$$

$$\tilde{c}_t = E_t\tilde{c}_{t+1} - \frac{1-h}{\sigma}(r_t - E_t\pi_{t+1}) \tag{13}$$

where lower case letters denote the logs of the respective variables, $\tilde{c}_t = \frac{1}{1-h}(c_t - hc_{t-1})$ and $\pi_t = p_t - p_{t-1}$ is CPI inflation.

In the rest of the world, a representative household solves the problem similar to that of the domestic household. The production in the small open economy is an insignificant fraction of the world's consumption basket and the rest of the world is characterised as a closed economy in the model. This implies that domestic inflation is equal to the CPI inflation in the rest of the world, i.e., $p_t^* = p_{F,t}^*$and foreign consumption approximately comprises of only foreign goods, i.e., $c_t^* = c_{F,t}^*$ for all $t$. Thus, the optimal decision is the same as the one determined above with all variables superscripted with an asterisk.

### *3.2 Pass-through, the Real Exchange Rate, and Deviations from PPP*

This section introduces the relationships between inflation, the real exchange rate, and the terms of trade (ToT), which are common variables used in open-economy models. In the case of a small open-economy model, it is assumed that the law-of-one-price (LoP) holds for the export sector, while there is incomplete pass-through for the imports sector, as domestic retailers may apply different margins on imports. This assumption follows from the notion that Botswana is a small open-economy, and hence would be a price taker, as it has little influence on international market prices. Thus, for imports, the LoP only holds at the boarder of entry, but rigidities arising from monopolistic competition at retail level and inefficient distribution networks allow for domestic import prices to differ from the world price.

First, I start of by log-linearising CPI around a steady state. The resulting expression can be used to define the link between aggregate prices and the ToT:

$$p_t \equiv (1-\alpha)p_{H,t} + \alpha p_{F,t} \tag{14}$$

$$= p_{H,t} + \alpha s_t$$

Where $s_t \equiv p_{F,t} - p_{H,t}$ denotes (log) ToT, i.e., the *domestic currency relative price of imports*. ToT equation holds independently of the degree of pass-through. Then taking the first difference of equation (14) yields an identity that links CPI inflation and domestic inflation and the change in ToT:

$$p_t - p_{t-1} = p_{H,t} - p_{t-1} + \alpha(s_t - s_{t-1})$$

$$\pi_t = \pi_{H,t} + \alpha \Delta s_t \tag{15}$$

$$\text{or} \quad \Delta s_t = \pi_{F,t} - \pi_{H,t}$$

Equation 15 implies that the gap between total inflation and domestic inflation depends on the change in the ToT and the degree of openness, $\alpha$.

Based on empirical evidence, pass-through is presumed to be incomplete in the model. Therefore, under such postulation the LoP does not hold. This means that the price of any imported goods in the market of small open economy is not equal to the price of the identical good in the foreign market in terms of domestic currency. As such here I define the real exchange rate, the LoP and draw the link between these two and ToT. Let $\mathcal{E}_t$ be the nominal exchange rate which is expressed in terms of domestic currency unit per unit of foreign currency. This means an increase in $\mathcal{E}_t$ implies a depreciation of the domestic currency. As such the real exchange rate and LoP gap are defined:

$$Q_t = \frac{\mathcal{E}_t P_t^*}{P_t} \tag{16}$$

and

$$\Psi_t = \frac{\mathcal{E}_t P_{F,t}^*}{P_{F,t}} \tag{17}$$

The LoP gap is an inverse mark-up between the world price of world goods and the domestic price of these imported goods. In order to show the effect of this inverse mark-up first I substitute $\psi_t = ln(\Psi_t)$ into the definition for $s_t$ which yields:

$$s_t = p_t^* - e_t - p_{H,t} - \psi_t \tag{18}$$

where $e_t$ is the log of $\mathcal{E}_t$.

Next, by substituting equation (18) into the log-linear form of equation (16), $q_t = ln(Q_t)$, and using equation (14) gives the relationship between ToT, LoP and the real exchange rate, as follows:

$$q_t = e_t + p_t - p_t^*$$

$$= p_t - p_{H,t} - s_t - \psi_t \tag{19}$$

$$= -\psi_t - (1-\alpha)s_t \tag{20}$$

$$\Rightarrow \psi_t = -[q_t + (1-\alpha)s_t]$$

From equation (20) there are two sources of deviation from aggregate PPP in this context. The first source is associated with heterogeneity of consumption baskets between the small economy and the rest of the world as shown by $(1-\alpha)$. Thus so long as $\alpha < 1$ there will be deviation. As parameter $\alpha$ approaches one, the aggregate consumption baskets of the two countries will be the same and relative price variations will not be required in equilibrium. The second source of deviation from PPP is the LoP gap. When the pass-through is incomplete, the LoP gap contributes to the variability of the real exchange rate. Moreover, it is inversely proportional to the real exchange rate and the degree of the openness of the domestic economy.

### *3.3 Risk Sharing and Uncovered Interest Parity*

Under the assumption that there is perfect capital mobility and agents in both economies have access to a complete set of internationally traded securities, the expected nominal return from risk-free bonds, in domestic currency terms, must be the same as the expected domestic currency return from foreign bonds, that is $E_t Q_{t,t+1} = E_t\left(Q_t^* \frac{\varepsilon_{t+1}}{\varepsilon_t}\right)$. This implies that the intertemporal optimality condition for the household will be the same across countries. As such international risk sharing may be defined as follows:

$$\beta E_t\left\{\frac{P_t}{P_{t+1}}\left(\frac{\tilde{C}_{t+1}}{\tilde{C}_t}\right)^{-\sigma}\right\} = \beta E_t\left\{\frac{P_t^*}{P_{t+1}^*}\frac{\varepsilon_{t+1}}{\varepsilon_t}\left(\frac{\tilde{C}_{t+1}^*}{\tilde{C}_t^*}\right)^{-\sigma}\right\} \tag{21}$$

where $\tilde{C}_t = C_t - hC_{t-1}$ and $\tilde{C}_t^* = C_t^* - hC_{t-1}^*$. Assuming the same habit formation parameter across the two countries, the following relationship must hold in equilibrium:

$$C_t - hC_{t-1} = \vartheta(C_t^* - hC_t^*)Q_t^{-\frac{1}{\sigma}} \tag{22}$$

where $\vartheta$ depends on initial conditions regarding relative net asset positions. Log-linearising equation (22) around the steady state gives:

$$c_t - hc_{t-1} = (c_t^* - hc_{t-1}^*) - \frac{1-h}{\sigma}q_t$$

$$= (y_t^* - hy_{t-1}^*) - \frac{1-h}{\sigma}q_t \tag{23}$$

The assumption of complete international financial markets also helps establish the uncovered interest parity condition (UIP), which makes use of the first order conditions for the optimal household level of domestic and foreign debt. Combining these two FOCs yields:

$$\frac{\beta R_t}{\pi_{t+1}}\lambda_{t+1} = \frac{\beta R_t^*}{\pi_{t+1}}\frac{\varepsilon_{t+1}}{\varepsilon_t}\phi_t\lambda_{t+1} \tag{24}$$

$$\therefore R_t = R_t^*\frac{\varepsilon_{t+1}}{\varepsilon_t}\phi_t$$

Given equation (16) can be expressed as $\frac{Q_{t+1}}{Q_t}\frac{\pi_{t+1}^*}{\pi_{t+1}}$ such that the final UIP condition is:

$$R_t = \frac{Q_{t+1}}{Q_t}\frac{\pi_{t+1}^*}{\pi_{t+1}}R_t^* exp\left[-\chi(FD_t) - \epsilon_t^{\phi}\right] \tag{25}$$

After log-linearising equation (25) around perfect foresight steady state a log-linear version of the UIP condition for nominal exchange rate is given by:

$$E_t\Delta e_{t+1} = r_t - r_t^* + \chi_{uip}fd_t + \epsilon_t^{rp}$$

and the risk premium is assumed to be constant. Similarly, the real exchange rate can be expressed as:

$$E_t\Delta q_{t+1} = (r_t - E_t\pi_{t+1}) - (r_t^* - E_t\pi_{t+1}^*) + \chi_{uip}fd_t + \epsilon_t^{rp}. \tag{26}$$

Equation (26) shows that the expected change in the real exchange rate depends on the difference between the current domestic and foreign real interest rates as well as the net foreign asset position of the country. $\epsilon_t^{rp}$ is the risk premium shock and it is assumed to follow an AR(1) process. Considering equation (26) and the assumption that domestic bonds have a net zero supply allows for a common expression for the net foreign asset position in the domestic country which takes the form:

$$fd_t = \frac{1}{\beta} fd_{t-1} - \alpha\left(s_t + \psi_{F,t}\right) + y_t - c_t$$

### *3.4 Firms*

***Production technology***

In the domestic goods market, there is a continuum of identical monopolistic competitive firms, indexed by $i \in [0,1]$ in the goods market. Each firm produces a differentiated good and is owned by a household. All goods are tradable. They operate a constant returns to scale technology represented by a linear production function:

$$Y_t(i) = A_t N_t(i) \tag{27}$$

where $a_t \equiv log A_t$, the log of labour productivity. It follows an AR(1) process, i.e,

$a_t = \rho_a a_{t-1} + \epsilon_t^a$ . Meanwhile, aggregate output can be written as:

$$Y_t = \left[\int_0^1 Y_t\,(i)^{\frac{\varepsilon-1}{\varepsilon}} di\right]^{\frac{\varepsilon}{\varepsilon-1}}. \tag{28}$$

Assuming a symmetric equilibrium across all $i$ firms, the log-linear approximation of the aggregate production can be written as:

$$y_t = a_t + n_t \ . \tag{29}$$

Given the production function and the real total costs $TC_t = \frac{W_t}{P_{H,t}} \frac{Y_t}{A_t}$ each firm's objective is to minimise costs which yields a log-linear real marginal costs of this form:

$$mc_t = w_t - p_{H,t} - a_t \tag{30}$$

### *3.5 Domestic Producers*

In the model, domestic firms are assumed to reset their prices in a Calvo-staggered fashion. Each firm sets new prices with probability $1 - \theta_H$ in any given period and the price set at time $t$ will still hold at time $t$+$k$. Hence, a measure of $1 - \theta_H$ of producers reset their prices, while a fraction $\theta_H$ keep their prices unchanged, that is $P_{H,t} = P_{H,t-1}$. A firm re-optimising in period $t$ sets an optimal new price, $P_{H,t}^{new}$ that maximises the current market value of the profits generated while that price remains effective. Firm $i$'s production is constrained by the sum of domestic and foreign demand, where the export price of the domestic good, $P_H^*(i)$, is assumed to be flexible and determined by the LoP. The optimal price setting problem is defined as follows:

$$\underbrace{max}_{P_{H,t}^{new}} \rightarrow \sum_{k=0}^{\infty} (\theta_H)^k E_t\{Q_{t,t+k}[Y_{t+k|t}(i)(P_{H,t}^{new} - MC_{t+k}^n)]\}$$

$$s.t: Y_{t+k}(i) = \left(\frac{P_{H,t}^{new}}{P_{H,t+k}}\right)^{-\varepsilon} \left(C_{H,t+k}(i) + C_{H,t+k}^*(i)\right) \quad (31)$$

where $MC_{t+k}^n$ is the nominal marginal costs and $\theta_H^k E_t Q_{t+k-1,t+k}$ is the stochastic discount factor and $1-\theta_H$ is the probability of being able to reset prices in each period. After firm optimisation, the resulting first order condition is:

$$\sum_{k=0}^{\infty} \theta_H^k E_t \left\{Q_{t,t+k} Y_{t+k|t}(i) \left(P_{H,t}^{new} - \frac{\varepsilon}{\varepsilon-1} MC_{t+k}^n\right)\right\} = 0 \quad (32)$$

