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Monetary Policy in Sub-Saharan Africa: Lessons from a Dynamic Stochastic General Equilibrium Model Applied to Mozambique

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Macroeconomic conditions in a number of sub-Saharan African countries have improved markedly in the past decade (IMF, 2005a), providing greater scope for stabilization policies. Higher economic growth rates have been associated with lower inflation rates, healthier public finances, and higher international reserves in a group of countries dubbed "mature stabilizers" (Selassie and others, 2006) or post-stabilization economies. Mozambique is one of these countries.

In general, the central banks of the mature stabilizers are no longer subsumed by the fiscal authorities' financing needs, a situation sometimes referred to as "fiscal dominance" (see Chapter 4). The possibility of an activist monetary policy provides the authorities with an important mechanism that can help them in their efforts to achieve economic stability.[1] Political economy arguments provide little scope for the use of discretionary fiscal policy for stabilization in low-income countries because

[1]In the mid-1990s, almost 80 percent of non-CFA countries used some form of exchange rate peg as a nominal anchor; today, the majority rely on a monetary anchor. The decisive shift away from exchange rates and toward money as the preferred nominal anchor for inflation, along with financial liberalization, provides an added impetus to analyze monetary policy for stabilization purposes (Adam and O'Connell, 2005).

of implementation lags and its susceptibility to the political cycle (Alesina and Tabellini, 2005). This view suggests that monetary policy, rather than fiscal policy, should be considered the primary tool for stabilizing the economy in the absence of fiscal dominance.

The use of monetary policy for macroeconomic stabilization in sub-Saharan Africa poses a number of challenges that have not been fully analyzed in the literature, which focuses on the conduct of monetary policy in industrial countries. While a number of studies have analyzed the sources of inflation in sub-Saharan Africa (for example, Barnichon and Peiris, 2007), only a few papers have analyzed the trade-offs between alternative monetary policy rules in sub-Saharan African 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, Galí, and Gertler, 1999; and Taylor, 1998), and provides few insights into the conduct of monetary policy in low-income countries, where the economy and monetary policy setting are quite different. Differences include the need to coordinate monetary and exchange rate policy with fiscal policy in order to manage large volatile aid inflows and government revenues from natural resource exploitation (IMF, 2005b). In particular, economic policy needs to consider the potential adverse effects of such shocks on the tradable sector—the so-called Dutch disease[3]—as well as the traditional objectives of inflation and output stabilization.[4] In addition, commercial banks in sub-Saharan Africa 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 interbank money markets and secondary markets for government debt are well developed, as in Mauritius and South Africa. Finally, the dominance of commercial banks and information asymmetries are likely to mean that

[2]This is due, in part, to the preoccupation with the need for fiscal control and effective nominal anchors to bring inflation down from very high levels, which has now been largely achieved in Mozambique (see Chapter 4).

[3]A key issue in sub-Saharan Africa is 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) estimate the median welfare cost of business cycles in developing countries to be between 10 and 30 times as large as in the United States.

the credit channel is a prominent part of the monetary policy transmission mechanism (Bernanke and Gertler, 1995).

This chapter attempts to analyze different monetary policy rules in sub-Saharan Africa, taking into account the sources of major exogenous shocks, transmission mechanisms, and level of financial development. We consider the best response of alternative monetary policy rules, in terms of minimizing macroeconomic volatility, to aid and numerous other exogenous shocks that are important in sub-Saharan Africa. In that sense, our focus is narrow and motivated by the interest of central bankers in sub-Saharan Africa, whose objective function is to minimize macroeconomic volatility and/or achieve a broad inflation target, given the pattern of exogenous shocks, particularly the spending of foreign aid, which is very large in many sub-Saharan African countries (IMF, 2005b). For example, aid inflows ranging between 10 and 20 percent of GDP have been mostly spent in Mozambique (see Chapter 6), requiring a monetary policy response to maintain macroeconomic stability in the face of large aid-financed liquidity injections. Although elements of these issues have been addressed, we are unaware of any study that has sought to analyze the implications of each of these factors in a unified framework applied to a country in sub-Saharan Africa. The aim of this chapter is to conduct such an analysis using a dynamic stochastic general equilibrium (DSGE) model estimated on data for Mozambique and to use such a model to evaluate the monetary policy trade-offs in the context of a full spending of scaled-up foreign aid inflows. To our knowledge, this is the first attempt to estimate a DSGE model for sub-Saharan Africa. More generally, we hope to provide a benchmark DSGE model incorporating features of sub-Saharan Africa and low-income countries that could serve as a starting point for macroeconomic policy analysis.

