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An Estimated DSGE Model for Monetary Policy Analysis in Low-Income Countries

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Abstract

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The views expressed in this Working Paper are those of the author(s) and do not necessarily represent those of the IMF or IMF policy. Working Papers describe research in progress by the author(s) and are published to elicit comments and to further debate.

This paper evaluates monetary policy-tradeoffs in low-income countries using a dynamic stochastic general equilibrium (DSGE) model estimated on data for Mozambique taking into account the sources of major exogenous shocks, and level of financial development. To our knowledge this is a first attempt at estimating a DSGE model for Sub-Saharan Africa excluding South Africa. Our simulations suggests that a exchange rate peg is significantly less successful than inflation targeting at stabilizing the real economy due to higher interest rate volatility, as in the literature for industrial countries and emerging markets.

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I. INTRODUCTION

The use of monetary policy for macroeconomic stabilization in low-income countries, particularly Sub-Saharan Africa (SSA) poses a number of challenges that have not been fully analyzed in a literature focusing mainly on the conduct of monetary policy in industrial countries. While a number of studies have analyzed the sources of inflation in developing countries and SSA (e.g., Loungani and Swagel 2001, and Barnichon and Peiris 2006), only a few papers have analyzed the trade-offs between alternative monetary policy rules in SSA and low-income countries, in general.² The vast literature on “the Science of Monetary Policy” is focused on industrial countries and advanced emerging markets (Clarida, Gali, Gertler 1999, and Taylor 1998), providing limited insights to the conduct of monetary policy in low-income countries where the characteristics of the economy and monetary policy setting is quite different.

These include the need to coordinate monetary and exchange rate policy with fiscal policy in order to manage large volatile aid inflows and/or government revenues from natural resource exploitation (IMF 2005a). In particular, economic policy needs to consider the potential adverse effects of such shocks on the tradable sector—the so-called Dutch disease problem³—as well as the traditional objectives of inflation and output stabilization.⁴ In addition, commercial banks in SSA are at the center of a formal financial system and for most countries the conduct of monetary policy focuses primarily on the supply of and demand for the monetary base (Adam and O’Connell 2005). As a result, interest rates represent a reliable instrument of monetary policy only in the very few cases where inter-bank money markets and secondary markets for government debt are well developed. Finally, the dominance of commercial banks and information asymmetries are likely to mean that the credit channel is a prominent part of the monetary policy transmission mechanism (Bernanke and Gertler 1995).

In such an environment, many view the current monetary policy setting in SSA as an interim stage in a move towards wider adoption of formal inflation targeting practices in which inflation

² This partly reflects the preoccupation with the need for fiscal control and effective nominal anchors to bring down inflation from very high levels, which have now been largely achieved in a group of post-stabilization countries dubbed “mature stabilizers” (see Adam and O’Connell 2005, Clément and Peiris (eds.), forthcoming, and IMF 2006).

³ A key issue in SSA concerns the impact of spending scaled-up foreign aid on the real exchange rate, exports, and competitiveness, which according to Rajan and Subramanian (2005) explains the weak link between aid inflows and growth in developing countries. Similar assertions have been made regarding the poor growth performance of natural resource rich economies (Sachs and Warner 1995).

⁴ Pallage and Robe (2003) estimates the median welfare cost of business cycles in developing countries between 10 and 30 times that of the United States.

(more precisely, expected inflation) is the intermediate target/goal,⁵ instead of either some monetary aggregate or the exchange rate, and where the interest rate rather than base money is the operational target (see Adam and O’Connell 2005). Thus, while elements of this debate will necessarily reflect themes in the current literature on monetary policy in emerging market countries (see IMF 2005b), the current policy arrangements in mature stabilizers are inflation-targeting frameworks in the broad sense of having the maintenance of a nominal anchor at their core (see Adam and O’Connell 2005). More precisely, they could be described as “Lite” inflation targeting regimes as in Stone (2003) where the monetary authority probably aim to bring inflation into the single-digits and maintain financial stability, including through a relatively interventionist exchange rate policy.⁶ In this respect, therefore, the relevant policy questions are not wholly those concerned with how, and over what horizon, countries may make the move towards formal inflation targeting; they must also include how best the available instruments of monetary policy be deployed in shock prone mature stabilizers (Adam and O’Connell 2005).

This paper attempts to evaluate monetary policy-tradeoffs in low-income countries using a dynamic stochastic general equilibrium (DSGE) model estimated on data for Mozambique—a mature stabilizer in SSA—taking into account the sources of major exogenous shocks, transmission mechanisms, and level of financial development. The central banks of many SSA countries conduct monetary policy through a combination of direct instruments (e.g. reserve requirements) as well as foreign exchange interventions and open market operations with the private sector that effect the monetary base. Therefore, like Adam and O’Connell (2005) and Buffie et al. (2004), we analyze the trade-offs of both foreign exchange sales and open market operations in the conduct of monetary policy in Mozambique. We compare three different rules for how the central bank deploys its available instruments. Under the first rule, the central bank stabilizes the exchange rate. The second and third rules assume that the central bank is set to stabilize some measure of inflation around a target. In particular, we consider, firstly, the case where monetary policy seeks to stabilize CPI inflation, secondly, a policy that stabilizes inflation in nontraded goods. To our knowledge this is a first attempt at estimating a DSGE model for SSA excluding South Africa. More generally, we hope to provide a benchmark DSGE model incorporating features of SSA and low-income countries that could serve as a starting point for monetary policy analysis.

⁵ It is now widely accepted that the primary role of monetary policy is to maintain price stability (IMF 2005b and Batini and Yates, 2003). This is often thought to correspond to an annual rate of inflation in the low single digits in industrial countries (Bernanke et al, 1999) and single-digit levels in low-income countries (Fischer 1993, Ghosh and Philips 1998).

⁶ Further, “lite” inflation targeting regimes employ less market oriented monetary targets and instruments are relatively nontransparent in the operation and objectives of monetary policy owing to shallow financial markets.

In line with the existing literature on the welfare implications of monetary policy, our model is solved using recent methods in computational economics which makes it feasible to compute higher-order approximations to the equilibrium conditions in dynamic general equilibrium models. We also consider the best response, in terms of minimizing macroeconomic volatility, of alternative monetary policy rules in response to foreign aid and numerous other exogenous shocks that are important in SSA, motivated by the interest of central bankers in SSA. To preview our results, both nontradable and CPI inflation targeting performs better than an exchange rate peg, in line with the findings of standard new open-economy macroeconomics (NOEM) models.

The next section will outline the DSGE model in detail. Section III will briefly outline the estimation procedure and discuss the results of the estimation. This will be followed by an evaluation of the response of the model to aid and technology shocks. The analysis will then be extended by considering the performance of different monetary policy rules—including inflation and exchange rate targeting—when the economy is subject to a more larger and more realistic number of shocks. Section V concludes.

II. DSGE MODEL

In this paper, we develop a macroeconomic model for monetary policy analysis in SSA using data for Mozambique. As compared to previous empirical analysis of the Mozambican economy or that matter most SSA countries; we conduct our analysis within the context of a microfounded DSGE model. DSGE models have several benefits which make them attractive for the analysis of macroeconomic policy:

- They are structural in the sense each equation has an economic interpretation. Policy interventions and their transmission mechanism can therefore be clearly identified, thereby facilitating a discussion of alternative policies.
- They are microfounded in the sense that it they explicitly derived from the optimizing behavior of households and firms in the economy. They thus describe the behavior of the agents in the economy in terms of parameters that are structural in the sense that one would not expect them to change as the result of changes in economic policy, thereby validating the analysis of alternative policies.
- They are stochastic in the sense that they explicitly discuss how random shocks, such as an aid shock or a shock to fiscal policy, affect the economy.
- They are forward-looking in the sense that agents optimize form rational, or model consistent, forecasts about the future evolution of the economy.

These characteristics make DSGE models particularly attractive for the purpose of analyzing the effect of alternative macroeconomic policies, for example the appropriate policy response to an

aid shock, which helps explain its widespread use among central banks and other policy institutions in OECD countries. This paper represents the first attempt at constructing such a model for Mozambique.

A traditional weakness of DSGE models has been the difficulty in parameterizing them using economic data. This problem is particularly severe in developing countries, such as Mozambique, where data series are short or, in many cases, lacking. In order to overcome this problem, research often resort to calibrating the parameters of the model using information from previous studies or characteristics, such as the volatility of the data. The difficulty of explicitly relating the model to the data seriously undermines its use as a tool for policy analysis.