Substituting $Q_{t,t+k} = B^k \left(\frac{C_{t+k}}{C_t}\right)^{-\sigma} \left(\frac{P_t}{P_{t+k}}\right)$ from the consumption Euler and taking out of the expectation summation all known variables at time t then rearranging yields:

$$\sum_{k=0}^{\infty} (\beta\theta_H)^k E_t \left\{P_{t+k}^{-} C_{t+k}^{-\sigma} Y_{t+k} \left(P_H^{new} - \frac{\varepsilon}{\varepsilon - 1} MC_{t+k}^n\right)\right\} = 0$$

$$\sum_{k=0}^{\infty} (\beta\theta_H)^k E_t \left\{C_{t+k}^{-\sigma} Y_{t+k} \frac{P_{H,t-1}}{P_{t+k}} \left(\frac{P_{H,t}^{new}}{P_{H,t-1}} - \frac{\varepsilon}{\varepsilon-1} MC_{t+k} \frac{P_{H,t+k}}{P_{H,t-1}}\right)\right\} = 0 \quad (33)$$

where $MC_{t+k} = \frac{MC_{t+k}^n}{P_{H,t+k}}$ is the real marginal cost. Log-linearising equation (33) around a zero-inflation steady state yields the log-linear optimal newly set domestic price:

$$p_{H,t}^{new} = (1 - \theta_H\beta) \sum_{K=0}^{\infty} (\theta_H\beta)^k E_t\{p_{H,t+K} + mc_{t+k}\} \quad (34)$$

The log-linear aggregate domestic price index evolves according to:

$$p_{H,t} = \theta_H p_{H,t-1} + (1 - \theta_H) p_{H,t}^{new} \quad (35)$$

Combining equation (34) and equation (35) and rearranging gives a forward looking domestic producers NKPC:

$$\pi_{H,t} = \beta E_t\{\pi_{H,t+1}\} + \lambda_H mc_t \quad (36)$$

It implies that the expectation about inflation in the future contributes more to today's inflation rather than past inflation (Clarida et al., 1999). In addition, the real marginal costs faced by the firm is a determinant of domestic inflation.

As already alluded above, inefficiencies in the distribution channel and monopolistic power keep domestic import prices over and above marginal costs forcing the retailers of imported goods to set the domestic currency price of imported goods by solving an optimal mark-up problem. As a result, the LoP fails to hold at retail level for domestic imports. This generates the l.o.p gap (the gap between the foreign producer's equilibrium price and the import price charged in the domestic market in domestic currency) in the short-run, while pass-through gets complete only asymptotically in the long-run. Consider a local retailer who imports good $j$ at a cost $\mathcal{E}_t P_{F,t}^{*}(j)$. This cost is the price paid in the world market. $\mathcal{E}_t$ is the level of the nominal exchange rate. The retailers face a downward sloping demand for imported goods like the local producers. Following a similar Calvo-pricing argument as before, the domestic importer's problem entails choosing a new price, $P_{F,t}^{new}(j)$ expressed in domestic currency to maximise the current market value of the profit. Retailer firm $j$'s imported goods are constrained by the demand of imported goods $j$ in the domestic market. The optimal price setting problem is defined as follows:

$$\underbrace{max}_{P_{F,t}^{new}} \rightarrow E_t \left\{ \sum_{k=0}^{\infty} \beta^k \Lambda_{t,t+k} \theta_F^k \left( P_{F,t}^{new}(j) - \mathcal{E}_{t,t+k} P_{F,t+k}^{*}(j) \right) C_{F,t+k}(j) \right\}$$

$$s.t: C_{F,t+k}(j) = \left( \frac{P_{F,t}^{new}(j)}{P_{F,t+k}} \right)^{-\varepsilon} C_{F,t+k} \qquad (37)$$

where $P_{F,t+k}^{*}(j)$ denotes the foreign-currency price of the imported good, $\theta_F^k$ is the probability that the price $P_{F,t}^{new}(j)$ set for good $j$ at time $t$ still holds $k$ periods ahead, and $\beta^k \Lambda_{t,t+k}$ is a relevant stochastic discount factor. The degree of domestic price stickiness $\theta_H$ is not necessarily equal to the degree of the import price stickiness, $\theta_F$. The FOC of this problem yields:

$$P_{F,t}^{new}(j) = \frac{\varepsilon}{\varepsilon - 1} \frac{E_t \{ \sum_{k=0}^{\infty} \beta^k \Lambda_{t,t+k} \theta_F^k (\mathcal{E}_{t+k} P_{F,t+k}^{*}(j) C_{F,t+k}(j)) \}}{E_t \{ \sum_{k=0}^{\infty} \beta^k \Lambda_{t,t+k} \theta_F^k C_{F,t+k}(j) \}} \qquad (38)$$

Taking logarithms of equation (38) and using a first order Taylor approximation around steady state yields:

$$p_{F,t}^{new}(j) = (1 - \theta_F \beta) E_t \{ \sum_{k=0}^{\infty} (\theta_F \beta)^k (\psi_{F,t+k} + p_{F,t+k}) \} \qquad (39)$$

The log-linear aggregate import price evolves according to:

$$p_{F,t} = \theta_F p_{F,t-1} + (1-\theta_F) p_{F,t}^{new} \tag{40}$$

combining equation (39) and equation (40) yields an aggregate supply curve for import prices:

$$\pi_{F,t} = \beta E_t\{\pi_{F,t+1}\} + \lambda_F \psi_{F,t} \tag{41}$$

where $\lambda_F = \frac{(1-\theta_F)(1-\theta_F\beta)}{\theta_F}$. Equation (41) shows that a percentage change of import price depends on the expectation about future import price changes and the l.o.p gap (the gap between the foreign producer's equilibrium price and the import price charged in the domestic market in domestic currency). In other words, as the world price of imports exceeds the local currency price of the same good, imported inflation increases. Consequently, the nominal depreciation of the domestic currency heightens the difference between the price paid by the importers in the world market and the local currency price charged in the domestic market. Consequently, this difference leads to increase the importer's marginal cost and thereby rises the imported inflation. However, how much nominal depreciation pass-through into imported inflation depends on the parameter $\theta_F$. An increase of $\theta_F$ implies a greater nominal rigidity, which in turn leads to decrease exchange rate pass-through.

Finally, log-linearisation of the definition of CPI and taking the first difference yields the linear relationship for overall inflation:

$$\pi_t = (1-\alpha)\pi_{H,t} + \alpha\pi_{F,t} \tag{42}$$

### *3.6 Decomposition of the Real Marginal Cost*

In order to obtain relationship between domestic real marginal cost and open economy factors in equilibrium, I rearrange equation (30) faced by the monopolistic firm (assuming a symmetric equilibrium) using the FOC in equation (12) and the log-linearised production function in equation (29):

$$\begin{aligned} mc_t &= w_t - p_{H,t} - a_t \\ &= (w_t - p_t) + (p_t - p_{H,t}) - a_t \\ &= \frac{\sigma}{1-h}(c_t - hc_{t-1}) + \varphi n_t + \alpha s_t - a_t \qquad (43) \\ &= \frac{\sigma}{1-h}(c_t - hc_{t-1}) + \varphi y_t + \alpha s_t - (1+\varphi) a_t \end{aligned}$$

This shows that in an open economy set-up real marginal costs are an increasing function of domestic output. Initially, the increase in output leads to increase in labour demand via the production function, and thereby the increase in labour demand causes the real wage to increase. Consequently, the real marginal cost increases. Domestic technology has a negative effect on the domestic real marginal cost through its direct effect on labour productivity. Moreover, open economy factors also affect the real marginal cost. The ToT has a positive effect on real marginal cost. It means that an improvement in the ToT increases the real marginal cost through its effect on export and as such aggregate demand.

### *3.7 Equilibrium*

#### *Aggregate demand and output*

Goods market clearing in the domestic economy requires that domestic output is equal to the sum of domestic consumption and foreign consumption of home produced goods (exports):

$$y_t = (1-\alpha)c_{H,t} + \alpha c^*_{H,t} \quad . \tag{44}$$

Acknowledging that

$$C_{H,t} = (1-\alpha)\left(\frac{P_{H,t}}{P_t}\right)^{-\eta} C_t \tag{45}$$

and

$$C^*_{H,t} = \alpha\left(\frac{\varepsilon_t P_{H,t}}{P^*_t}\right)^{-\eta} C^*_t \ , \tag{46}$$

log-linearising the two demand functions gives:

$$\begin{aligned} c_{H,t} &= -\eta(p_{H,t} - p_t) + c_t \\ &= \alpha\eta s_t + c_t \end{aligned} \tag{47}$$

$$\begin{aligned} c^*_{H,t} &= -\eta(e_t + p_{H,t} - p^*_t) + c^*_t \\ &= -\eta(p_{H,t} - p_{F,t} - \psi_t) + c^*_t \\ &= \eta(s_t + \psi_t) + c^*_t \end{aligned} \tag{48}$$

From equation (47), an increase in $s_t$, which implies an increase in domestic competitiveness in the world market, leads to domestic agents substituting out of foreign-produced goods into home-produced goods for a given level of consumption. The magnitude of substitution depends on $\eta$, the elasticity of substitution between foreign and domestic goods; and the degree of openness, $\alpha$. Similarly, from equation (48) an increase in $s_t$ will result in foreigners substituting out of foreign goods and consume more home goods for a given level of income.

Substituting equations (47) and (48) into (44) yields the goods market clearing condition for the small open economy:

$$y_t = (1-\alpha)[\eta\alpha s_t + c_t] + \alpha[\eta(s_t + \psi_t) + c_t^*]$$
$$= (1-\alpha)c_t + \alpha y_t^* + (2-\alpha)\alpha\eta s_t + \alpha\eta\psi_t \qquad (49)$$

When $\alpha = 0$, this becomes a closed economy.

### *3.8 Policy rule*

Bank of Botswana's monetary policy objective is to achieve price stability, which is defined as a sustainable level of inflation that is within the medium-term objective range of 3 – 6 percent. Such a low and predictable level of inflation contributes towards the broader national objective of sustainable economic growth and development that is attained through savings mobilisation and productive investment, and which fosters international competitiveness of domestic producers (Bank of Botswana, 2018). Against this background, the assumption is that the monetary authority follows a generalised Taylor (1993) rule, where the short-term interest rate is adjusted in response to developments in core inflation, the output gap and nominal exchange rate depreciation. Under a sticky-price setting the optimal policy may be approximated by this simple Taylor rule type of function:

$$r_t = \rho_r r_{t-1} + (1-\rho_r)[\varrho_1\pi_t + \varrho_2 y_t + \varrho_3\Delta e_t] + \epsilon_t^r \qquad (50)$$

where $\rho_r$ is the degree of interest rate smoothing, $\varrho_{1,}\varrho_2$ and $\varrho_3$ are the relative weights on inflation, output growth and change in nominal exchange rate. From equation (50), the nominal interest rate is determined by past interest rates, current all-goods CPI inflation rate, output growth and the change in the nominal exchange rate. The final term $\epsilon_t^r$, is an uncorrelated monetary policy shock that follows an AR (1) specification.

#### *Foreign Economy*

The large foreign economy is assumed to be exogenous to the domestic economy and it is approximated by autoregressive processes, AR(1):

$$y_t^* = \rho_{y^*} y_{t-1}^* + \epsilon_t^{y^*} \qquad (50)$$
$$\pi_t^* = \rho_{\pi^*} y_{t-1}^* + \epsilon_t^{\pi^*}$$
$$r_t^* = \rho_{\pi^*} r_{t-1}^* + \epsilon_t^{r^*}$$

where $y_t^*$, $\pi_t^*$ $r_t^*$denote foreign economy measures for output, inflation and the interest rate, respectively.