We will begin with a survey of the literature on the impact of macroeconomic volatility in low-income countries and go on to the role of monetary policy in sub-Saharan Africa. We will then briefly outline the DSGE model, with details in Appendix III, before outlining the estimation procedure and discussing the results of the estimation, followed by an evaluation of the response of the model to aid shocks under different assumptions about the conduct of monetary policy. The analysis will then be extended to consider the performance of different monetary policy rules—including inflation and exchange rate targeting—when the economy is subject to a larger and more realistic number of shocks. The chapter will draw insights from the experience of Mozambique and conclude by discussing the future challenges in the conduct of monetary policy for Mozambique and lessons for sub-Saharan Africa more generally.

Analytical Overiew and Literature Survey

Economic theory suggests that economic performance is related to endowments: the more endowed a country is with natural resources, labor, and human and physical capital, the greater its income and wealth.[5] Endowments are clearly an important part of the growth story, but they are not the whole story. Economies are subject to shocks of many kinds. Some of these are external: the international prices of a country's main imports/exports or the world's generosity toward low-income countries may change dramatically over time. These terms of trade and capital account shocks may have significant impacts on domestic macro variables (Peiris, 2002). In addition, countries may be subject to internal shocks, such as changes in the policy environment owing to political upheavals and civil conflict, weather-related events, or attempts to react to changes in the external environment. When an economy suffers a shock, many things are affected. The real exchange rate, a determinant of the country's international competitiveness, may be subject to wide swings. The relative performance of different sectors—especially the export and import sectors—will be affected; once-profitable projects may go bankrupt, while other activities receive unexpected windfalls. Public budgets may be affected, causing major changes in domestic debt and interest rates, which may, in turn, result in a credit crunch, disrupting capital formation as well as leading to lower capacity utilization and, hence, reduced output and increased unemployment. In a shock-prone economy, agents must wrestle not only with the shocks that have occurred but also with those that may happen. This generates an important source of instability and uncertainty. Volatility and uncertainty negatively affect the productive capacity of the economy.

Macroeconomic stability appears to be a prerequisite for long-term economic growth. Table 5.1 shows the long-run growth rate and growth volatility for the world and major geographical regions. Low-income countries not only register, on average, lower growth rates than industrial countries, they also suffer from twice as much volatility. Sub-Saharan Africa, in particular, experiences the worst growth performance and the highest level of volatility except for the Middle East and North Africa, while Asia has the best growth performance and relatively low volatility (see also IMF, 2005c). The table is only illustrative, however: the rate of economic growth depends on many factors other than volatility, and because Table 5.1 does not account for those factors, the apparent association could be

[5]Chapter 3 provides a survey of the literature on the sources of economic growth, so this section will focus on the role of macroeconomic stability and stabilization policies.

Table 5.1 Long-Run Per Capita GDP Growth and Volatility: World and Major Regions, 1961–94

	Per capita GDP growth *(In percent)*	Per capita growth volatility *(Standard deviation)*
World	1.80	5.37
OECD	2.69	2.81
Least developed countries	1.65	5.81
Latin America	2.10	5.17
Middle East and North Africa	1.37	8.01
Asia	2.88	4.38
Sub-Saharan Africa	0.76	6.14

Source: Elbadawi and Schmidt-Hebbel (1998).

spurious. Furthermore, even if the relationship is real, the simple relationship provides no information on the mechanisms through which volatility affects growth, information that is important for the design of policy responses.

More recently, a small but growing body of rigorous empirical studies on the links between macroeconomic volatility and macroeconomic performance generally confirms a negative relation (Kose, Prasad, and Terrones, 2005). These studies have generally focused on volatility in real GDP, terms of trade, economic policy, inflation, and real exchange rates, as well as composite indices of macroeconomic volatility and their impact on GDP growth, investment, and exports.

High output volatility can adversely affect economic growth, particularly in low-income countries (IMF, 2005c). Ramey and Ramey (1995) find statistically significant evidence of a strong negative relationship between volatility in real GDP and the average rate of economic growth in a sample of 92 countries. Moreover, they show that the negative effect of volatility on growth is not transmitted through investment but is mainly a direct effect. Hausmann and Gavin (1995) also suggest that volatility in a country's terms of trade and the real exchange rate has a significant negative effect on growth. In addition, they provide evidence that monetary and fiscal policy volatility has a negative effect only when real exchange rate volatility is excluded from cross-country regressions. The negative relationship between inflation and growth at high rates of inflation is also empirically well supported (Fischer, 1993; and Ghosh and Phillips, 1998), while high inflation rates are associated with greater inflation volatility.