In order to overcome the problem of the parameterizing the data, this paper makes use of recent advances in Bayesian econometrics. Within this framework, the Kalman filter is used to allow inferences about the unobserved variables in the model and prior empirical or theoretical knowledge about the parameters of interest is used to increase the efficiency of the estimation, thereby overcoming the problem of short data series. These Bayesian inferences has been successfully applied to the estimation of DSGE models by, inter alia Juillard et al. (2004) Smets and Wouters (2003, 2005), Lubik and Schorfheide (2005) and Saxegaard (2006b). As far as we are aware, this paper represents the first attempt at estimation of a DSGE model using Bayesian methods on data for a country in SSA other than South Africa.

The use of Bayesian inference has a number of benefits which are worth highlighting. Firstly, this approach allows us to incorporate prior empirical or theoretical knowledge about our parameters of interest. Thus, if it is known that a parameter, such as the discount rate, must lie between zero and one, it seems that this information would be a useful addition to our estimation procedure. More generally, the incorporation of prior information allows us to formalize the use of information about parameters from prior studies.

It should be noted, however, that the impact of prior information on the estimation procedure is one of the main criticisms of Bayesian methods. However, Fernández-Villaverde and Rubio-Ramírez (2004) show that asymptotically the parameter point estimates converge to their true values and thus that the importance of the prior disappears as the sample grows. In small samples such as ours, the same authors provide compelling evidence for the strong performance of Bayesian methods.

Secondly, Bayesian inference provides a natural framework for parameterizing and evaluating simple macroeconomic models, such as ours, which are likely to be fundamentally misspecified. As pointed out by Fernández-Villaverde and Rubio-Ramírez (2004) and Schorfheide (2000), the inference problem is not to determine whether the model is ‘true’ or the ‘true’ value of a particular parameter, but rather to determine which set of parameter values maximize the ability of the model to summarize the features of the data.

Finally, Bayesian methods provide a simple framework for comparing and choosing between different misspecified models that may not be nested, on the basis of the probability that the model assigns to having observed the data (the marginal likelihood of the data, given the model). Geweke (1998) shows that this is directly related to the predictive performance of the model and is thus a natural benchmark for assessing the usefulness of economic models for policy analysis and forecasting.

A. Structure of the Model

The model is based on the open-economy DSGE model outlined in Kollmann (2002) and Saxegaard (2006a). The augmented model features an explicit treatment of the conduct of monetary policy in SSA as in Adam and O'Connell (2005) by assuming that the monetary authority affects the money supply through the sale of foreign exchange and bond transactions; though the bonds are bought by the banking sector instead of consumers as in Agénor and Montiel (2007) and Peiris (2002). The model incorporates credit frictions by assuming that firms have to borrow at a premium over deposit rates to finance part of the inputs in the production process as in Atta-Mensah and Dib (2003). The premium, in turn, is inversely related to the ratio of firms' assets (the value of their beginning-of-period physical capital stock times the price of the domestic good) over their liabilities, which consist of beginning-of-period borrowing as in Agénor and Montiel (2007). Learning by doing is incorporated as in Pratti and Tressel (2006) by assuming that productivity is a function of the size of the tradable sector and public investment expenditure.

The basic structure of the model consists of perfectly competitive firms that produce a final nontradable good which is consumed by a representative household and the fiscal authorities, in addition to being used for investment. The inputs used in the production of the final good are either produced domestically or imported by monopolistically competitive intermediate goods firms.⁷ The domestically produced goods, which are produced using capital, labor and borrowing from a financial intermediary as inputs, are sold either in the domestic market or exported overseas. For simplicity we assume that the capital account is closed. The markets for capital, labor, and commercial bank loans are competitive. The model is completed with a description of the fiscal and monetary authorities.

In order to provide a rationale for monetary and fiscal stabilization policy, four sources of inefficiency are included in the model: (a) monopolistically competitive product markets; (b) sluggish price adjustment in the domestic economy using the specification of Rotemberg (1982); (c) capital adjustment costs and investment adjustment costs using the specification of Christiano et al. (2005); and (d) adjustment costs in commercial bank reserves and an interest

⁷ The product market as modelled in this paper is equivalent to a more realistic model with monopolistically competitive final goods firms. The approach adopted in this paper is common in the literature because it allows the model to be somewhat simplified.

rate spread which depends on the net worth of companies as described above. This framework captures many of the rigidities which previous studies have found are important to describe the dynamics in the data and serves as a useful starting point for developing a DSGE model for Mozambique.

B. Household Behavior

The objective of the consumer is to maximize the expected value of the discounted sum of period utility functions:

$$E_0 \sum_0^{\infty} \beta^t \left(u_t^C (1-b) \ln(C_t - bC_{t-1}) - \frac{u_t^L}{\psi} L_t^\psi + \frac{\kappa}{1-\varepsilon} \left(\frac{M_t^C}{P_t} \right)^{1-\varepsilon} \right) \quad (0.1)$$

where C_t is consumption, L_t is labor supply, M_t^C/P_t is the real value of the consumers' holdings of domestic currency, and P_t is the consumer price index. $\beta \in (0,1)$ is the consumer subjective discount factor. Note that we assume habit formation in consumption. We assume that the capital account is closed. The consumer budget constraint is therefore given by:

$$\begin{aligned} & M_t^C(j) + D_t(j) + P_t(C_t(j) + I_t(j)) \\ &= M_{t-1}^C(j) + D_{t-1}(j)(1+i_{t-1}) + \Pi_t^f \\ &+ \int_0^1 \Pi_t^d(s) ds + W_t L_t(j) + R_t K_t(j) - T_t \end{aligned} \quad (0.2)$$

where Π_t^f and Π_t^d are profits from commercial banks and nontradable firms, respectively. The capital stock evolves according to the following rule:

$$K_{t+1} = (1-\delta)K_t + \Psi_t K_t \quad (0.3)$$

where δ is the rate of depreciation and Ψ_t is an adjustment cost function that is a function of the ratio of investment to capital:

$$\Psi_t \equiv \frac{I_t(j)}{K_t(j)} - \frac{\phi_1}{2} \left[\frac{I_t(j)}{K_t(j)} - \delta(1+u_t^I) \right]^2 - \frac{\phi_2}{2} \left[\frac{I_t(j)}{K_t(j)} - \frac{I_{t-1}}{K_{t-1}} \right]^2 \quad (0.4)$$

where $\phi_1, \phi_2 \geq 0$ and u_t^I is a shock to the depreciation rate as originally proposed by Ambler and Paquet (1994) as a method to account for the low correlation between labor productivity and hours observed in the data.

The consumer's problem can thus be written as:

$$\max_{C_t, M_t^c, D_t, L_t, K_{t+1}, I_t} E_t \sum_{t=0}^{\infty} \beta^t \left\{ -\lambda_t \begin{bmatrix} U(C_t(j), L_t(j), M_t^c(j)) \\ M_t^c(j) + D_t(j) \\ + P_t(C_t(j) + I_t(j)) - M_{t-1}^c(j) \\ - D_{t-1}(j)(1 + i_{t-1}) - \Pi_t^f \\ - \int_0^1 \Pi_t^d(s) ds - W_t L_t(j) \\ - R_t K_t(j) + T_t \\ + \omega_t [(1 - \delta) K_t + \Psi_t K_t - K_{t+1}] \end{bmatrix} \right\} \quad (0.5)$$

where λ_t and ω_t are lagrange multipliers.

The relevant first-order conditions for consumption, labor, money and deposits are:

$$\frac{u_t^c (1-b)}{C_t(j) - b C_{t-1}} = \lambda_t P_t \quad (0.6)$$

$$u_t^L L(j)_t^{w-1} = \lambda_t W_t \quad (0.7)$$

$$\frac{\kappa}{P_t} \left(\frac{M_t^c(j)}{P_t} \right)^{-\varepsilon} = \lambda_t - \beta E_t (\lambda_{t+1}) \quad (0.8)$$

$$\lambda_t = \beta E_t [\lambda_{t+1} (1 + i_t)] \quad (0.9)$$

The first-order conditions for capital and investment are, respectively:

$$E_t \left\{ \beta \lambda_{t+1} R_{t+1} - \omega_t + \beta \omega_{t+1} \left[(1 - \delta) + \Psi_{t+1} - \frac{I_{t+1}(j)}{K_{t+1}(j)} \Psi'_{t+1} \right] \right\} = 0 \quad (0.10)$$

$$P_t \lambda_t = \omega_t \Psi'_t \quad (0.11)$$

where:

$$\Psi'_t = \frac{\partial \Psi_t}{\partial I_t(j) / \partial K_t(j)} = 1 - \phi_1 \left[\frac{I_t(j)}{K_t(j)} - \delta (1 + u_t^I) \right] - \phi_2 \left[\frac{I_t(j)}{K_t(j)} - \frac{I_{t-1}}{K_{t-1}} \right] \quad (0.12)$$

C. Final Goods Production

Final good producers produce a good Z_t by aggregating over a continuum of domestically and imported intermediate goods, indexed by $s \in [0, 1]$. The aggregating technology is given by the CES aggregate:

$$Z_t = \left[(\alpha^d)^{1/\mathcal{G}} (Q_t^d)^{(\mathcal{G}-1)/\mathcal{G}} + (1 - \alpha^d)^{1/\mathcal{G}} (Q_t^m)^{(\mathcal{G}-1)/\mathcal{G}} \right]^{\mathcal{G}/(\mathcal{G}-1)} \quad (0.13)$$

for some elasticity of substitution $\mathcal{G} > 1$. Q_t^d and Q_t^m are CES indices of domestic and imported intermediate goods:

$$Q_t^i = \left[\int_0^1 q_t^i(s)^{(\nu-1)/\nu} \right]^{\nu/(\nu-1)} \quad (0.14)$$

for $i = d, m$. Profit maximization implies the standard demand functions for intermediate goods:

$$Q_t^i = \alpha^i \left[P_t^i / P_t \right]^{-\theta} Z_t \quad (0.15)$$

with an associated cost-minimizing price index.