### *3.9 The linearised system*

Below is a summary of the key log–linearised model equations which were obtained using Uhlig (1999) procedure. They will be coded on Dynare and model ran via Matlab. These equations are rearranged to include some domestic and foreign shocks.

1. Law of one price:

$$\psi_t = -[q_t + (1-\alpha)s_t]$$

2. Terms of trade:

$$\Delta s_t = \pi_{F,t} - \pi_{H,t}$$

3. Uncovered interest rate parity condition with a risk premium shock:

$$E_t \Delta q_{t+1} = (r_t - E_t \pi_{t+1}) - (r_t^* - E_t \pi_{t+1}^*) + \chi_{uip} fd_t + \epsilon_t^{rp}$$

4. Domestic inflation:

$$\pi_{H,t} = \beta E_t\{\pi_{H,t+1}\} + \lambda_H mc_t$$

5. Imported inflation:

$$\pi_{F,t} = \beta E_t\{\pi_{F,t+1}\} + \lambda_F \psi_{F,t} + \epsilon_t^{cp}$$

6. Overall inflation:

$$\pi_t = (1-\alpha)\pi_{H,t} + \alpha \pi_{F,t}$$

7. Firm's real marginal cost:

$$mc_t = \frac{\sigma}{1-h}(c_t - hc_{t-1}) + \varphi y_t + \alpha s_t - (1+\varphi)a_t$$

8. Consumption Euler equation:

$$c_t - hc_{t-1} = E_t(c_{t+1} - hc_t) - \frac{1-h}{\sigma}(r_t - E_t \pi_{t+1})$$

9. The flow budget constraint:

$$fd_t = \frac{1}{\beta} fd_{t-1} - \alpha(s_t + \psi_{F,t}) + y_t - c_t$$

10. Goods market clearing condition:

$$y_t = (1-\alpha)c_t + \alpha y_t^* + (2-\alpha)\alpha\eta s_t + \alpha\eta\psi_t$$

11. Monetary policy rule:

$$r_t = \rho_r r_{t-1} + (1-\rho_r)[\varrho_1 \pi_t + \varrho_2 \Delta y_t + \varrho \phi_3 \Delta e_t] + \epsilon_t^r$$

12. Exogenous processes:

$$a_t = \rho_a a_{t-1} + \epsilon_t^a$$

$$y_t^* = \rho_{y^*} y_{t-1}^* + \epsilon_t^{y^*}$$

$$\pi_t^* = \rho_{\pi^*} y_{t-1}^* + \epsilon_t^{\pi^*}$$

$$r_t^* = \rho_{\pi^*} r_{t-1}^* + \epsilon_t^{r^*}$$

***Calibrations***

For calibration purposes, parameter values were adopted from Justiniano et al (2010).

**Table 1: Priors Description and density functions**

| NAME | DESCRIPTION | PRIOR DENSITY | VALUE |
|---|---|---|---|
| $\sigma$ | Inverse intertemporal elasticity of substitution in consumption | G | 1.31 |
| $\varphi$ | Inverse Frisch | G | 1.12 |
| $\theta_H$ | Calvo domestic price | B | 0.79 |
| $\theta_F$ | Calvo foreign price | B | 0.55 |
| $\eta$ | Elasticity H-F goods | G | 0.58 |
| $\rho_r$ | Taylor rule, smoothing | B | 0.84 |
| $\varrho_1$ | Taylor rule, inflation | G | 1.83 |
| $\varrho_2$ | Taylor rule, output | G | 0.09 |
| $\varrho_3$ | Taylor rule, exchange rate | G | 0.14 |
| $\rho_a$ | Technology | B | 0.69 |
| $\rho_{rp}$ | Risk premium | B | 0.94 |
| $\rho_{y^*}$ | AR(1) process for foreign output | B | 0.8 |
| $\rho_{\pi^*}$ | AR (1) process for foreign inflation | B | 0.5 |
| $\rho_{r^*}$ | AR(1) process for foreign interest rate | B | 0.8 |
| $\rho_{cp}$ | Import cost-push | B | 0.94 |
| $h$ | Habit formation | B | 0.33 |

*Distributions: B, beta; G, gamma; I, inverse-gamma. The subjective discount factor and bond cost are fixed at 0.99 and 0.001, respectively. Meanwhile the degree of openness is calibrated at 0.942 as an average share of exports and imports to GDP for 10 years. The priors for all the shocks incorporated in the model are set to 0.005 and follow an inverse-gamma distribution.*

# 4. DATA AND ESTIMATION METHOD[3]

This section provides a summary description of the data and estimation technique. The model is estimated using quarterly data for Botswana. The sample spans over the period 2004Q1-2017Q4, which is mainly dictated by the availability of data. The observed variables are compiled from data from the Bank of Botswana: real GDP is seasonally adjusted then detrended using the Hodrick Prescott (HP) Filter, inflation is computed by annualizing the quarterly log-difference in the consumer price index, and interest rate (91-day Treasury bill rate) are annualized percentages. In this manner, I ensure that data is stationary. The Bayesian method of estimation was used to estimate all the coefficients in the model with the use of priors set during the calibration stage. All data transformations are done using Eviews, meanwhile the estimation techniques are carried out on Matlab.

[3] The Bayesian estimation techniques and priors adopted in this study are based on work done by Justiniano and Preston (2010).

## 5. RESULTS

### *ERPT analysis results*[4]

For the estimation of ERPT, I use data over the period 2004Q1 to 2017Q4. This data is integrated of order 1, meaning that the variables are non-stationary at levels. This was cross checked by differencing the data and testing again which resulted in all variables being stationary. Consequently, since I(I) series have a tendency of being cointegrated, I tested for cointegration using the Johansen cointegration test and the results indicated that the variables are cointegrated with both the max-eigen value test and trace test indicating 1 cointegration equation. Thus, the VECM was estimated using 1 cointegrating equation.

### *VECM Estimates of the Pass-through Effects in the Long-Run*

**Table 2: Normalized Cointegrating Coefficients**

1 Cointegrating Equation(s): Log likelihood 437.0313

Normalized cointegrating coefficients (standard error in parentheses)

| INFLATION | GDP | M1 | NER |
|---|---|---|---|
| 1.000000 | -0.145132 | -0.399852 | 0.551078 |
| | (0.07669) | (0.06869) | (0.06926) |
| | [-1.89] | [-5.82] | [7.99] |

1 Cointegrating Equation(s): Log likelihood 411.4467

Normalized cointegrating coefficients (standard error in parentheses)

| INF_BOTS | GDP | M1 | NER |
|---|---|---|---|
| 1.000000 | -0.325563 | -0.215520 | 0.771621 |
| | (0.12496) | (0.11363) | (0.11656) |
| | [-2.61] | [-1.90] | [6.62] |

***The standard errors are given in parentheses and t-statistics in brackets.***

The equations above shows the long-run relationship between inflation (CPI/importables inflation) and GDP, M1 and NER, for which the signs are reversed when interpreting the relationships. Using the rule of thumb, "t-statistic > 2" then reject the null hypothesis, all the variables are significant in the long-run to explain inflation in Botswana.

According to the normalized equation coefficients, long-run ERPT elasticity into Botswana's CPI inflation for the sample period is 0.55, when the South African rand/ Botswana pula bilateral exchange rates (Rand/Pula henceforth) is used to proxy nominal exchange rate. Meanwhile, the coefficient is 0.77 when using importables price index. Thus, the pass-

[4] This section mainly summaries the results and discusses only the key finding of the VECM pertaining to pass-through.

through effects is found to be higher in imports than consumer prices, suggesting that there is some habit of local currency pricing. Also this coefficient carries an appropriate sign (that is negative when reversed), implying that an increase in the NER leads to a decrease in inflation since the domestic currency will be appreciating against the rand. Narrow money supply and nominal GDP positively impact on domestic inflation as suggested by theory with coefficients 0.40 and 0.14 percent, respectively. Overall, the pass-through is higher in the long-run.

***VECM Estimates of the Pass-through Effects in the Short-Run***

Most of the coefficients in the short-run dynamics are insignificant in explaining Botswana's inflation except for GDP and some carry unexpected signs (this is the case in both instances where inflation is proxied by CPI inflation or imports price index). In particular, the coefficients associated with exchange rate pass-through which is the variable of interest, carry the right negative sign but are all insignificant. This may be attributed to the unreliability of developing countries data, in this instance Botswana data.

It can be observed from the results that the coefficient of the error correction term (ecm) has the expected negative sign and it is significant because the t-statistic is greater than 2 .The significance of the ecm term supports cointegration and suggests that there exists a long-run steady state equilibrium between inflation and the explanatory variables. In this instance, ecm terms indicate a feedback of about 12 percent and 5 percent of previous quarters equilibrium, for when using CPI inflation and imported price index, respectively. That is after a year about 48 or 20 percent of disequilibrium would have been taken care off. It shows that the speed of adjustment is relatively low.

By examining the overall models, the $R^2$ is about 60 percent for each of the models, indicating that about 60 percent of the variations in inflation are explained by money supply (M1), nominal Gross domestic product and nominal exchange rate (Rand/Pula).The adjusted $R^2$s lie in the 40s, implying that about 40 percent of variations in Botswana's inflation are explained by the money supply, nominal exchange rate and nominal GDP.

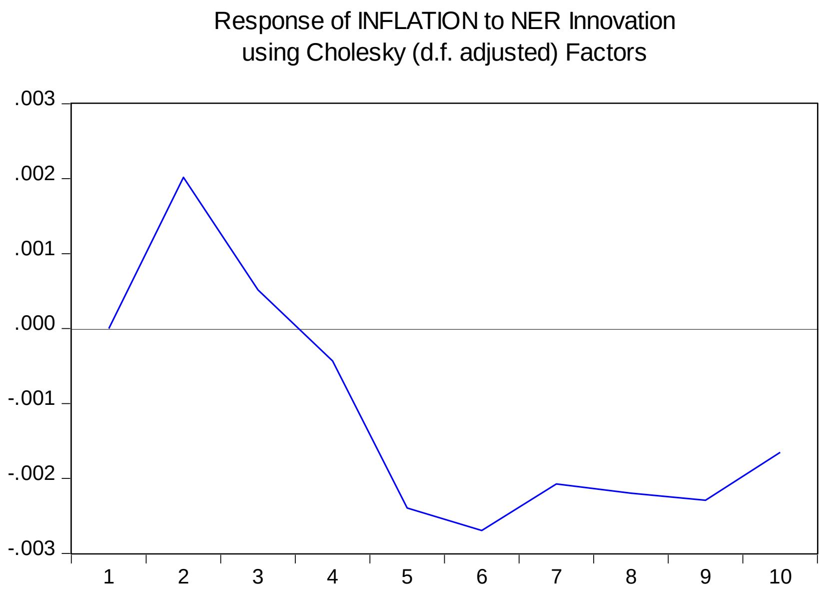



*Figure 1: Impulse Response Functions – NER innovation*

Figure 1 above shows the response of inflation to NER. It analyses how inflation responds if there is a positive shock of one standard deviation to the Rand/Pula exchange rate. Looking at the graph, a positive shock of one standard deviation to NER does not lead to a contemporaneous movement in inflation. It is only after a quarter that inflation responds but the response is rather puzzling as it first increases for about a quarter and then starts declining as anticipated until it reaches a minimum after about 8 months. This may be due to some form of price puzzle or exchange rate disconnect or the use of only few variables.

In a nutshell, the results show that there is some form of incomplete exchange rate pass-through and the speed of adjustment in the short-run is very low. Although not complete, ERPT coefficients are seemingly high for the long-run as is the case in other studies. In addition, as shown by the diagnostic test results in the appendices, the model is stable and does not suffer from any autocorrelation or heteroscedasticity.