Solimano and Servén (1993) also find that volatility in real GDP has significant negative effects on investment. Moreover, Aizenman and Marion (1996) suggest that the finding of no statistically significant impact

of GDP volatility on investment in Ramey and Ramey (1995) and many other observers was due to the measure of gross domestic investment used. Aizenman and Marion (1996) show that government spending, money growth, and real exchange rate volatility have a statistically significant negative impact on private investment in a sample of 43 countries when controlling for other potential determinants of private investment. In addition, Servén (1997) shows that inflation volatility and terms of trade volatility are significantly associated with reduced private investment in a group of predominantly African developing countries, after controlling for standard investment determinants in a panel regression approach. More recently, Servén (2002) finds that real exchange rate volatility has a negative and highly significant impact on private investment in developing countries, and the greater the volatility, the larger the impact. Bleany and Greenaway (2001) also find that real exchange rate volatility has a significant negative impact on investment in a panel of sub-Saharan African countries.

Finally, the evidence suggests that real exchange rate effects on export growth can be significant in sub-Saharan Africa (Gupta, Powell, and Yang, 2006). Balassa (1990) estimates that a 1 percent change in the level of the real exchange rate is associated with a change of 0.8 percent to 1 percent in the share of exports in GDP. In addition, Arellano and others (2005) show that manufactured exports drop by 1 percentage point of total exports in countries receiving additional aid equal to 1 percentage point of GDP, compared with the mean of a sample of 73 aid-receiving countries. Peiris (2002) also estimates that real exchange rate volatility has a significant negative impact on export performance in emerging markets, corroborating evidence from earlier work by Caballero and Corbo (1989). In this context, as in standard Dutch disease models of the kind formulated by Van Wijnbergen (1984) and Krugman (1987), the policy response becomes particularly important because the tradable sector may have a disproportionately large role to play in economic development thanks to the "learning by doing" externalities in the export sector. This line of thinking is borne out in Sekkat and Varoudakis (2000), who studied African manufacturing firms.

Consolidating macroeconomic stability in sub-Saharan Africa is likely to be a necessary condition for achieving sustained economic growth and poverty reduction—and, hence, the Millennium Development Goals (MDGs). Several studies have built on Hausmann, Pritchett, and Rodrik's (2004) analysis of jumps in countries' medium-term growth trends, which they label growth accelerations. Their study found that the onset of accelerations had a strong correlation with real exchange rate depreciation and

macroeconomic stability. This finding for growth acceleration over the past decade or so in sub-Saharan Africa has been confirmed by IMF (2005c). Almost all of the sub-Saharan countries experiencing sustained growth avoided real exchange rate overvaluation during the growth period. IMF (2005c) also notes the close link between avoidance of exchange rate misalignment and achievement of macroeconomic stability, reinforcing the case for prudent macroeconomic management. Macroeconomic volatility may also directly increase poverty and worsen the distribution of income (Hausmann and Gavin, 1995), particularly if it causes an economic crisis. The welfare effects of such an impact could be very large. Overall, the literature summarized here and the available evidence suggest non-trivial gains to consolidating macroeconomic stability in sub-Saharan Africa, especially reducing variability in output, the inflation rate, and the real exchange rate. This is clearly a challenge for Mozambique, a country that not only receives large amounts of aid but that is also susceptible to terms of trade shocks and weather-related shocks to output.

Role of Monetary Policy in Sub-Saharan Africa

The monetary policy trade-offs policymakers face are determined by the structure of the shocks confronting the economy and the transmission mechanisms that link monetary policy instruments to inflation and real variables. While a vast literature on industrial countries and emerging markets focuses on the efficacy of alternative monetary policy rules,[6] the challenges in the conduct of stabilization policies in low-income countries have received less attention. We therefore extend the work of a few authors who have recently begun to analyze the monetary policy trade-offs in sub-Saharan Africa (for example, Adam and O'Connell, 2005; Buffie and others, 2004; and Mirzoev, 2007).[7] However, we will not discuss in much detail the broader impact of exchange rate regime choice in sub-Saharan Africa as in Bleaney and Fielding (2002), although their finding that the volatility of both output and inflation is higher in the CFA countries than in other developing countries with floating exchange rates provides further motivation to evaluate monetary rules in low-income countries.

[6]These include Ball (2000); Christiano, Eichenbaum, and Evans (2005); Devereux, Lane, and Xu (2004); Svensson (2000); and Taylor (1993, 1998).

[7]Prati and Tressel (2006) also analyze the role of macroeconomic polices in response to aid volatility but do not distinguish between monetary and fiscal policies.