D. Intermediate Goods Production

Following Pratti and Tressel (2006), we incorporate learning by doing in the production function as well as credit constraints following Atta-Mensah and Dib (2003). The credit constraints are incorporated by assuming that intermediate good firms use an intermediate good input \mathcal{G}_t that is funded by borrowing from a financial intermediary. Following Atta-Mensah and Dib (2003), we assume that firms borrow to pay for intermediate goods inputs as opposed to wages or capital because it is equivalent to using the loan as a variable in the production function and it generates more dynamics in the model.

The production technology is Cobb-Douglas:

$$Y_t = \theta_t \mathcal{G}_t^\varsigma \left(L_t^\alpha K_t^{1-\alpha} \right)^{1-\varsigma} \quad (0.16)$$

where θ_t represents productivity that we assume is affected by both the size of the tradable sector and the amount of government expenditure on capital goods:

$$\theta_t = (1 - \rho^\theta) \left[h(G_t^K) + u_t^\gamma Q_t^x \right] + \rho^\theta \theta_{t-1} + u_t^\theta \quad (0.17)$$

where we allow productivity to follow a stochastic autoregressive process and where Q_t^x are exports. The function $h(\cdot)$ embodies the technology whereby government spending on investment goods produces the productivity enhancing public good. It satisfies $h'(\cdot) > 0, h''(\cdot) < 0$. u_t^γ captures the degree of learning by doing.

The problem facing the firm is to minimize costs subject to satisfying demand:

$$\min_{K_t, L_t, \mathcal{G}_t^\varsigma} W_t L_t + R_t K_t + (1 + i_t^L) P_t \mathcal{G}_t + P_t \lambda_t \left[Y_t - \theta_t \mathcal{G}_t^\varsigma \left(L_t^\alpha K_t^{1-\alpha} \right)^{1-\varsigma} \right] \quad (0.18)$$

where we assume for the moment that the firm takes prices as given. The first-order condition for K_t, L_t and \mathcal{G}_t^ς are:

$$R_t = (1 - \varsigma)(1 - \alpha) \lambda_t P_t \theta_t \mathcal{G}_t^\varsigma \left(L_t^\alpha K_t^{1-\alpha} \right)^{-\varsigma} K_t^{-\alpha} \quad (0.19)$$

$$W_t = (1 - \varsigma) \alpha \lambda_t P_t \theta_t \mathcal{G}_t^\varsigma \left(L_t^\alpha K_t^{1-\alpha} \right)^{-\varsigma} L_t^{\alpha-1} \quad (0.20)$$

$$(1 + i_t^L) = \lambda_t \varsigma \theta_t \mathcal{G}_t^{\varsigma-1} \left(L_t^\alpha K_t^{1-\alpha} \right)^{1-\varsigma} \quad (0.21)$$

Nominal marginal costs can be written as the ratio of the nominal wage to the marginal product of labor:

$$MC_t = \frac{W_t}{(1-\varsigma)\alpha_t\theta_t\mathcal{G}_t^\varsigma \left(L_t^\alpha K_t^{1-\alpha}\right)^{-\varsigma} L_t^{\alpha-1}} \quad (0.22)$$

We assume that each domestic firm sells its output both on the domestic and export market so that $Y_t = Q_t^D + Q_t^X$. For simplicity, we assume that the demand for export goods has the same structure as domestic demand:

$$Q_t^X = \alpha^i \left[P_t^X / P_t^* \right]^{-\eta} \quad (0.23)$$

where P_t^* is the world price index which is considered to be exogenous.

E. Price-Setting by Intermediate Goods Producers

Intermediate goods producers' faces quadratic adjustment costs in setting prices measured in terms of the intermediate good and given by:

$$\frac{\phi}{2} \left[\frac{P_t^D / P_{t-1}^D}{P_{t-1}^D / P_{t-2}^D} - 1 \right]^2 Q_t^D \quad (0.24)$$

Hence, we assume that the cost of price adjustment is related to the change in inflation relative to the past observed inflation rate. Juillard et al. (2004) argues that this allows for more realistic inflation dynamics in the model with a backward-looking term in the solved out Phillips curve.

The optimal price-setting equation for the nontradable price can then be written as:

$$P_t^D = \frac{\nu}{(\nu-1)} MC_t - \frac{\phi}{(\nu-1)} P_t \frac{\pi_t^D}{\pi_{t-1}^D} \left[\frac{\pi_t^D}{\pi_{t-1}^D} - 1 \right] + \frac{\phi}{(\nu-1)} P_t E_t \left\{ \rho_{t,t+1} \frac{Q_{t+1}^D}{Q_t^D} \frac{\pi_{t+1}^D}{\pi_t^D} \left[\frac{\pi_{t+1}^D}{\pi_t^D} - 1 \right] \right\} \quad (0.25)$$

which reduces to the well-known results that prices are set as a markup over marginal cost if prices are flexible. For simplicity, we assume that the law of one price holds in the export market so that $P_t^X = P_t^d / e_t$. Importing firms are assumed to be owned by risk-neutral foreigners who purchase goods at the exogenous world price and re-sell them in the domestic market. For simplicity, we assume that changes in the exchange rate are passed through immediately to the import price so that $P_t^M = u_t^{tot} \frac{\nu}{(\nu-1)} e_t P_t^*$ where u_t^{tot} is a shock to the terms of trade of the economy.

F. Financial Intermediary

The financial sector is assumed to convert deposits from households into loans to intermediate goods firms and the public sector and bank reserves similar to Agénor and Montiel (2007):

$$D_t = B_t^P + \mathcal{G}_t + R_t \quad (0.26)$$

Thus, for a given level of bank reserves, an increase in the amount of deposits at the financial intermediary reduces the amount of money in circulation and thus the utility from liquidity services.

Deposits are assumed to earn the same rate of interest as the interest on government bonds. Lending to intermediate good firms earns an interest which is a markup over the interest rate on deposits where the markup is a function $g(\cdot)$ of firms' beginning of period net worth (the value of their capital stock over their liabilities) as in Agénor, and Montiel (2007):

$$\frac{i_t^L + u_t^i}{i_t} = g(\eta; P_t K_t / \mathcal{G}_{t-1}) \quad (0.27)$$

u_t^i is a mean zero shock to the lending rate. Commercial banks are assumed to maintain reserves equal to required reserves in steady-state and to use reserves to smooth movements in their net liabilities:

$$R_t = \alpha D_t + \varpi_1 \Delta B_t^P + \varpi_2 \Delta \mathcal{G}_t - \varpi_1 \Delta D_t + u_t^R \quad (0.28)$$

G. The Public Sector

The central bank's balance sheet is:

$$\Delta M_t^C + \Delta R_t = e_t \Delta Z_t + \Delta B_{t+1} \quad (0.29)$$

where e_t is the nominal exchange rate, Z_t are international reserves and B_{t+1} are government securities held by the central bank maturing next period. We assume for simplicity that no interest is earned on international reserves. Under the assumption that profits of the central bank are transferred to the fiscal agent, the public sector's budget constraint takes the form:

$$\Delta B_{t+1} + \Delta B_{t+1}^P = P_t G_t + i_{t-1} B_t^P - T_t - e_t A_t \quad (0.30)$$

where A_t is aid and B_t^P are bonds issued to the financial sector which we assume earn the same rate of interest as household deposits. A share μ_t of government spending is spent on a productivity enhancing investment good:

$$G_t = \mu_t G_t^K + (1 - \mu_t) G_t^C \quad (0.31)$$

The consolidated budget constraint is then:

$$M_t^0 + B_{t+1}^P - e_t Z_t = M_{t-1}^0 + (1 + i_{t-1}) B_t^P - e_t Z_{t-1} + P_t G_t - T_t - e_t A_t \quad (0.32)$$

where M_t^0 is base money defined as $M_t^0 = M_t^C + R_t$. As such, volatility in aid inflows and interest payments on bonds issued to the financial sector transmits into volatility in the path of expected future seigniorage, specifically currency in circulation.