*Impulse Response Functions from calibrated model*

For this part of the paper will discuss the impulse response functions (IRFs) for monetary policy shock, risk premium shock and the imports cost-push shock which were generated from the model simulations.

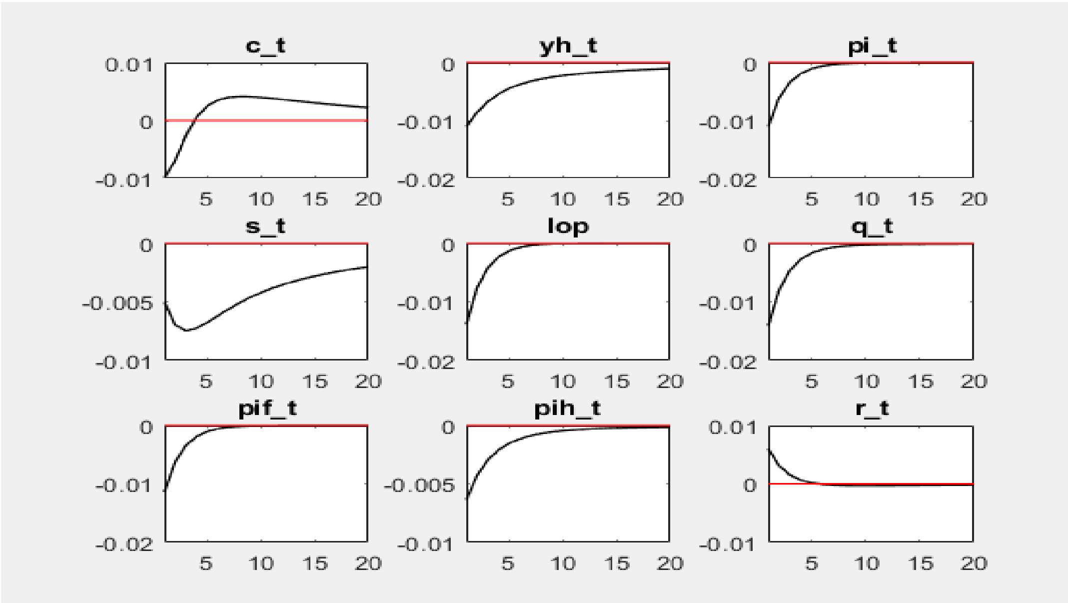



*Figure 2: Impulse Response Functions – Monetary policy Shock*

Initially, the contractionary monetary policy leads to an increase in production costs for the firms, which in turn leads to an increase in retail prices. The increase in prices result in a decrease in consumption spending which in turn results in a decrease in production. Thus, a positive innovation in the monetary policy rule leads to a decline in, consumption, output and inflation. The terms of trade also decline, although when expressed as a percentage of output it would initially increase before it decreases. Additionally, the increased interest rates makes the country more appealing for investment purposes as such resulting in demand for the domestic currency. This leads to appreciation of the pula as shown in figure 2. Thus resulting in a decline in inflation since the real exchange rate declines (appreciation of domestic currency), by a magnitude that is greater than the decline in inflation.

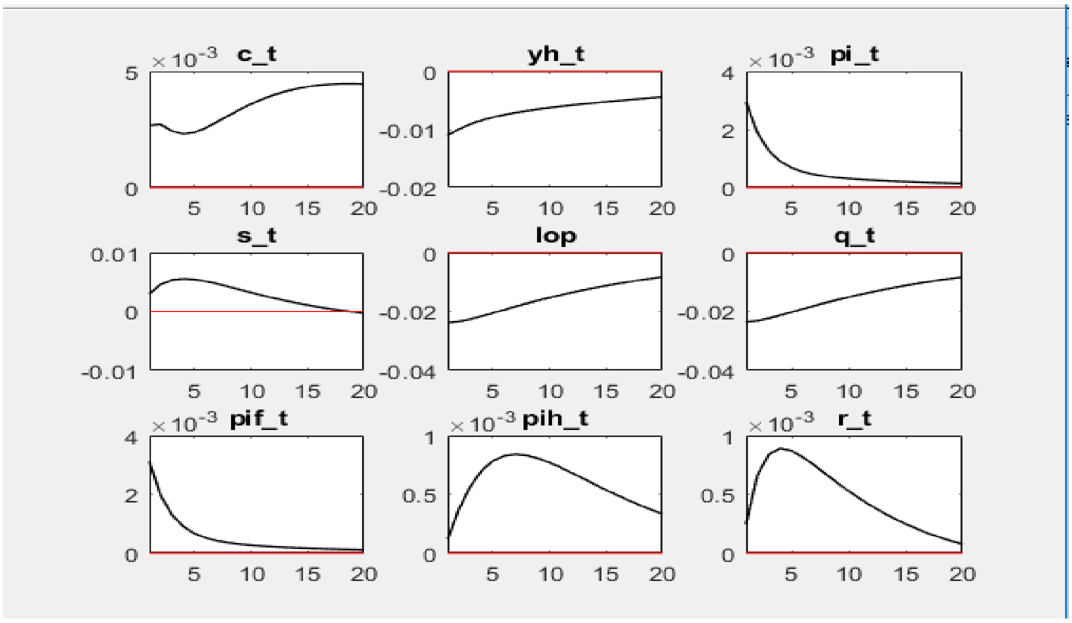



*Figure 3: Impulse Response Functions – Import cost-push shock*

Following a positive innovation in the cost-push shock both domestic consumption and output decline, with consumption declining more than output. This reflects the high dependence on foreign goods plus high degree of openness introduced in this model using the developments of imports and exports in Botswana over the past 10 years. This shock also leads to an increase in imported inflation and the overall CPI inflation. Interest rate rises as a result of heightened inflationary pressures. The real exchange rate depreciates and the terms of trade improves for a short while and starts to decline as the currency depreciation reduces over time. There is a negative deviation in the LoP, which in turn leads to some of the effect of the cost-push shock being offset since the lop is the marginal costs of importing firms.

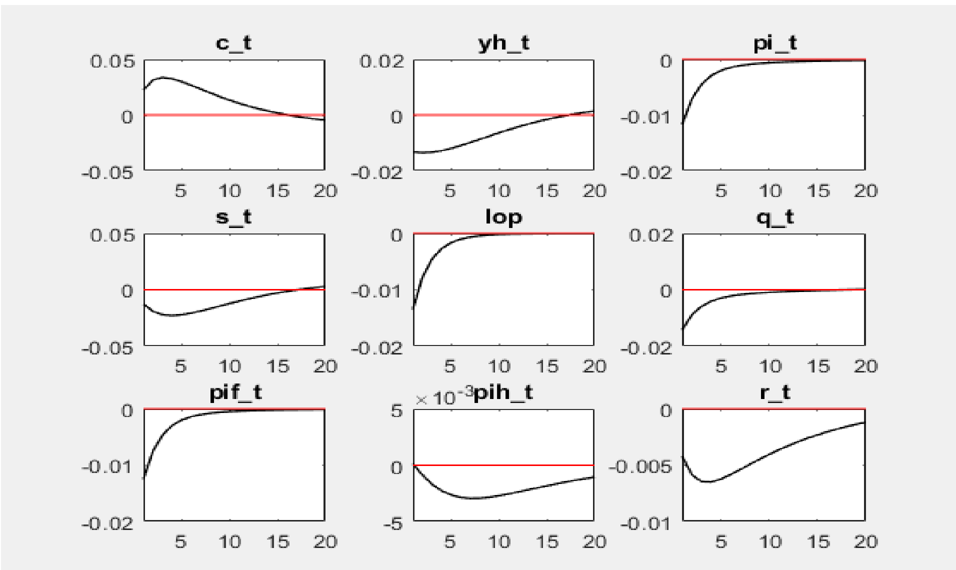



*Figure 4: Impulse Response Functions – risk premium cost-push shock*

Following a shock to the risk premium, the value of the currency depreciates and the terms of trade deteriorates. Interest rates initially decrease due to the decline in output and inflation. Comparing the impact of the risk premium shock on the real exchange rate, the impact is less than that of the import cost shock on the same variable. This may be due to the high degree of trade openness for the Botswana economy as indicated by the value for alpha.

***Estimated parameters and shocks***

The estimation seeks to investigate the conduct of monetary policy as carried out by Bank of Botswana. That is, how the bank responds to inflation, the output gap and exchange rate movements. This is analysed by estimating how much weight the central bank places on changes in these three variables. In addition, it is also worth analysing the level of price rigidity for both domestic producers and importers as well as the magnitude of habit formation in the Botswana economy. Lastly, I will discuss three shocks that are more eminent in affecting the real economy fluctuations as suggested by the estimates.

Table 3 below presents results for selected prior and posterior means, standard deviation and interval after conducting a Bayesian estimation. All estimated posteriors are statistically significant as they lie in between the 90 percent confidence intervals. The posterior estimates for the policy responses – weights central bank places on variables- were 1.76 for inflation, 0.10 for exchange rate depreciation, 0.09 for output gap and 0.81 for interest rate in the previous period.  The results show that Bank of Botswana in its interest setting decision is most concerned about price stability as stated even in its monetary policy statement. The result posits that the central bank considers exchange rate changes as the second important variable to respond to though the weight given to it is quiet low. Moreover, the relatively high posterior parameter value for the lag of interest rate indicates that the bank is more concerned about interest rate smoothing.

Table 3: Prior and Posterior parameter estimates

| Parameter | Description | Prior | Posterior | Interval |
|---|---|---|---|---|
| $\rho_r$ | Taylor rule, smoothing parameter | 0.840 | 0.8131 | [0.8097: 0.8172] |
| $\varrho_1$ | Taylor rule, inflation | 1.830 | 1.7569 | [1.7472: 1.7671] |
| $\varrho_2$ | Taylor rule, output | 0.090 | 0.0895 | [0.0792: 0.1020] |
| $\varrho_3$ | Taylor rule, exchange rate | 0.140 | 0.1030 | [0.1006: 0.1054] |
| $h$ | Habit | 0.330 | 0.4405 | [0.4301: 0.4458] |
| $\theta_H$ | Calvo domestic prices | 0.790 | 0.9054 | [0.8978: 0.9130] |
| $\theta_F$ | Calvo import prices | 0.550 | 0.5297 | [0.5247: 0.5360] |
| $\epsilon_t^r$ | monetary policy shock | 0.005 | 0.2295 | [0.2145: 0.2490] |
| $\epsilon_t^{cp}$ | imports cost push shock | 0.005 | 0.0656 | [0.0514: 0.0786] |
| $\epsilon_t^{rp}$ | risk premium shock | 0.005 | 0.0793 | [0.0660: 0.0947] |

The estimation of the habit formation parameter for consumption is relatively high than the prior (h=0.44), indicating a relatively high degree of households' habit persistence in Botswana compared to an Australia prior used because Australia is a small open economy that also is a large commodity exporter. Current consumption is statistically significant for future consumption decisions for Botswana consumers but in a relatively higher magnitude than for Australian (the prior). The probability of not changing the price in a given period (Calvo parameter) is 0.9054 for domestic producers and 0.5297 for importing firms. The posterior for home producers increased and the posterior for foreign producers decreased in comparison to the priors. Thus, 91 percent of domestic firms and 53 percent of importing firms do not reoptimize prices every three months. Local producers seem to display a higher price stickiness.

Regarding the shocks, estimates show that monetary policy shocks, risk premium shocks and cost-push shocks are more pronounced, implying that they are the main shocks responsible for business cycle fluctuations in Botswana. Moreover, this solidly shows that monetary policy is indeed a credible stabilising tool as shown by the high magnitude of impact of the monetary shock. Additionally, the cost-push shock is estimated to have a very high persistence rate (see rhocp_p in the estimations table in the appendix).