Numerous exogenous shocks buffet sub-Saharan Africa, with foreign aid playing a dominant role in non-oil-producing countries outside the CFA zone. To characterize these sources of shocks in sub-Saharan Africa, Adam and O'Connell (2005) estimate a set of country-specific vector autoregression (VAR) models on a small panel of data spanning the period since 1970 for 11 non-CFA economies, including Mozambique. The four principal exogenous sources of volatility are export commodity prices; variations in agricultural output; intermediate input prices (specifically, oil prices); and aid flows. The estimated variance-covariance matrix suggests that the two volume and two price shocks defined by the VAR are large. The mean (conditional) standard deviation of aid is 2.07 percent of GDP a year, and that of agricultural supply 1.6 percent of GDP. The price shocks are larger, with mean standard deviations of 6.5 percent a year for oil and 4.5 percent a year for non-oil commodity prices. With commodity exports accounting for about 10 percent of total GDP in the sample countries, the income effect of commodity price shocks is only about one-fourth of the mean aid shock. Similar conclusions are obtained for Mozambique in Chapters 4 and 6, where the standard deviation of aid is about 1 percent of GDP and aid shocks dominate the impact of commodity and oil prices on the real economy. Note, however, that Raddatz (2007) finds that external shocks explain a small fraction of the output variance of a typical low-income country and that other factors, most likely internal, are the main sources of fluctuations.

Monetary operations and the transmission mechanism of monetary policies are different in sub-Saharan Africa. In industrial countries and emerging markets, short-term market interest rates are the main instrument of monetary policy. In sub-Saharan Africa, the absence of liquid interbank and other securities markets that are not dominated by the central banks' own operations makes it nearly impossible to identify a transmission mechanism from a target interest rate to the price objective so that policymakers can determine the optimal level they should seek. Instead, sub-Saharan African countries conduct monetary policy through a combination of direct instruments (for example, reserve requirements) as well as foreign exchange interventions and open market operations with the private sector that affect the monetary base.[8] Therefore, like Adam and O'Connell (2005) and Buffie and others (2004), we analyze the trade-offs of both foreign exchange sales and open market operations in the conduct

[8]Applied research on mature stabilizers like Mozambique and Uganda has shown an identifiable transmission mechanism from base money (and broader monetary aggregates) to prices but not from domestic interest rates (Mikkelsen and Peiris (2005) and Chapter 4).

of monetary policy in sub-Saharan Africa. Mirzoev (2007), on the other hand, does not include domestic bonds, so the sterilization option cannot be discussed. However, the paper does usefully provide a list of omissions in the literature, all of which are covered in this chapter, that represent an agenda for future work.

- First, we allow the stock of physical capital to be determined by monopolistic firms.
- Second, productivity is not fixed. A higher level of exports, in particular, can raise aggregate productivity through positive spillovers of know-how and through dynamic learning by doing. Similarly, more public investment could lead to greater private sector productivity.
- Third, foreign currency is used only as a medium of exchange (to purchase imports) and not as means of saving,[9] while private agents do not have access to foreign borrowing. To capture this feature, a closed capital account is assumed.[10] As a result, the exchange rate is determined mostly by external trade and central bank actions, rather than by private capital flows, and the only source of financing for the trade deficit is the sale of aid dollars by the central bank.
- Finally, the model is calibrated to a particular country (Mozambique), estimating structural parameters using Bayesian techniques where possible.

In addition, we provide a role for commercial bank credit to firms in transmitting monetary policy impulses to spending in sub-Saharan Africa. African commercial banks routinely hold nearly double the amount of legally required reserves against deposits,[11] which could imply a weak credit channel in the transmission of monetary policy. Saxegaard (2005) argues, however, that if banks maintain excess reserves on a prudential basis—for example, because of extreme volatility in the deposit base or

[9]Buffie and others (2004) and Adam and O'Connell (2005) examine the effects of aid inflows in a model with currency substitution, while the model presented here, like workhorse DSGE models used in the literature in industrial countries, is more explicit in accounting for the consumption-labor choice and for the effects of the profitability of domestic firms on household income.

[10]We could have assumed, however, that banks hold foreign currency sold by the central bank earning a given world interest rate, but this would not have altered the results significantly unless one assumed uncovered interest parity (UIP), which seems unlikely in the countries under discussion.

[11]The median ratios of required reserves and excess reserves to deposits at the end of 2004 were both roughly 7 percent in the 44 sub-Saharan African countries studied in Saxegaard (2005). In most sub-Saharan African countries, including Mozambique, reserves are unremunerated deposits at the central bank.

unavoidably high lending risks—then an increase in bank liquidity is likely to be allocated partly to reserves and partly to new loans. In this situation, a cost-of-capital/bank lending channel may exist even in the presence of statutory excess reserves. In any case, the recent low level of excess reserves in a number of mature stabilizers in sub-Saharan Africa, including Mozambique and Uganda, suggests that monetary innovations are likely to have an impact on bank behavior. Moreover, Mikkelsen and Peiris (2005) have shown that changes in domestic credit to the private sector have had a significant positive impact on real economic activity in Uganda, suggesting that the impact of a bank lending channel could be quite large in sub-Saharan Africa. Therefore, we incorporate credit frictions following the recent literature on "financial accelerator" effects (Bernanke, Gertler, and Gilchrist, 1999). Overall, the inclusion of a banking system in the DSGE model illuminates the potential interactions between monetary impulses and financial development as well as the crowding-out effects of domestic debt issuance.