H. Fiscal and Monetary Policy Rules

In our model the fiscal and monetary authorities have access to four different instruments of which three can be used independently. The fiscal agent controls government spending, taxation and net domestic borrowing, whereas the monetary authority controls the level of international reserves.

Following Adam and O'Connell (2005), we can analyze fiscal policy rules of the form:

$$\begin{aligned} T_t &= T - (1-\iota)\omega(e_t A_t - eA) \\ P_t G_t &= PG + \iota\omega(e_t A_t - eA) \end{aligned} \quad (0.33)$$

where ω and ι determine the fraction of aid used to reduce taxes and increase expenditure and thus increase the primary fiscal deficit (before grants). A ω less than one unambiguously lowers the primary deficit after grants. If ω equals zero, the primary deficit after grants falls by the amount of aid. If ω is between zero and one so that part of the aid is spent, ι determines the allocation of that spending between the private and the public sector. If ι equals zero the increased spending is carried out by the government whereas if ι is one the increased spending is done by the private sector. We assume the fiscal regime remains unchanged and foreign aid, which is very large in many SSA countries (IMF 2005a), is fully spent, unless otherwise stated.⁸

The effect of a shock to aid on international reserves and the monetary base will depend on the actions of the central bank. We follow Adam and O'Connell (2005) and Peiris (2002) in our specification of the policy rules for the central bank. Foreign exchange rate intervention is governed by:

$$\Delta Z_t = z_1 (Z - Z_{t-1}) + (1 - z_2 \omega)(A_t - A) + z_3 \log\left(\frac{e_t / e_{t-1}}{\pi / \pi^*}\right) + z_4 \log\left(\frac{\pi_t}{\pi}\right) + u_t^z \quad (0.34)$$

where z_1 governs the authorities commitment to a constant level of reserves and z_2 determines the commitment to an absorb as you spend scenario whereby the sale of foreign exchange is conducted in line with government spending increases financed by the aid inflows. z_3 governs the commitment to a crawling peg where the crawl is determined by the steady-state inflation differential ($\pi - \pi^*$) between at home and the rest of the world. Finally, z_4 determines the extent

⁸ For example, aid inflows ranging between 10 to 20 percent of GDP have been mostly spent in Mozambique (Clément and Peiris 2007), requiring a monetary policy response to maintain macroeconomic stability in the face of large aid-financed liquidity injections.

to which the sale of foreign exchange reserves are used to achieve a given target of the inflation rate π . u_t^z is a shock to foreign currency reserves.

Any foreign exchange rate intervention will have an impact on the monetary base and the exchange rate with possible implications for inflation and output volatility. The authorities have the option of conducting open-market operations on a temporary basis. Thus we have:

$$\Delta B_t^P = b_1 e_t \Delta Z_t + b_2 \log\left(\frac{\pi_t}{\pi}\right) + b_3 (Y_{t-1} - Y) + b_4 (B^P - B_{t-1}^P) + u_t^B \quad (0.35)$$

where b_1 governs the extent to which bond operations are used to sterilize the impact of foreign exchange interventions on the monetary base; b_2 determines the commitment to the inflation target; b_3 governs the effect of output gap considerations in the conduct of monetary policy; and $b_4 \succ 0$ entails that all bond operations are unwound over time. $u_t^{B^P}$ is a shock to domestic bonds.

I. Market Clearing and Aggregation

In general equilibrium, supply equals demand in the intermediate and final goods market at posted prices:

$$\begin{aligned} Y_t &= Q_t^d + Q_t^x \\ Z_t &= C_t + I_t + G_t + \mathcal{G}_t - \frac{\phi}{2} \left[\frac{P_t^D / P_{t-1}^D}{P_{t-1}^D / P_{t-2}^D} - 1 \right]^2 Q_t^D \end{aligned} \quad (0.36)$$

The model can alternatively be closed using the balance of payments identity:

$$e_t \Delta Z_t = e_t A_t + e_t P_t^x Q_t^x - P_t^m Q_t^m \quad (0.37)$$

J. Stochastic Shocks

A number of stochastic shocks are included in the model in order to ensure that the model is not stochastically singular and in order to be better able to reproduce the dynamics in the data. In particular, the number of exogenous shocks must be at least as large as the number of observed variables in order to estimate the model using classical Maximum Likelihood or Bayesian methods. Our model includes 14 structural shocks: two preferences shocks to the marginal utility of consumption and labor (u_t^C, u_t^L) , a shock to technology, a shock to investment and a shock to the markup (u_t^Y, u_t^I, u_t^V) , four external shocks, one to aid, one to world inflation, one to world interest rates and one to the terms of trade $(u_t^A, u_t^{\pi^*}, u_t^{tot}, u_t^{i^*})$, a shock to the share of capital expenditure in government expenditure (u_t^μ) , a shock to learning by doing (u_t^γ) , a shock to lending rates and commercial bank reserves (u_t^i) , and a shock to government bonds and

foreign currency reserves (u_t^B, u_t^Z) . With the exception of the shock to the markup, which is assumed to be a white noise process, all shocks are assumed to follow a first-order process.

III. EMPIRICAL FINDINGS

The model described above was estimated on quarterly data for Mozambique covering the period 1996Q1 to 2005Q4 on 18 key macroeconomic variables: GDP, consumption, exports, imports, the real exchange rate, inflation, export price inflation, import price inflation, M2, currency in circulation, deposit rates, lending rates, foreign currency reserves, government bonds, commercial bank reserves, aid, government spending, and lending to the private sector. This vastly exceeds the number of observed variables included in recent papers that use Bayesian techniques to estimate DSGE models, such as Juillard et al (2004) and Saxegaard (2006b). The remaining endogenous variables in the model are assumed to be unobserved.

Prior to estimation, the macroeconomic variables were transformed into real per capita measures. Following the approach in Juillard et al. (2004) we remove a time trend in the data on the key macro variables using the Hodrick-Prescott filter. In addition, we remove seasonal effects in the series where these are evident using the X12arima filter and transform all variables to mean zero variables.

Following Juillard et al. (2004) and Saxegaard (2006b), our estimation strategy involves fixing the parameters that determine the steady-state of the model, based either on findings from previous studies, notably Tarp et al. (2002), or in order to replicate features in the data, and then estimating the parameters that determine the dynamic properties of the model. The calibrated parameters values and calibrated steady-state ratios are summarized in Appendix 1.

As mentioned previously, estimation of the model by Bayesian methods allows the incorporation of prior empirical or theoretical knowledge through the specification of a prior distribution for the parameters to be estimated. Our choice of prior distributions is guided both by theoretical restrictions imposed on some of the parameters as well as empirical evidence. In instances where the literature and theory provide little or no guidance, diffuse priors are chosen. The choice of priors together with the resulting parameter estimates (posterior distribution) is summarized in Appendix 2 and 3, which provides a visual representation of this information by plotting the prior and posterior distribution together with the posterior mode.⁹ These plots allow us to make some statements about the relative importance of the prior and the data in the construction of the posterior distribution. In other words, the plots allow us to judge whether or not the data is informative about our parameters. Overall, the Bayesian estimation methodology

⁹ The estimation is carried out using the software package DYNARE (Juillard, 2004) which utilizes Chris Sims' CSMINWEL routine for to maximize the likelihood of the model and the Metropolis-Hasting algorithm with two separate chains of 100000 draws each so as to eliminate the importance of the steady-state.

yields plausible parameter estimates for the model, which are broadly in line with the results from previous studies. A comparison of the one-step ahead forecasts with the actual data (Appendix 4) reveals that the model is able to replicate fairly well the movements in the data.