## 6. CONCLUSION

This study contributes to the empirical literature of Botswana by analysing monetary policy in a new Keynesian framework, an assessment that has not been done before in the country. This is done through a 3 stages procedure: first the estimation of the exchange rate pass-through to inflation is estimated using VECM to confirm that even in the case of Botswana pass-through is low or incomplete. Furthermore, the paper calibrates a DSGE model with a degree of trade openness suggested by Botswana data. Lastly, the paper employs Bayesian estimation techniques to estimate parameters and magnitude of shocks that affect business cycles in the Botswana economy. For the first assessment, the results show that indeed ERPT is incomplete in Botswana as in the short-run only about 12 or 5 percent of disequilibrium is corrected in the short-run for when using CPI inflation and imports price index, respectively. Hence prices are not transferred one for one between the exporting and importing economies.

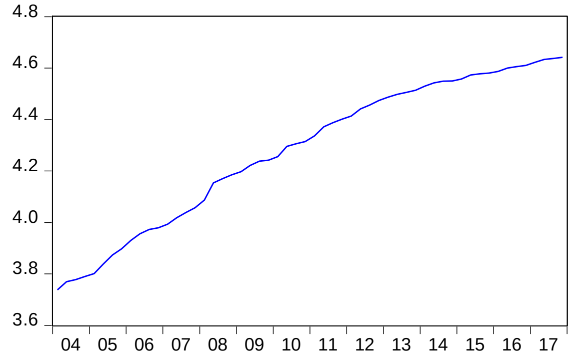
The pass-through increases in the long-run as shown by the high coefficients in the cointegration normalized equations. The coefficients suggest that about 55 and 77 percent of change in inflation (CPI/imports inflation) is due to exchange rate pass-through. Results of the DSGE simulations and estimations suggest that Bank of Botswana puts more weight on controlling inflation than the output gap or the exchange rate. In addition the consumers in the country seem to smooth their consumption as indicated by a high habit formation parameter. Price rigidity is more in the domestic producers' sector than the importing firms sector suggesting that indeed the overall price dynamics in the country are mainly explained by the importing firms who frequently change their optimisation prices given the exchange rate developments and other costs they face. Since the economy is highly open. The imports cost-push shock has more impact on the economy's business cycle than the risk premium shock. However, the monetary policy shock dominates the two shocks. This result postulates that the monetary authorities can use monetary policy to stabilise or stimulate economic activity given the high impact of its shock. Overall, given the results from this study, it is important for Bank of Botswana to regard inflation, exchange rate depreciation and output gap when implementing monetary policy though with more weight given to CPI inflation (not only domestic inflation), followed by the exchange rate then the output gap. In addition, given the high impact of the cost-push shock they have to keep a close eye on the importables price index as it contributes more even to the overall CPI. As such these results are useful for policy makers and in particular in guiding their policy decision making because of the suggested variables that may influence business cycle fluctuations in Botswana. They also confirm the already existing monetary policy of Botswana which is solely price stability.

# APPENDIX

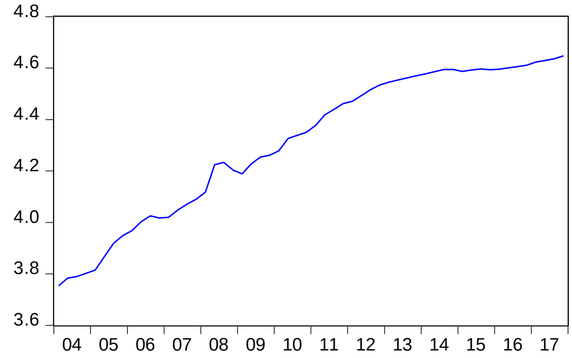
## ERPT HYPOTHESIS TESTING RESULTS

### TIME LINE PLOTS

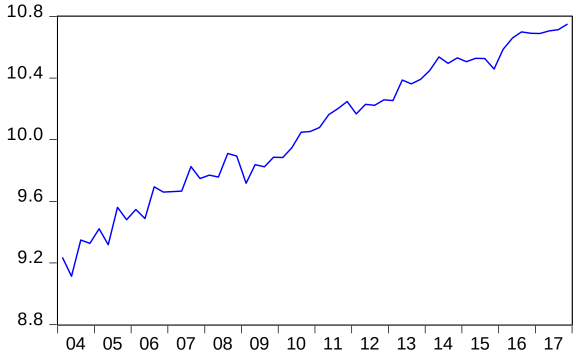
INFLATION



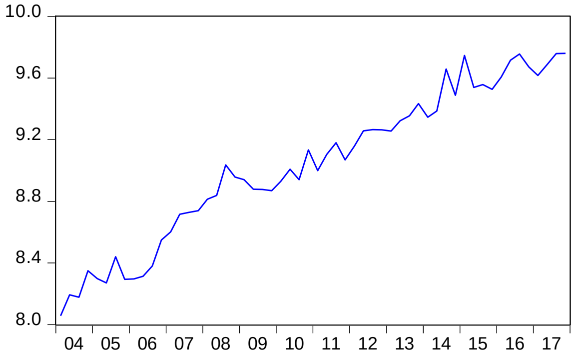

INF_BOTS



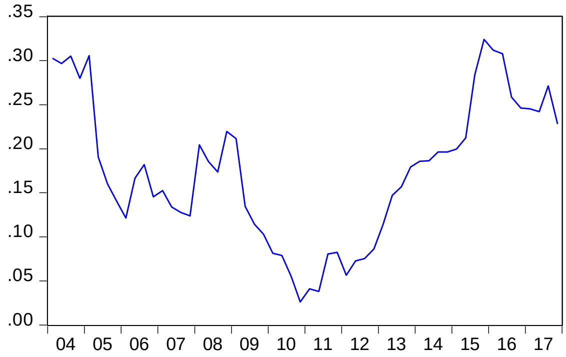

GDP




M1




NER



VAR Lag Order Selection Criteria
Endogenous variables: INFLATION GDP M1 NER
Exogenous variables: C
Date: 12/01/18 Time: 03:02
Sample: 2004Q1 2017Q4
Included observations: 51

| Lag | LogL | LR | FPE | AIC | SC | HQ |
|---|---|---|---|---|---|---|
| 0 | 176.6584 | NA | 1.35e-08 | -6.770918 | -6.619402 | -6.713019 |
| 1 | 398.5696 | 400.3104 | 4.20e-12 | -14.84587 | -14.08829* | -14.55637* |
| 2 | 418.9092 | 33.50039 | 3.59e-12 | -15.01605 | -13.65240 | -14.49496 |
| 3 | 436.6831 | 26.48670 | 3.46e-12 | -15.08561 | -13.11591 | -14.33293 |
| 4 | 458.2512 | 28.75743* | 2.95e-12* | -15.30397* | -12.72820 | -14.31969 |
| 5 | 471.2993 | 15.35068 | 3.67e-12 | -15.18821 | -12.00638 | -13.97234 |

* indicates lag order selected by the criterion
LR: sequential modified LR test-statistic (each test at 5% level)
FPE: Final prediction error
AIC: Akaike information criterion

Trend assumption: Linear deterministic trend
Series: INFLATION GDP M1 NER
Lags interval (in first differences): 1 to 2

Unrestricted Cointegration Rank Test (Trace)

| Hypothesized No. of CE(s) | Eigenvalue | Trace Statistic | 0.05 Critical Value | Prob.** |
|---|---|---|---|---|
| None * | 0.483427 | 64.02382 | 47.85613 | 0.0008 |
| At most 1 | 0.279956 | 29.01522 | 29.79707 | 0.0613 |
| At most 2 | 0.167031 | 11.60776 | 15.49471 | 0.1767 |
| At most 3 | 0.035606 | 1.921530 | 3.841466 | 0.1657 |

Trace test indicates 1 cointegrating eqn(s) at the 0.05 level
* denotes rejection of the hypothesis at the 0.05 level
**MacKinnon-Haug-Michelis (1999) p-values

Unrestricted Cointegration Rank Test (Maximum Eigenvalue)

| Hypothesized No. of CE(s) | Eigenvalue | Max-Eigen Statistic | 0.05 Critical Value | Prob.** |
|---|---|---|---|---|
| None * | 0.483427 | 35.00860 | 27.58434 | 0.0046 |
| At most 1 | 0.279956 | 17.40746 | 21.13162 | 0.1536 |
| At most 2 | 0.167031 | 9.686229 | 14.26460 | 0.2333 |
| At most 3 | 0.035606 | 1.921530 | 3.841466 | 0.1657 |

Max-eigenvalue test indicates 1 cointegrating eqn(s) at the 0.05 level
* denotes rejection of the hypothesis at the 0.05 level
**MacKinnon-Haug-Michelis (1999) p-values

| 1 Cointegrating Equation(s): | Log likelihood | 437.0313 | |
|---|---|---|---|

Normalized cointegrating coefficients (standard error in parentheses)

| INFLATION | GDP | M1 | NER |
|---|---|---|---|
| 1.000000 | -0.145132 | -0.399852 | 0.551078 |
| | (0.07669) | (0.06869) | (0.06926) |

Adjustment coefficients (standard error in parentheses)

| | |
|---|---|
| D(INFLATION) | -0.170439 |
| | (0.04201) |
| D(GDP) | 0.785999 |
| | (0.24885) |
| D(M1) | 0.258055 |
| | (0.37325) |
| D(NER) | -0.105080 |
| | (0.14958) |

| 1 Cointegrating Equation(s): | Log likelihood | 437.0313 | |
|---|---|---|---|

Normalized cointegrating coefficients (standard error in parentheses)

| INFLATION | GDP | M1 | NER |
|---|---|---|---|
| 1.000000 | -0.145132 | -0.399852 | 0.551078 |
| | (0.07669) | (0.06869) | (0.06926) |
| | [-1.89] | [-5.82] | [7.99] |

Vector Error Correction Estimates
Date: 12/01/18 Time: 03:21
Sample (adjusted): 2005Q2 2017Q4
Included observations: 51 after adjustments
Standard errors in ( ) & t-statistics in [ ]

| Cointegrating Eq: | CointEq1 |
|---|---|
| INFLATION(-1) | 1.000000 |
| GDP(-1) | 0.376811 |
| | (0.17619) |
| | [ 2.13867] |
| M1(-1) | -0.786675 |
| | (0.15630) |
| | [-5.03325] |
| NER(-1) | 0.374427 |
| | (0.14095) |
| | [ 2.65654] |
| C | -1.033158 |

| Error Correction: | D(INFLATION) | D(GDP) | D(M1) | D(NER) |
|---|---|---|---|---|
| CointEq1 | -0.117241 | 0.006990 | 0.115531 | 0.229649 |
| | (0.02904) | (0.16517) | (0.28747) | (0.10360) |
| | [-4.03789] | [ 0.04232] | [ 0.40189] | [ 2.21665] |