The response to aid shocks will be used to focus the analysis of alternative monetary policy rules. The macroeconomic challenges of managing aid inflows can be subdivided to the degree of spending and absorption of foreign aid (IMF, 2005b).[12] "Spending captures the extent to which the government uses aid to finance an increase in expenditures or a reduction in taxation" (IMF, 2005b, p. 10). Even if the aid comes tied to particular expenditures, governments can choose whether or not to increase the overall fiscal deficit as aid increases. Therefore, when discussing monetary policy rules in subsequent sections, we will assume that all aid is spent and not consider alternative fiscal rules, even though the framework presented is more generally applicable.[13]

For a given fiscal policy, absorption is controlled by the central bank through its decision about how much of the foreign exchange associated with aid it should sell. The IMF has argued that "an *increase* in aid can serve some combination of three purposes: an increase in the rate of reserve accumulation, an increase in non-aid capital outflows, or an increase in the non-aid current account deficit" (IMF, 2005b, p. 9). In this

[12]This definition of aid absorption in IMF (2005b) differs from that of domestic absorption (the sum of private consumption and investment, and government expenditure).

[13]Chapter 6 discusses in more detail the fiscal response to aid shocks and concludes that a scaling up of aid should be mostly spent in normal circumstances, as has been the case in Mozambique, albeit with a few caveats. This does not mean that fiscal policy has no role to play in consolidating macroeconomic stability—quite the contrary—but it is probably ill suited for short-term demand management, the focus of this chapter.

interpretation, aid absorption is defined as the extent to which a country's non-aid current account deficit (in foreign currency terms) widens in response to an increase in aid inflows.[14] Note, therefore, that for the purpose of this paper we exclude sterilization using open market operations from the definition of absorption.

This chapter focuses on the case where aid dollars are gifted to the government, which immediately sells them to the central bank. The government decides how much to spend, while the central bank decides how much of the aid-related foreign exchange to sell on the market (absorb).[15] If the central bank chooses not to sell the aid-related foreign exchange but instead to conduct open market operations to mop up liquidity, we call this sterilization.

The structure of our model, outlined below with monetary policy rules including foreign exchange sales and domestic debt operations, allows a comprehensive analysis of the issues involved in spending and absorbing foreign aid. The spending and the degree of absorption of aid is a point of departure in the literature on sub-Saharan Africa, however, and one should also consider whether the policy rules are robust to a wider array of exogenous shocks and more general rules discussed in the literature in industrial countries and emerging markets.

DSGE Model

In this chapter, we develop a macroeconomic model for monetary policy analysis in sub-Saharan Africa using data for Mozambique. Compared with previous empirical analysis of the Mozambican economy or, for that matter, most sub-Saharan African countries, we conduct our analysis within the context of a microfounded DSGE model. DSGE models have

[14]With this definition, aid that finances capital outflows is not absorbed. However, as the capital account is closed in our model (and in much of the literature on sub-Saharan Africa), the sale of foreign exchange by the central bank is equivalent to absorption. If the capital account is open, absorption is not controlled by the central bank.

[15]If aid is received in kind, or if the government spends aid dollars directly on imports, spending and absorption are equal, and there is no impact on macroeconomic variables, such as the exchange rate, the price level, and the interest rate. Aid could also go to the private sector directly. If the private sector uses the dollars to directly finance imports, there is unlikely to be much macroeconomic impact. When the private sector sells the dollars to the central bank and uses the local currency proceeds to finance domestic expenditures, the same issues will arise as in the case of government spending (IMF, 2005b).

several benefits that make them attractive for the analysis of macroeconomic policy:

- They are structural in the sense that each equation has an economic interpretation. Policy interventions and their transmission mechanisms can therefore be clearly identified, facilitating a discussion of alternative policies.
- They are microfounded in the sense that they are 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 a 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 and 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 their widespread use by central banks and other policy institutions in countries belonging to the Organization for Economic Cooperation and Development (OECD). This chapter 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. To overcome this problem, research often resorts 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 can undermine its use as a tool for policy analysis.

To overcome the problem of parameterizing the data, this chapter 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 have been successfully applied to the estimation of DSGE models by, among others, Juillard and others (2006); Smets and Wouters (2003,

2005); Lubik and Schorfheide (2005); and Saxegaard (2006a). As far as we know, this chapter represents the first attempt at estimating a DSGE model using Bayesian methods on data for a country in sub-Saharan Africa other than South Africa.