IV. MONETARY POLICY RULES IN A SHOCK-PRONE ECONOMY

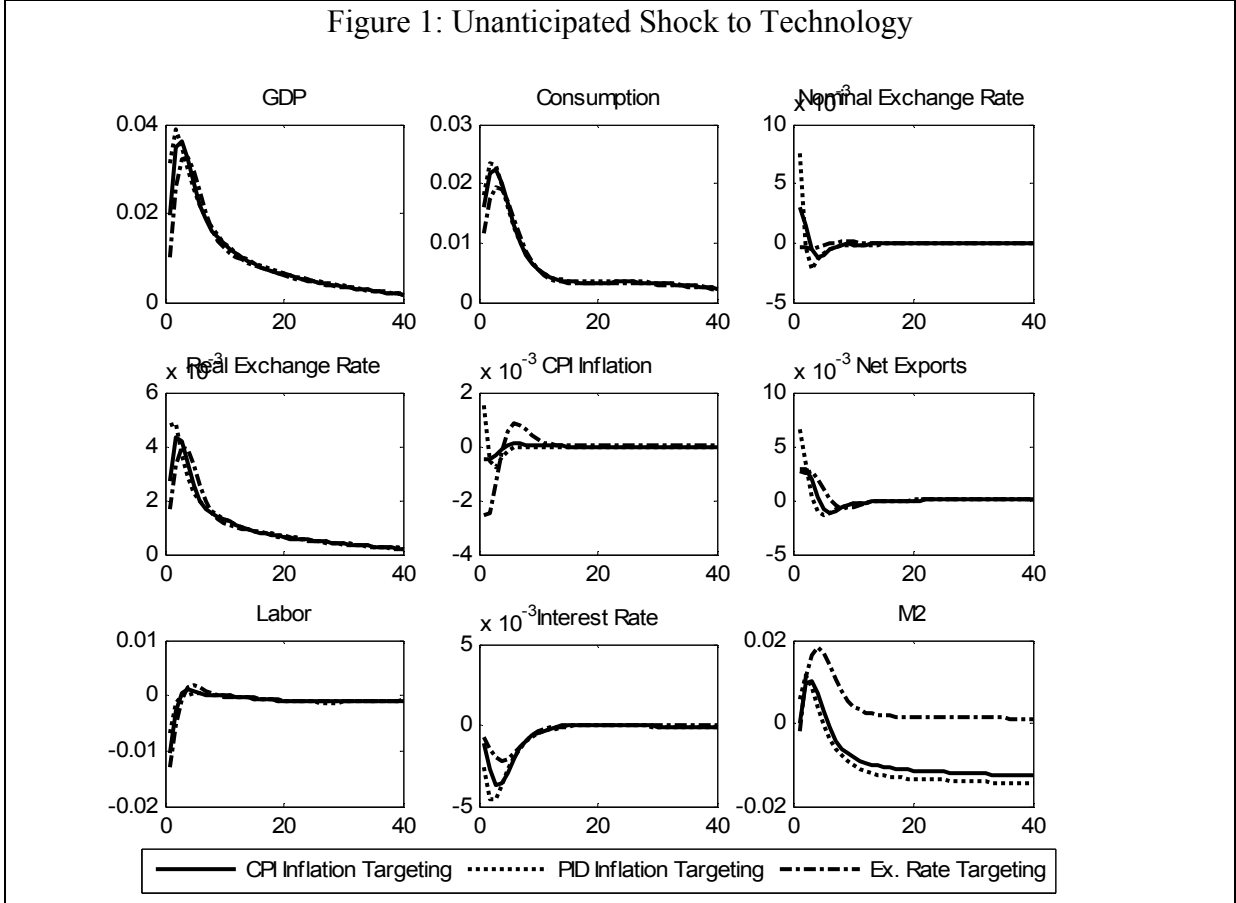
The discussion in the previous section suggests that the model appears to be able to deliver reasonable parameter estimates when estimated using Bayesian estimation techniques. In this section, we explore the impact of alternative shocks under three alternative monetary policy rules. First, we analyze the effect of a persistent (autocorrelation coefficient of 0.8) shock to technology before turning our attention to analyze the effect of a similarly persistent aid shock which raises aid by 2 percent of steady-state GDP. With the exception of the policy rules and the assumption that all aid is spent by the government, the parameterization of the model is that resulting from the estimation results discussed above. The response of the system is analyzed under the assumption that the authorities aim to stabilize either CPI inflation ($b_2 = z_4 = 10$), nontradable inflation (same but with nontradable inflation), or the rate of depreciation (equal to the long-run inflation differential between Mozambique and the rest of the world) of the nominal exchange rate ($z_3 = 10$).

Figure 1 show the impulse responses associated with an unanticipated shock to technology. Not surprisingly, the impulse response functions resemble those reported in Saxegaard (2006a) although differences do exist due mainly to the assumption of a closed capital account and flexible import and export prices. In particular, under all policy rules output rises in response to the improvement in production technology. As is standard in new-Keynesian models (see Galí, 1999), labor falls as a result of the interaction between sticky prices and technological change. Technological change induces a decline in marginal costs across all firms. However, due to the assumption of price adjustment costs, firms do not fully adjust prices. Hence, although the aggregate price level will fall, aggregate demand will increase less than proportionally to the increase in productivity and thus firms will react by reducing employment.

The extent to which employment falls will depend on the response of monetary policy. Clearly, the fact that aggregate demand does not rise proportionally to the increase in productivity means that there will be downward pressure on nontradable prices. As a result, under nontradable (PID) inflation targeting, the government increases the supply of base money with the result that interest rates fall. This is less true in the case of CPI inflation targeting due to the effect of imported inflation. It is even less true under exchange rate targeting where the interest rate only falls due to nominal rigidities.

The differences in the response of monetary policy translates directly into the behavior of inflation, which increases under PID inflation targeting due to the expansionary monetary policy but falls under exchange rate targeting as monetary policy does not offset the effect of

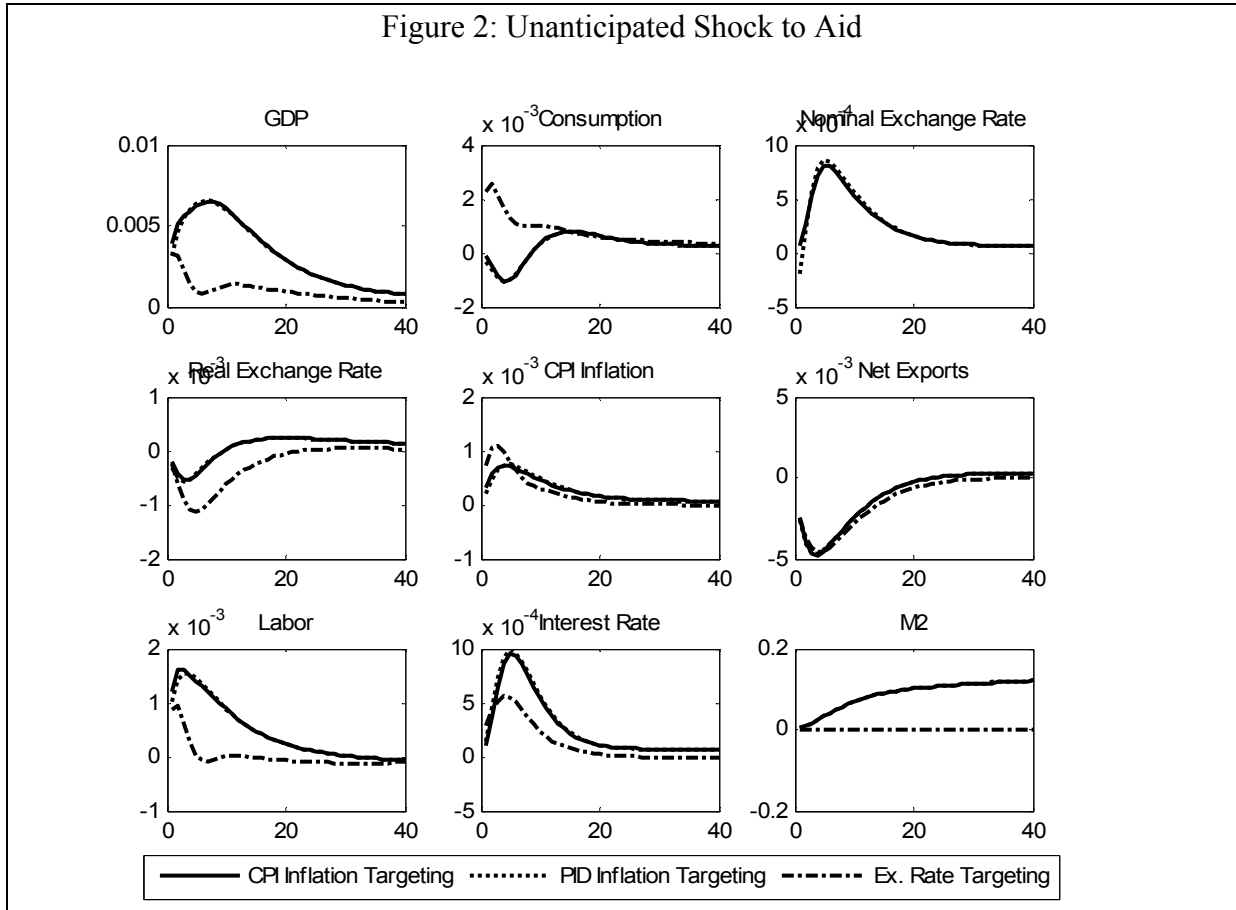
declining marginal cost on firm behavior. This in turn implies that the improvement in competitiveness arising from the technology shock occurs through a decline in prices under exchange rate targeting and through nominal exchange rate depreciation under PID and CPI inflation targeting.