| | | | | |
|---|---|---|---|---|
| D(INFLATION(-1)) | 0.113591 | 0.936417 | 1.216488 | 0.617883 |
| | (0.14730) | (0.83792) | (1.45836) | (0.52557) |
| | [ 0.77117] | [ 1.11755] | [ 0.83415] | [ 1.17563] |
| D(INFLATION(-2)) | -0.150811 | 1.220795 | 0.150042 | 0.299150 |
| | (0.14779) | (0.84071) | (1.46321) | (0.52732) |
| | [-1.02046] | [ 1.45210] | [ 0.10254] | [ 0.56730] |
| D(INFLATION(-3)) | -0.101347 | -2.617026 | -0.899792 | 0.849287 |
| | (0.13822) | (0.78631) | (1.36854) | (0.49320) |
| | [-0.73321] | [-3.32822] | [-0.65748] | [ 1.72198] |
| D(INFLATION(-4)) | 0.025780 | 0.763523 | 1.074826 | -0.831166 |
| | (0.14843) | (0.84436) | (1.46957) | (0.52961) |
| | [ 0.17369] | [ 0.90426] | [ 0.73139] | [-1.56938] |
| D(GDP(-1)) | 0.033847 | -0.460507 | 0.343462 | -0.224379 |
| | (0.03120) | (0.17751) | (0.30895) | (0.11134) |
| | [ 1.08468] | [-2.59420] | [ 1.11169] | [-2.01520] |
| D(GDP(-2)) | 0.064804 | -0.045278 | 0.294569 | -0.116232 |
| | (0.03150) | (0.17919) | (0.31188) | (0.11240) |
| | [ 2.05728] | [-0.25268] | [ 0.94451] | [-1.03413] |
| D(GDP(-3)) | 0.093063 | 0.017375 | 0.170805 | -0.181376 |
| | (0.03004) | (0.17091) | (0.29746) | (0.10720) |
| | [ 3.09756] | [ 0.10166] | [ 0.57421] | [-1.69192] |
| D(GDP(-4)) | 0.063194 | 0.251781 | 0.208766 | -0.085509 |
| | (0.02406) | (0.13685) | (0.23819) | (0.08584) |
| | [ 2.62679] | [ 1.83977] | [ 0.87647] | [-0.99614] |
| D(M1(-1)) | -0.067784 | 0.139760 | -0.458413 | 0.101580 |
| | (0.02465) | (0.14024) | (0.24408) | (0.08796) |
| | [-2.74964] | [ 0.99660] | [-1.87816] | [ 1.15482] |
| D(M1(-2)) | -0.051219 | -0.063146 | -0.116257 | 0.112795 |
| | (0.02505) | (0.14249) | (0.24799) | (0.08937) |
| | [-2.04486] | [-0.44317] | [-0.46880] | [ 1.26207] |
| D(M1(-3)) | -0.037719 | -0.255723 | -0.219581 | 0.179406 |
| | (0.02202) | (0.12527) | (0.21803) | (0.07858) |
| | [-1.71282] | [-2.04133] | [-1.00711] | [ 2.28322] |
| D(M1(-4)) | -0.025235 | -0.057755 | -0.256839 | 0.088637 |
| | (0.01770) | (0.10072) | (0.17529) | (0.06317) |
| | [-1.42533] | [-0.57343] | [-1.46519] | [ 1.40305] |
| D(NER(-1)) | 0.108716 | -0.427263 | -0.351137 | 0.059680 |
| | (0.04732) | (0.26916) | (0.46846) | (0.16883) |
| | [ 2.29769] | [-1.58738] | [-0.74955] | [ 0.35349] |
| D(NER(-2)) | -0.010431 | 0.537319 | 1.040450 | -0.249774 |
| | (0.04935) | (0.28074) | (0.48861) | (0.17609) |
| | [-0.21137] | [ 1.91396] | [ 2.12942] | [-1.41846] |
| D(NER(-3)) | 0.039736 | -0.317734 | 0.147246 | 0.218270 |
| | (0.05493) | (0.31246) | (0.54383) | (0.19599) |
| | [ 0.72343] | [-1.01686] | [ 0.27076] | [ 1.11368] |
| D(NER(-4)) | -0.048851 | 0.140578 | 0.027699 | -0.352532 |

| | | | | |
|---|---|---|---|---|
| | (0.04992) | (0.28398) | (0.49425) | (0.17812) |
| | [-0.97858] | [ 0.49503] | [ 0.05604] | [-1.97915] |
| C | 0.016283 | 0.034131 | 0.005957 | -0.013980 |
| | (0.00470) | (0.02676) | (0.04657) | (0.01678) |
| | [ 3.46199] | [ 1.27566] | [ 0.12793] | [-0.83306] |
| R-squared | 0.642782 | 0.722325 | 0.502603 | 0.399063 |
| Adj. R-squared | 0.458760 | 0.579280 | 0.246369 | 0.089490 |
| Sum sq. resids | 0.002573 | 0.083251 | 0.252180 | 0.032753 |
| S.E. equation | 0.008829 | 0.050227 | 0.087417 | 0.031504 |
| F-statistic | 3.492968 | 5.049638 | 1.961497 | 1.289074 |
| Log likelihood | 179.9486 | 91.28612 | 63.02484 | 115.0742 |
| Akaike AIC | -6.350924 | -2.873966 | -1.765680 | -3.806831 |
| Schwarz SC | -5.669104 | -2.192145 | -1.083859 | -3.125010 |
| Mean dependent | 0.016475 | 0.026072 | 0.028658 | -0.001521 |
| S.D. dependent | 0.012001 | 0.077436 | 0.100697 | 0.033016 |

| | |
|---|---|
| Determinant resid covariance (dof adj.) | 1.37E-12 |
| Determinant resid covariance | 2.41E-13 |
| Log likelihood | 451.4397 |
| Akaike information criterion | -14.72312 |
| Schwarz criterion | -11.84433 |
| Number of coefficients | 76 |

1 Cointegrating Equation(s): Log likelihood 411.4467

Normalized cointegrating coefficients (standard error in parentheses)

| INF_BOTS | GDP | M1 | NER |
|---|---|---|---|
| 1.000000 | -0.325563 | -0.215520 | 0.771621 |
| | (0.12496) | (0.11363) | (0.11656) |
| | [-2.61] | [-1.90] | [6.62] |

Adjustment coefficients (standard error in parentheses)

| | |
|---|---|
| D(INF_BOTS) | -0.202623 |
| | (0.05158) |
| D(GDP) | 0.382739 |
| | (0.18229) |
| D(M1) | -0.130170 |
| | (0.27690) |
| D(NER) | -0.008552 |
| | (0.11009) |

Vector Error Correction Estimates
Date: 12/01/18 Time: 03:55
Sample (adjusted): 2005Q2 2017Q4
Included observations: 51 after adjustments
Standard errors in ( ) & t-statistics in [ ]

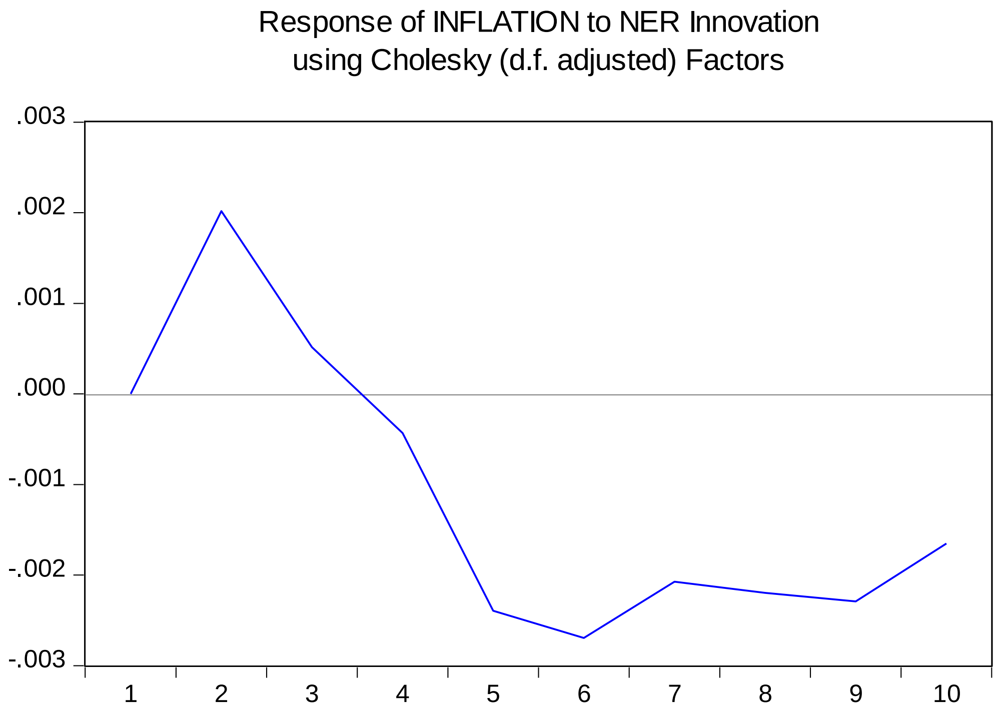
| Cointegrating Eq: | CointEq1 |
|---|---|
| INF_BOTS(-1) | 1.000000 |
| GDP(-1) | 1.738310 |
| | (0.65304) |
| | [ 2.66187] |
| M1(-1) | -1.833981 |

| | | | | | |
|---|---|---|---|---|---|
| | (0.58751) | | | | |
| | [-3.12160] | | | | |
| NER(-1) | 0.138764 | | | | |
| | (0.53939) | | | | |
| | [ 0.25726] | | | | |
| C | -5.266243 | | | | |

| Error Correction: | D(INF_BOTS) | D(GDP) | D(M1) | D(NER) |
|---|---|---|---|---|
| CointEq1 | -0.045856 | 0.005106 | 0.075017 | 0.089899 |
| | (0.01609) | (0.05224) | (0.08908) | (0.03016) |
| | [-2.85070] | [ 0.09774] | [ 0.84209] | [ 2.98107] |
| D(INF_BOTS(-1)) | 0.276788 | 0.604600 | 0.677541 | 0.151224 |
| | (0.16070) | (0.52194) | (0.88997) | (0.30127) |
| | [ 1.72237] | [ 1.15838] | [ 0.76130] | [ 0.50195] |
| D(INF_BOTS(-2)) | -0.242060 | 0.828098 | 0.190524 | 0.254021 |
| | (0.16633) | (0.54022) | (0.92114) | (0.31182) |
| | [-1.45531] | [ 1.53290] | [ 0.20683] | [ 0.81463] |
| D(INF_BOTS(-3)) | -0.137037 | -1.297789 | 0.332972 | 0.586019 |
| | (0.15834) | (0.51425) | (0.87687) | (0.29684) |
| | [-0.86549] | [-2.52364] | [ 0.37973] | [ 1.97421] |
| D(INF_BOTS(-4)) | -0.025860 | 0.663460 | 0.177162 | -0.374914 |
| | (0.15835) | (0.51431) | (0.87697) | (0.29687) |
| | [-0.16330] | [ 1.28999] | [ 0.20202] | [-1.26288] |
| D(GDP(-1)) | 0.048541 | -0.511152 | 0.139274 | -0.272357 |
| | (0.05811) | (0.18872) | (0.32179) | (0.10893) |
| | [ 0.83540] | [-2.70855] | [ 0.43281] | [-2.50026] |
| D(GDP(-2)) | 0.113113 | -0.067861 | 0.072226 | -0.224043 |
| | (0.06102) | (0.19820) | (0.33795) | (0.11440) |
| | [ 1.85358] | [-0.34239] | [ 0.21372] | [-1.95835] |
| D(GDP(-3)) | 0.180994 | 0.029036 | 0.110336 | -0.242828 |
| | (0.05698) | (0.18505) | (0.31553) | (0.10681) |
| | [ 3.17668] | [ 0.15691] | [ 0.34968] | [-2.27336] |
| D(GDP(-4)) | 0.094877 | 0.255948 | 0.186708 | -0.091217 |
| | (0.04753) | (0.15438) | (0.26324) | (0.08911) |
| | [ 1.99600] | [ 1.65787] | [ 0.70926] | [-1.02360] |
| D(M1(-1)) | -0.056657 | 0.139886 | -0.439378 | 0.087457 |
| | (0.03571) | (0.11599) | (0.19777) | (0.06695) |
| | [-1.58651] | [ 1.20605] | [-2.22162] | [ 1.30631] |
| D(M1(-2)) | -0.060981 | -0.059451 | -0.087666 | 0.090232 |
| | (0.03886) | (0.12622) | (0.21522) | (0.07286) |
| | [-1.56916] | [-0.47102] | [-0.40733] | [ 1.23850] |
| D(M1(-3)) | -0.047104 | -0.235385 | -0.176604 | 0.175054 |
| | (0.03568) | (0.11589) | (0.19760) | (0.06689) |
| | [-1.32012] | [-2.03114] | [-0.89372] | [ 2.61693] |
| D(M1(-4)) | -0.017695 | -0.039009 | -0.235441 | 0.104815 |
| | (0.02978) | (0.09671) | (0.16491) | (0.05582) |
| | [-0.59426] | [-0.40335] | [-1.42771] | [ 1.87759] |