The use of Bayesian inference has a number of benefits worth highlighting. First, it 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 0 and 1, 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, therefore, that the importance of the prior information disappears as the sample grows. The same authors provide compelling evidence for the strong performance of Bayesian methods in small samples such as ours.

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 to ascertain the "true" value of a particular parameter but, rather, to determine which 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, based on the probability 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.

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 the explicit treatment of the conduct of monetary policy in sub-Saharan Africa, as in Adam and O'Connell (2005), by assuming that the monetary authority affects the money supply through foreign exchange sales and bond

issuance, although the bonds are bought by the banking sector instead of consumers, as is the case in Agénor and Montiel (2006) and Peiris (2002). The model incorporates credit frictions by assuming that firms have to borrow at a premium over deposit rates to finance some 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 multiplied by the price of the domestic good) to their liabilities, which consist of beginning-of-period borrowings, as in Agénor and Montiel (2006). Learning by doing is incorporated, as in Prati 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 that 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. The domestically produced goods, which are produced using capital, labor, and credit from a financial intermediary as inputs, are either sold in the domestic market or exported overseas. For the sake of simplicity, we assume that the country has a closed capital account. The markets for capital, labor, and commercial bank loans are competitive. The model is completed with a description of the fiscal and monetary authorities.

To provide a rationale for monetary and fiscal stabilization policy, four sources of inefficiency are included in the model: (1) monopolistically competitive product markets; (2) sluggish price adjustment in the domestic economy using the specification of Rotemberg (1982); (3) capital adjustment costs and investment adjustment costs using the specification of Christiano, Eichenbaum, and Evans (2005); and (4) adjustment costs in commercial bank reserves and an interest rate spread determined by the net worth of companies as described above. This framework, which is described in detail in Appendix III, captures many of the rigidities that previous studies have found are important in describing the dynamics in the data and serves as a useful starting point for developing a DSGE model for Mozambique.

Empirical Findings

The model described above is estimated on quarterly data for Mozambique from 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. The number of variables vastly exceeds the number of observed variables in recent papers that use Bayesian techniques to estimate DSGE models, such as Juillard and others (2006) and Saxegaard (2006b). The remaining endogenous variables in the model are assumed to be unobserved.

Prior to estimation, the macroeconomic variables are transformed into real per capita measures. Following the approach in Juillard and others (2006), 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 0 variables.

Following Juillard and others (2006) 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 and others (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 parameter values and calibrated steady-state ratios are summarized in Appendix I.

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 and by 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 II. These plots allow us to make some statements about the relative importance of the priors and the data in the construction of the posterior distribution. In other words, the plots allow us to judge whether or not the data are informative about our parameters. Overall, the Bayesian estimation methodology yields plausible parameter estimates for the model that are broadly in line with the results from previous studies. A comparison of the fitted values with the actual data reveals that the model is able to replicate the movements in the data fairly well.

Managing Aid Shocks

The discussion in the previous section suggests that the model appears to be able to deliver reasonable parameter estimates when using Bayesian

estimation techniques. We now turn our attention to the use of the estimated model to analyze the appropriate monetary management of aid shocks. We analyze the effect of a persistent aid shock (autocorrelation coefficient of 0.7) that 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 discussed above.

We analyze two scenarios. In the first scenario, aid is fully spent by the government but not absorbed; in the second scenario, the aid is both fully spent and fully or partially absorbed. In the scenario in which the aid is not absorbed, we consider two cases—one in which the increase in reserves is sterilized and one in which it is not so that government bond holdings remain unchanged. Finally, we also consider a scenario in which half of the aid is absorbed and the remaining increase in reserves is sterilized. In terms of the policy rules described in Appendix III (equations (34) and (35)), these scenarios can be defined as follows:

- Spend and don't absorb ($z_2 = 0$; $b_1 = 1$)
- Spend and don't absorb, but sterilize ($z_2 = 0$; $b_1 = 1$)
- Spend and absorb ($z_2 = 1$; $b_1 = 0$)
- Spend, absorb half, and sterilize half ($z_2 = 0.5$; $b_1 = 1$)