Due to the importance of aid shocks in low-income countries we also analyze the impulse responses following an unanticipated shock to aid. The response of the economy to an unanticipated aid shock under different assumptions about foreign exchange sales (absorption) and bond sales (sterilization) has been analyzed extensively in Clément and Peiris (2007). The aid, which is fully spent by the government, leads to an increase in the demand for nontradable goods as well as imports. As a result of the former there is an increase in labor as well as GDP, whilst the increased demand for imports leads to a deterioration in the trade balance.

Under both CPI and nontradable inflation targeting, the authorities react to the increasing pressure on prices by contracting base money with the result that interest rates rise sharply. This is less true under exchange rate targeting where the authorities contract base money only to the extent necessary to counter the pressure on the exchange rate caused by the deterioration the trade balance. As a result, inflation volatility is higher under exchange rate

targeting than under inflation targeting. Interestingly, this also translates into higher real exchange rate volatility when the monetary authorities stabilize the path of the nominal exchange rate.



It is worth pointing out the fact that under inflation targeting—where part of the increase in base money is sterilized—interest rates remain high due to the persistent increase in the stock of government bonds. The persistent increase in inflation under inflation targeting reflects an increase in marginal costs reflecting the higher interest rates associated with sterilization.

We now proceed to an overall evaluation of the three monetary policy regimes. In particular, we investigate whether stabilizing inflation or the nominal exchange rate might provide a better recipe for macroeconomic policy in a shock-prone economy where the economy is subject to a wider array of shocks, in terms of macroeconomic volatility and traditional welfare based measures.¹⁰

¹⁰ It is well known (see inter alia Schmitt-Grohe and Uribe (2004) and Saxegaard (2006b)) that up to a first-order approximation, monetary policy is neutral in the sense that the policy rules we consider imply the same (nonstochastic) steady-state for the economy. We therefore follow the literature in evaluating welfare using a second-order approximation to the model where the expected variability of the economy will have an effect on welfare.

Table 1: Standard Deviations of Macroeconomic Variables								
	GDP	Consumption	Net Exports	CPI Infl.	Nom. Ex. Rate	Real Ex. Rate	Interest Rate	Welfare
CPI Inflation Targeting	0.4822	0.3023	0.0438	0.0049	0.0424	0.0518	0.0369	-7.2561
NTP Inflation Targeting	0.4842	0.3025	0.0425	0.0103	0.0382	0.0510	0.0355	-7.2578
Crawling Ex. Rate Peg	0.4892	0.3033	0.0541	0.0391	0.0072	0.0521	0.0410	-7.2861

Table 1, shows standard deviations of key macroeconomic variables for CPI inflation targeting, nontradable inflation targeting and the crawling exchange rate peg. Contrary to the discussion above, we use the estimated value for the share of aid that is spent and the distribution of this expenditure between the public and the private sector, as well as the estimated persistence and standard deviations of the structural shocks.

The results confirm the well-known result that because of higher interest rate volatility the exchange rate peg is significantly less successful than inflation targeting at stabilizing the real economy, although the differences are relatively small.¹¹ Not surprisingly, the exchange rate peg also implies significantly higher CPI inflation volatility which, despite of lower nominal exchange rate volatility, leads to higher real exchange rate volatility.

With the exception of the difference in CPI inflation volatility, the two inflation targeting rules perform relatively similarly in terms of macroeconomic volatility, a fact that may be related to the openness of the economy. In terms of overall welfare, there is some evidence that CPI inflation targeting outperforms nontradable inflation targeting, although the differences are small relative to the differences between inflation and exchange rate targeting.¹²

V. CONCLUSIONS

A key contribution of this paper has been to consider the best response, in terms of minimizing macroeconomic volatility and traditional welfare based measures, of alternative monetary policy rules in response to aid and numerous other exogenous shocks in an

¹¹ It should be noted, however, that the costs of interest rate volatility on the real economy may be lower in low income countries compared to more developed economies due to a weak interest rate channel.

¹² The similarity between CPI and nontradable inflation targeting is consistent with findings in Kollmann (2002) and Saxegaard (2006b).

estimated DSGE model for a SSA country. To our knowledge this is a first attempt at estimating a DSGE model for SSA which provides a benchmark DSGE model incorporating characteristics of SSA and low-income countries that could serve as a starting point for macroeconomic policy analysis.

SSA countries like Mozambique are prone to numerous exogenous shocks and our simulations suggests that a exchange rate peg is significantly less successful than inflation targeting at stabilizing the real economy due to higher interest rate volatility, although the differences are relatively small. Importantly, the exchange rate peg also implies significantly higher CPI inflation volatility which, despite of lower nominal exchange rate volatility, leads to higher real exchange rate volatility. This finding is of interest to SSA central bankers, as there does not seem to be any gains from targeting the nominal exchange rate in terms of minimizing real exchange rate volatility and thus the performance of the tradable goods sector, including in the presence of aid and terms of trade shocks. “Lite” inflation targeting regimes with an appropriate combination of foreign exchange interventions and open market operations may thus be more suitable for countries in SSA during a gradual transition to a fully-fledged inflation targeting framework as conditions permit.

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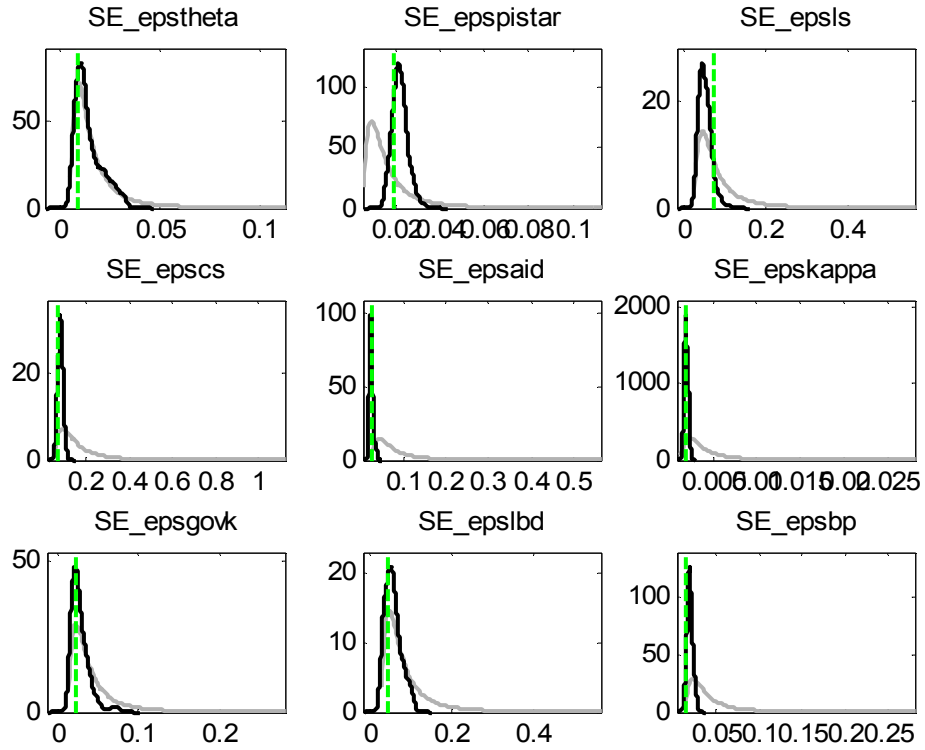
APPENDIX 1: CALIBRATION