| | | | | |
|---|---|---|---|---|
| D(NER(-1)) | 0.154425 | -0.357929 | -0.422842 | 0.026404 |
| | (0.08459) | (0.27474) | (0.46847) | (0.15858) |
| | [ 1.82556] | [-1.30280] | [-0.90261] | [ 0.16650] |
| D(NER(-2)) | -0.094564 | 0.506337 | 0.977860 | -0.152735 |
| | (0.08673) | (0.28169) | (0.48032) | (0.16260) |
| | [-1.09031] | [ 1.79748] | [ 2.03583] | [-0.93934] |
| D(NER(-3)) | -0.019508 | -0.343434 | 0.257826 | 0.198257 |
| | (0.09631) | (0.31279) | (0.53336) | (0.18055) |
| | [-0.20256] | [-1.09795] | [ 0.48340] | [ 1.09806] |
| D(NER(-4)) | -0.125073 | 0.250605 | 0.075490 | -0.287362 |
| | (0.09301) | (0.30209) | (0.51511) | (0.17437) |
| | [-1.34469] | [ 0.82956] | [ 0.14655] | [-1.64796] |
| C | 0.010844 | 0.026472 | 0.020133 | -0.001657 |
| | (0.00523) | (0.01698) | (0.02896) | (0.00980) |
| | [ 2.07384] | [ 1.55869] | [ 0.69525] | [-0.16898] |
| R-squared | 0.601893 | 0.706930 | 0.496116 | 0.462868 |
| Adj. R-squared | 0.396807 | 0.555955 | 0.236540 | 0.186163 |
| Sum sq. resids | 0.008330 | 0.087866 | 0.255468 | 0.029275 |
| S.E. equation | 0.015887 | 0.051600 | 0.087986 | 0.029785 |
| F-statistic | 2.934835 | 4.682419 | 1.911254 | 1.672786 |
| Log likelihood | 149.9882 | 89.91018 | 62.69443 | 117.9364 |
| Akaike AIC | -5.176006 | -2.820007 | -1.752723 | -3.919076 |
| Schwarz SC | -4.494186 | -2.138186 | -1.070902 | -3.237255 |
| Mean dependent | 0.016322 | 0.026072 | 0.028658 | -0.001521 |
| S.D. dependent | 0.020456 | 0.077436 | 0.100697 | 0.033016 |

| | |
|---|---|
| Determinant resid covariance (dof adj.) | 4.17E-12 |
| Determinant resid covariance | 7.31E-13 |
| Log likelihood | 423.1125 |
| Akaike information criterion | -13.61225 |
| Schwarz criterion | -10.73346 |
| Number of coefficients | 76 |

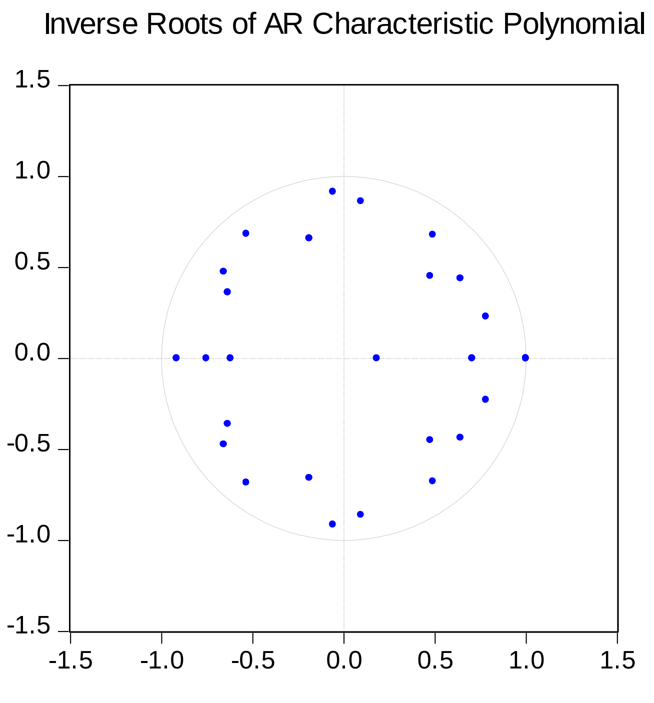



Variance decomposition for CPI inflation

| Period | S.E. | INFLATION | GDP | M1 | NER |
|---|---|---|---|---|---|
| 1 | 0.008829 | 100.0000 | 0.000000 | 0.000000 | 0.000000 |
| 2 | 0.013178 | 94.24054 | 0.132320 | 3.284275 | 2.342869 |
| 3 | 0.015970 | 89.63354 | 0.289884 | 8.377078 | 1.699494 |
| 4 | 0.019300 | 76.34474 | 3.725009 | 18.71619 | 1.214063 |
| 5 | 0.024068 | 64.09429 | 5.386428 | 28.74769 | 1.771592 |
| 6 | 0.028651 | 54.63178 | 5.054573 | 38.17945 | 2.134196 |
| 7 | 0.032417 | 47.40549 | 5.331793 | 45.18630 | 2.076415 |
| 8 | 0.036348 | 41.15927 | 5.760252 | 51.06311 | 2.017368 |
| 9 | 0.040904 | 36.92757 | 5.453618 | 55.71224 | 1.906576 |
| 10 | 0.045812 | 33.47699 | 4.621345 | 60.25183 | 1.649834 |

Cholesky Ordering: INFLATION GDP M1 NER

DIAGONISTIC TESTS



VEC Residual Serial Correlation LM Tests
Date: 11/30/18 Time: 19:37
Sample: 2004Q1 2018Q4
Included observations: 52

Null hypothesis: No serial correlation at lag h

| Lag | LRE* stat | df | Prob. | Rao F-stat | df | Prob. |
|---|---|---|---|---|---|---|
| 1 | 32.02352 | 36 | 0.6582 | 0.864550 | (36, 68.6) | 0.6784 |
| 2 | 44.10930 | 36 | 0.1662 | 1.284584 | (36, 68.6) | 0.1849 |
| 3 | 35.18212 | 36 | 0.5073 | 0.968670 | (36, 68.6) | 0.5312 |
| 4 | 47.64331 | 36 | 0.0928 | 1.419032 | (36, 68.6) | 0.1064 |

Null hypothesis: No serial correlation at lags 1 to h

| Lag | LRE* stat | df | Prob. | Rao F-stat | df | Prob. |
|---|---|---|---|---|---|---|
| 1 | 32.02352 | 36 | 0.6582 | 0.864550 | (36, 68.6) | 0.6784 |
| 2 | 74.33488 | 72 | 0.4021 | 0.980437 | (72, 54.8) | 0.5355 |
| 3 | 136.4964 | 108 | 0.0332 | 1.091432 | (108, 24.4) | 0.4188 |
| 4 | 1694.435 | 144 | 0.0000 | NA | (144, NA) | NA |

VAR Residual Heteroskedasticity Tests (Levels and Squares)
Date: 11/30/18 Time: 19:40
Sample: 2004Q1 2018Q1
Included observations: 55

Joint test:

| Chi-sq | df | Prob. |
|---|---|---|
| 543.2980 | 504 | 0.1098 |

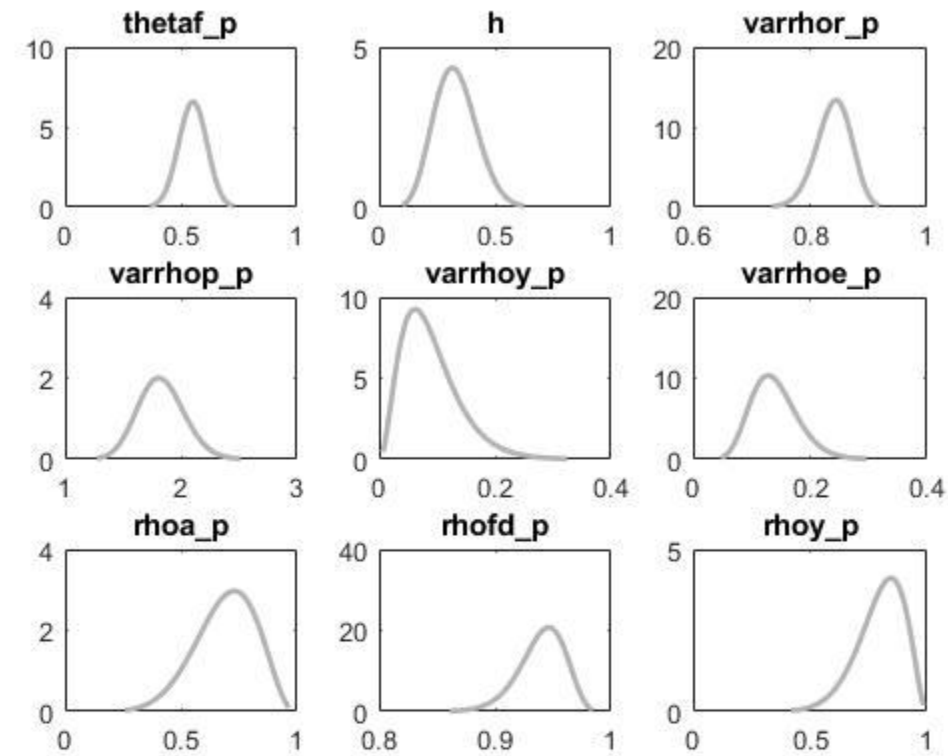
ESTIMATION RESULTS

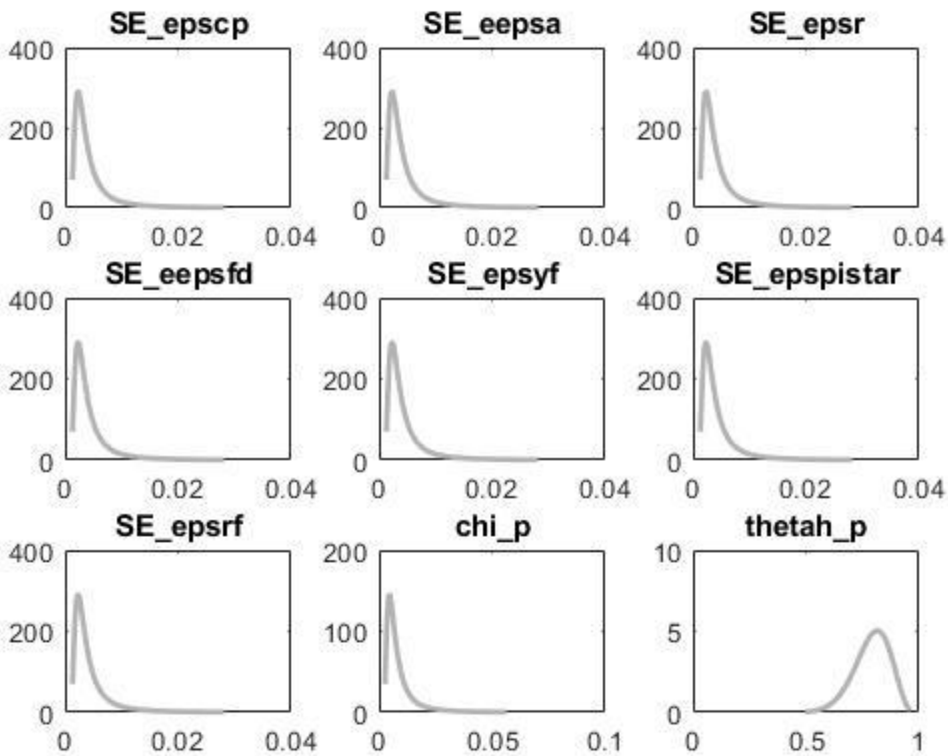
Parameters

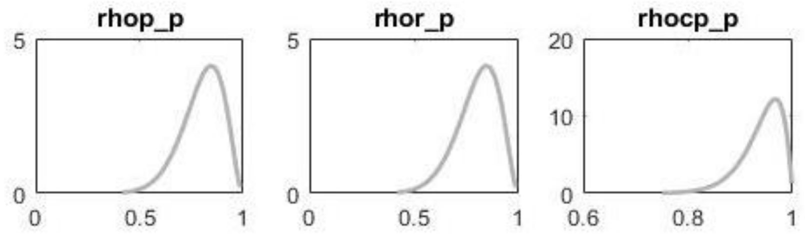
| | prior mean | post. mean | 90% HPD interval | | prior | pstdev |
|---|---|---|---|---|---|---|
| chi_p | 0.010 | 0.0028 | 0.0021 | 0.0037 | invg | Inf |
| thetah_p | 0.790 | 0.9054 | 0.8978 | 0.9130 | beta | 0.0800 |
| thetaf_p | 0.550 | 0.5297 | 0.5247 | 0.5360 | beta | 0.0600 |
| h | 0.330 | 0.4405 | 0.4301 | 0.4458 | beta | 0.0900 |
| varrhor_p | 0.840 | 0.8131 | 0.8097 | 0.8172 | beta | 0.0300 |
| varrhop_p | 1.830 | 1.7569 | 1.7472 | 1.7671 | gamm | 0.2000 |
| varrhoy_p | 0.090 | 0.0895 | 0.0792 | 0.1020 | gamm | 0.0500 |
| varrhoe_p | 0.140 | 0.1030 | 0.1006 | 0.1054 | gamm | 0.0400 |
| rhoa_p | 0.690 | 0.6581 | 0.6474 | 0.6706 | beta | 0.1300 |
| rhofd_p | 0.940 | 0.9549 | 0.9533 | 0.9563 | beta | 0.0200 |
| rhoy_p | 0.800 | 0.8052 | 0.8000 | 0.8090 | beta | 0.1000 |
| rhop_p | 0.800 | 0.8301 | 0.8181 | 0.8425 | beta | 0.1000 |
| rhor_p | 0.800 | 0.7974 | 0.7916 | 0.8039 | beta | 0.1000 |
| rhocp_p | 0.940 | 0.9949 | 0.9906 | 0.9978 | beta | 0.0400 |

Shocks

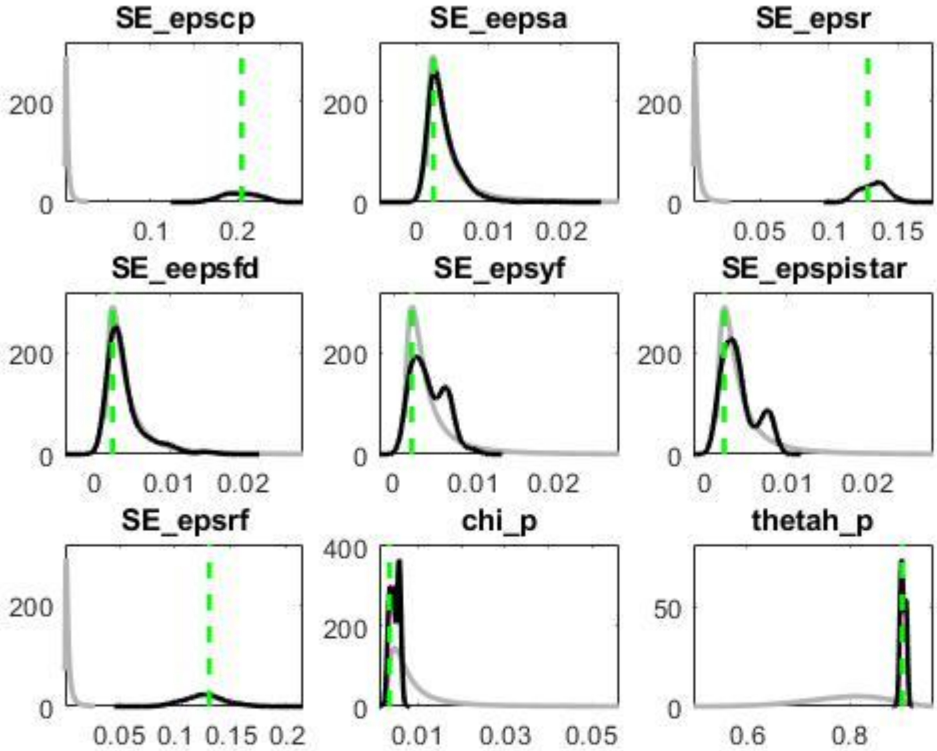
PRIORS DISTRIBUTIONS

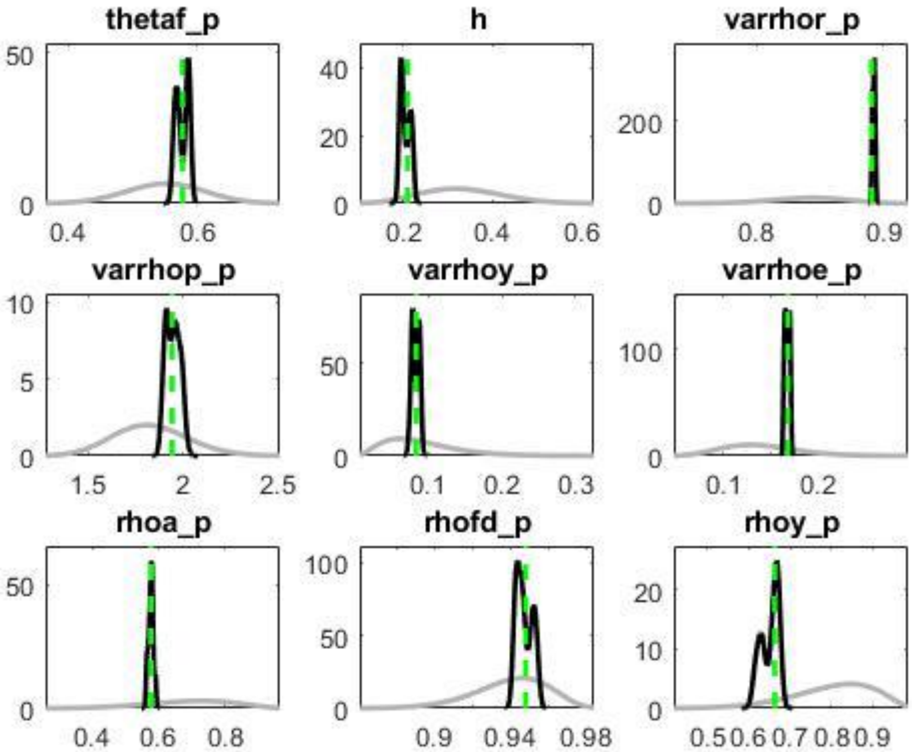

thetaf_p
h
varrhor_p
varrhop_p
varrhoy_p
varrhoe_p
rhoa_p
rhofd_p
rhoy_p

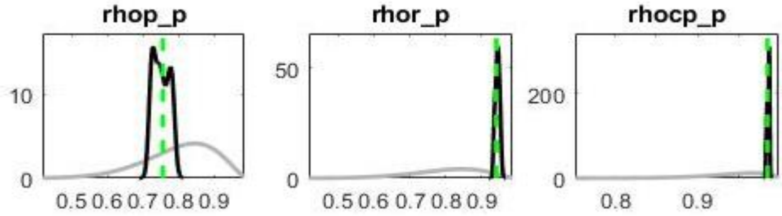

SE_epscp
SE_eepsa
SE_epsr
SE_eepsfd
SE_epsyf
SE_epspistar
SE_epsrf
chi_p
thetah_p



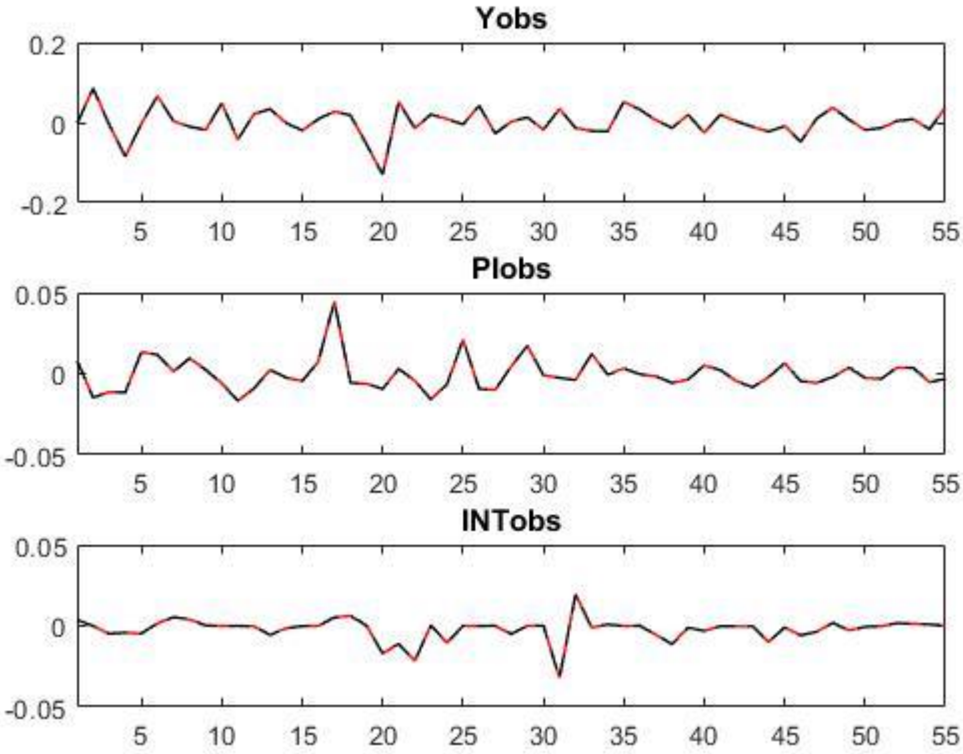

PRIORS AND POSTERIOR DISTRIBUTIONS


SE_epscp
SE_eepsa
SE_epsr
SE_eepsfd
SE_epsyf
SE_epspistar
SE_epsrf
chi_p
thetah_p
200
0
0.1 0.2
0 0.01 0.02
0.05 0.1 0.15
0.05 0.1 0.15 0.2
400
0.01 0.03 0.05
50
0.6 0.8


thetaf_p
h
varrhor_p
varrhop_p
varrhoy_p
varrhoe_p
rhoa_p
rhofd_p
rhoy_p
50
0
0.4 0.6
40
20
0.2 0.4 0.6
200
0.8 0.9
10
5
1.5 2 2.5
0.1 0.2 0.3
100
0.1 0.2
0.4 0.6 0.8
0.9 0.94 0.98
20
10
0.5 0.6 0.7 0.8 0.9


rhop_p
10
0
0.5 0.6 0.7 0.8 0.9
rhor_p
50
0
0.5 0.6 0.7 0.8 0.9
rhocp_p
200
0
0.8
0.9

OBSERVED VARIABLES



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