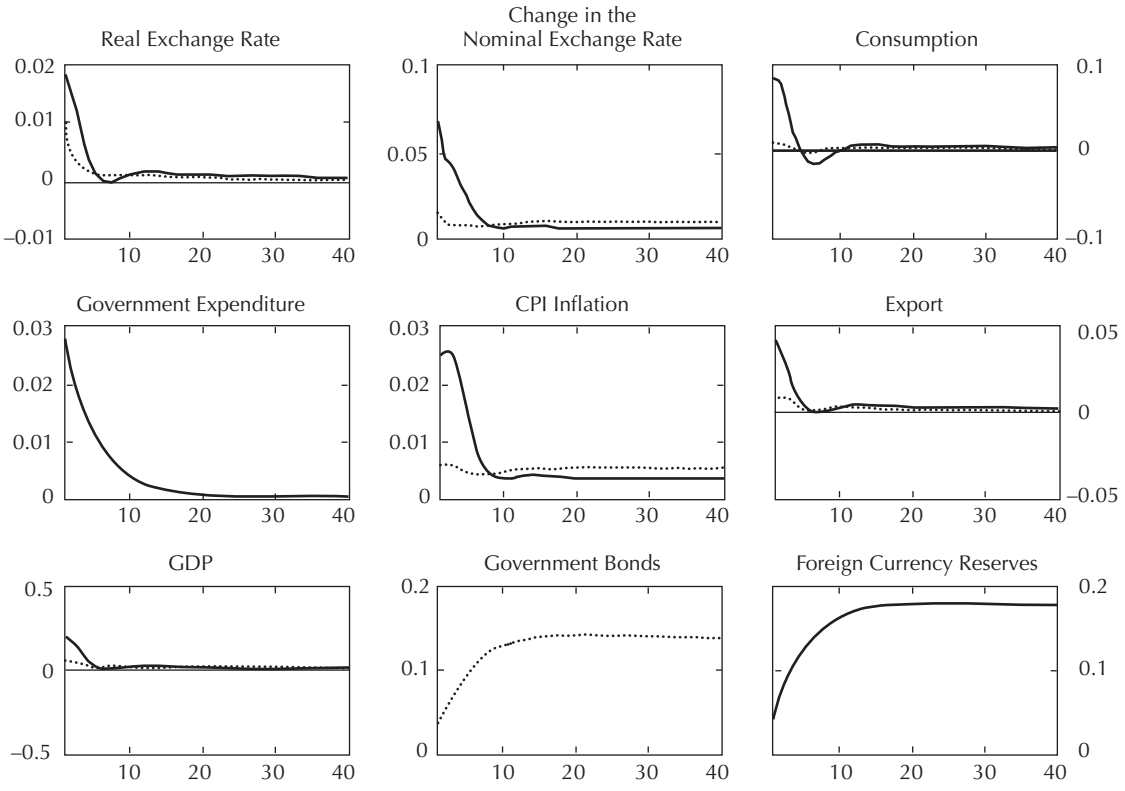
In all cases we assume a low weight on the stabilization of government bonds and foreign exchange reserves ($z_1 = b_4 = 0.0001$). The different scenarios are presented in Figures 5.1 and 5.2 and described below.

Spend and Don't Absorb

In Figure 5.1, we consider the effects of a spend-and-don't-absorb scenario where the resulting increase in reserves matches the increase in aid. The unbroken line describes a scenario in which the increase in reserves is not sterilized, whereas the broken line assumes that the government sterilizes the increase in reserves by issuing bonds.