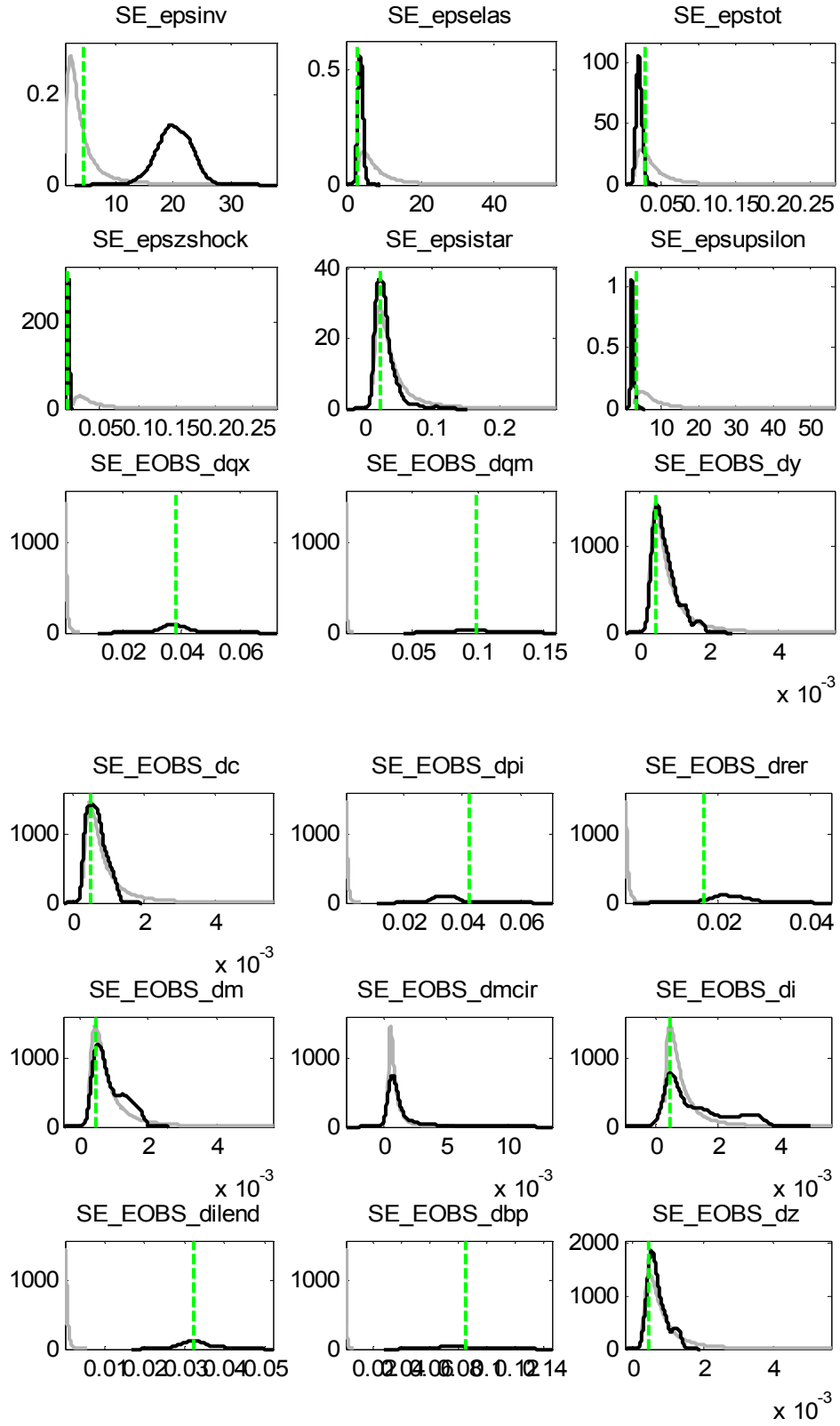
Parameter	Value	Description
ϱ	1.5	Home elasticity of substitution
η	3.5	Foreign elasticity of substitution
$\psi - 1$	1.5	Inverse of Frisch elasticity
ε	2	Inverse of elasticity of money supply
α^d	0.731	Share of nontradables in CPI
$\nu/(\nu - 1)$	1.09	Markup factor for intermediary goods.
ς	0.15	Cost share of borrowing
α	0.41	Cost share of capital
δ	0.025	Quarterly depreciation rate of capital
β	$(1.093/1.123)^{1/4}$	Quarterly subjective discount rate
u^γ	0.5	Steady-state learning by doing
u^μ	0.3	Steady-state share of government investment
π	$(1.093)^{1/4}$	Steady-state CPI inflation
π^*	$(1.059)^{1/4}$	Steady-state foreign inflation
$i + 1$	$(1.123)^{1/4}$	Steady-state domestic interest rate
$i^* + 1$	$(1.117)^{1/4}$	Steady-state foreign interest rate
$(M^c)/(M^0 + D)$	0.22	Currency to M2 Ratio
$(M^0 + D)/Y$	0.7	M2 to GDP Ratio
T/Y	0.15	Steady-state tax to GDP ratio
A/Y	0.15	Steady-state aid to GDP ratio
Z	4.6 months of imports	Steady-state level of foreign currency reserves

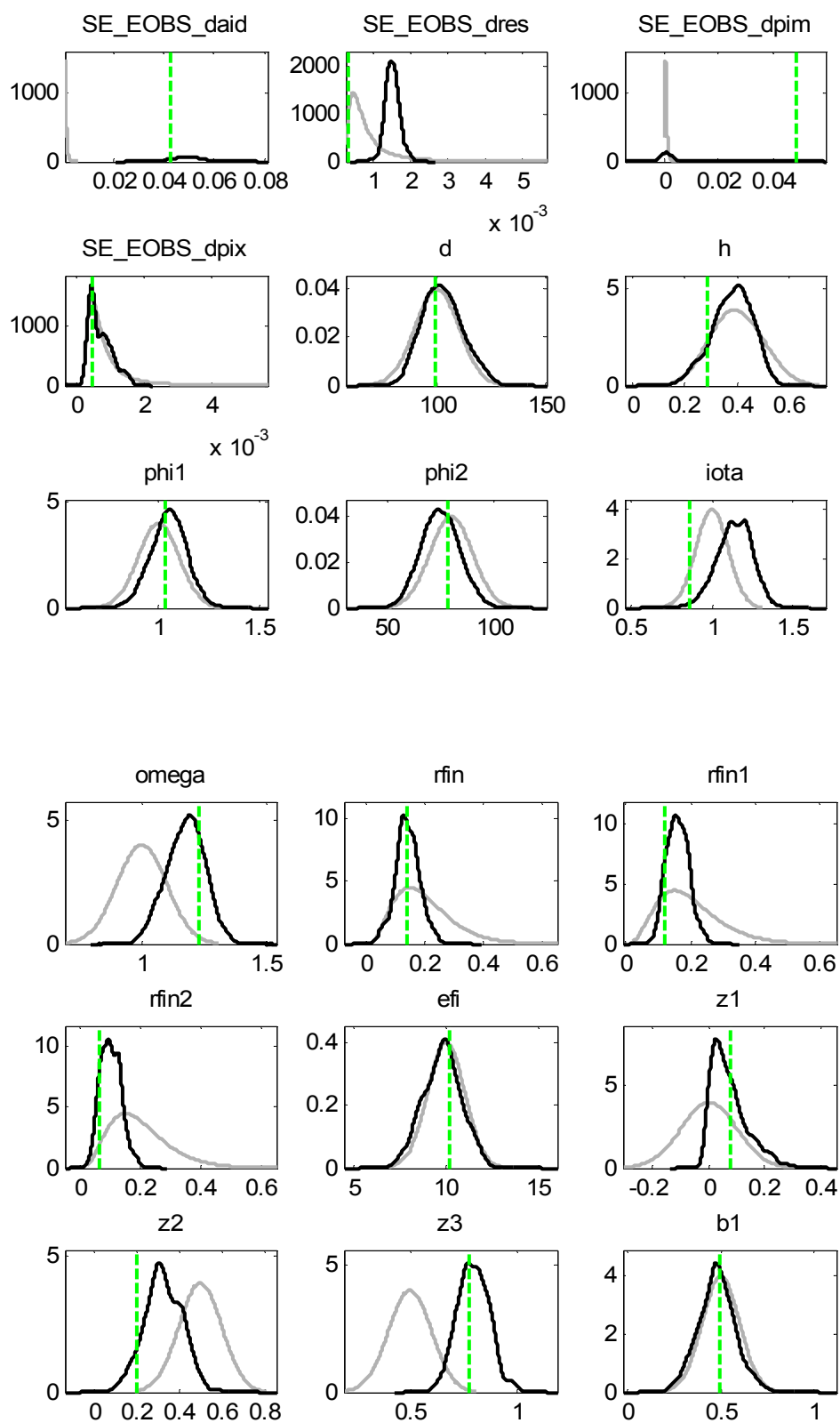
APPENDIX II: ESTIMATION RESULTS

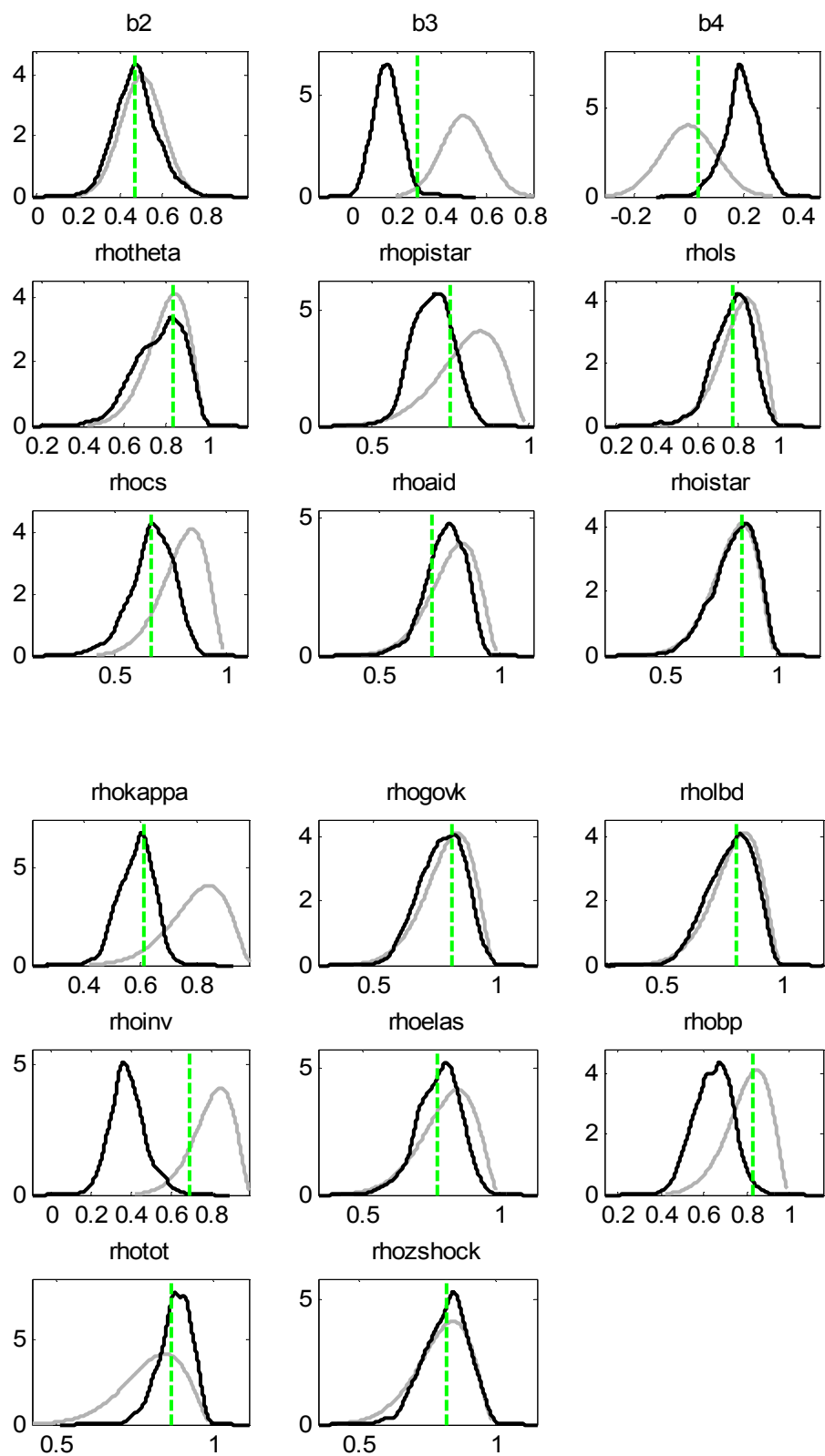
Parameter	Description	Density	Prior		Posterior		
			S.D.	Mean	90% Interval		
ϕ	Cost of Non-tradable Goods Price Adjustment	normal	100.000	10.0000	86.8394	101.4355	117.1080
b	Habit Persistence	beta	0.400	0.1000	0.2534	0.3833	0.5036
ϕ_1	Capital Stock Adjustment Costs	normal	1.000	0.1000	0.9078	1.0412	1.1971
ϕ_2	Investment Level Adjustment Costs	normal	80.000	10.0000	60.6232	76.5648	90.0185
ω	Share of Aid Spent	normal	1.000	0.1000	0.9647	1.1450	1.3188
ι	Share of Aid Spent by Public Sector	normal	1.000	0.1000	1.0438	1.1920	1.2892
$\bar{\omega}_1$	Commercial Bank Reserve Smoothing (Bonds)	gamma	0.200	0.1000	0.0797	0.1440	0.2190
$\bar{\omega}_2$	Commercial Bank Reserve Smoothing (Lending)	gamma	0.200	0.1000	0.1036	0.1592	0.2119
$\bar{\omega}_3$	Commercial Bank Reserve Smoothing (Deposits)	gamma	0.200	0.1000	0.0424	0.1012	0.1510
η	Interest Rate Spread Markup Factor	normal	10.000	1.0000	8.1881	9.7740	11.5823
z_1	International Reserves Stabilization	normal	0.001	0.1000	-0.0121	0.7730	0.1737
z_2	Exchange Rate Stabilization	normal	0.500	0.1000	0.1816	0.3193	0.4713
z_3	Absorption	normal	0.500	0.1000	0.6741	0.7971	0.9065
b_1	International Reserves Sterilization	normal	0.500	0.1000	0.2949	0.4751	0.6245
b_2	Inflation Stabilization	normal	0.500	0.1000	0.3079	0.4630	0.6291
b_3	Output Stabilization	normal	0.500	0.1000	0.0570	0.1634	0.2490
b_4	Bond Stabilization	normal	0.001	0.1000	0.0950	0.1991	0.2953
ρ^Y	Technology Shock Persistence	beta	0.800	0.1000	0.5890	0.7430	0.9471
ρ^{π^*}	Foreign Inflation Shock Persistence	beta	0.800	0.1000	0.5928	0.6951	0.7942
ρ^L	Labor Supply Shock Persistence	beta	0.800	0.1000	0.6305	0.7691	0.9216
ρ^C	Consumption Shock Persistence	beta	0.800	0.1000	0.5092	0.6596	0.8185
ρ^A	Aid Shock Persistence	beta	0.800	0.1000	0.6551	0.7735	0.9077
ρ^{i^*}	Foreign Interest Rate Shock Persistence	beta	0.800	0.1000	0.6581	0.8025	0.9579
ρ^μ	Government Investment Shock Persistence	beta	0.800	0.1000	0.4929	0.5852	0.6816
ρ^γ	Learning by Doing Shock Persistence	beta	0.800	0.1000	0.6418	0.7723	0.9313
ρ^I	Investment Shock Persistence	beta	0.800	0.1000	0.6375	0.7671	0.9349
ρ^j	Interest Rate Spread Shock Persistence	beta	0.800	0.1000	0.2398	0.3930	0.5251
ρ^B	Bond Shock Persistence	beta	0.800	0.1000	0.6558	0.7740	0.9040
ρ^{tot}	Terms of Trade Shock Persistence	beta	0.800	0.1000	0.4902	0.6486	0.7749
ρ^Z	International Reserves Shock Persistence	beta	0.800	0.1000	0.7996	0.8725	0.9606
u^Y	Size of Technology Shock	invgamma	0.002	Inf	0.0048	0.0048	0.0248
u^{π^*}	Size of Foreign Inflation Shock	invgamma	0.002	Inf	0.0166	0.0084	0.0281
u^L	Size of Labor Supply Shock	invgamma	0.100	Inf	0.0273	0.0209	0.0746
u^C	Size of Consumption Shock	invgamma	0.200	Inf	0.0611	0.0529	0.1012
u^A	Size of Aid Shock	invgamma	0.100	Inf	0.0196	0.0122	0.0329
u^μ	Size of Government Investment Shock	invgamma	0.050	Inf	0.0016	0.0118	0.0023
u^γ	Size of Learning by Doing Shock	invgamma	0.100	Inf	0.0132	0.0257	0.0431
u^B	Size of Bond Shock	invgamma	0.050	Inf	0.0241	0.0102	0.0873
u^I	Size of Investment Shock	invgamma	5.000	Inf	0.0136	1.3207	0.0248
u^j	Size of Interest Rate Spread Shock	invgamma	10.000	Inf	15.6574	2.4793	24.7542
u^{tot}	Size of Terms of Trade Shock	invgamma	0.050	Inf	2.8191	0.0130	4.9487
u^Z	Size of International Reserves Shock	invgamma	0.050	Inf	0.0145	0.0062	0.0268
u^{i^*}	Size of Foreign Interest Rate Shock	invgamma	0.050	Inf	0.0065	0.0164	0.0105
u^v	Size of Price Markup Shock	invgamma	10.000	Inf	0.0121	1.6522	0.049

APPENDIX III: PRIOR AND POSTERIOR DISTRIBUTIONS









APPENDIX IV: ACTUAL AND ONE-STEP AHEAD FORECASTS