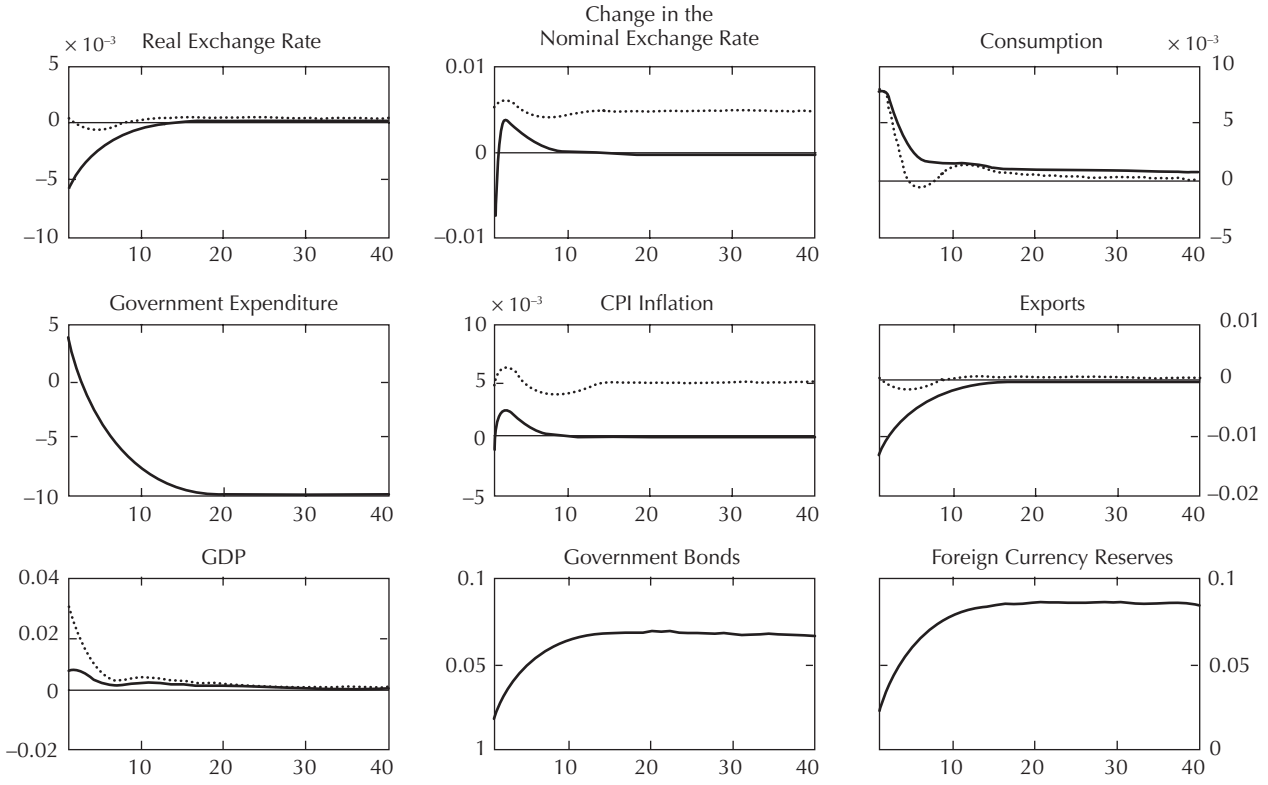
An increase in aid that is spent but neither absorbed nor sterilized is equivalent to a pure monetary expansion and therefore causes the depreciation of the nominal exchange rate. Inflation rises rapidly because of the instant adjustment of the nominal exchange rate and the prices of traded goods. However, because domestic prices are sticky, this adjustment is accompanied by a real depreciation of the exchange rate, as in Mirzoev (2007). This real depreciation would be even more pronounced were it not for prices rising because of the increase in government expenditure. The depreciation boosts exports, and demand for domestic goods also grows, implying an overall increase in GDP. Interestingly, unlike Mirzoev (2007),

Figure 5.1. Effects of a Spend-and-Don't-Absorb Scenario



Source: Authors' calculations.

Figure 5.2. Spend and Absorb All Aid; or Absorb Half, Sterilize Half



Source: Authors' calculations.

we see a temporary rise in private consumption. This is because, in our calibration, the spike in prices leads to an initial decline in real money balances, causing an increase in deposit rates and thus a wealth effect. In addition, wage income rises because price rigidity pushes up real wages and consumers try to compensate for the inflation tax by increasing labor supply. These effects offset the substitution effects of the rise in interest rates and lead to a temporary rise in consumption. As prices adjust to increased demand, the real exchange rate appreciates back to its equilibrium level and consumption falls along with household income.

Figure 5.1 also illustrates how these results change when we assume that the rise in base money is sterilized by the issuance of government bonds. The issuance of government bonds offsets the monetary expansion by driving up real interest rates. The rise in real interest rates and slowing of output expansion reduce the increase in consumption. The mopping up of liquidity reduces the initial depreciation of the nominal and real exchange rates and thus the rise in CPI inflation, dampening the impact on exports. This, together with the cost-of-capital/bank lending channel reduces the initial boost to output. Intuitively, the aid (and spending) shock has less of an impact on inflation and real variables when the monetary authority sterilizes the liquidity injected into the economy.

Spend and Absorb All of the Aid; or Absorb Half, Sterilize Half

Figure 5.2 analyzes the case where all the aid is spent and fully absorbed so that there is no change in foreign exchange reserves (unbroken line). It also shows the scenario where half of the aid is absorbed and the remaining increase in reserves is sterilized (broken line). This is equivalent to the 50-50 rule first suggested by Atingi-Ego (2005) and analyzed by Adam and O'Connell (2005). In this scenario, the performance of the recipient economy is substantially worse than it is in a spend-and-absorb scenario.

When all of the aid that is spent is absorbed, the nominal exchange rate appreciates; the real exchange rate also appreciates because of price stickiness. The real exchange rate appreciation reduces imported inflation and thus inflation. Consumers feel better off and consumption rises, whereas exports fall because of the real appreciation. This is the Dutch disease problem referred to earlier in this chapter. In spite of the drop in exports, GDP expands slightly, thanks to stronger domestic demand.

How do these results change when only half of the aid-induced spending is absorbed and the remaining increase in reserves is sterilized? Our results suggest that the partial sale of the foreign exchange dampens the appreciation of the real exchange rate. The nominal exchange rate actu-

ally depreciates in a persistent fashion, although the depreciation is offset by a persistent increase in CPI inflation. The increase in inflation reflects an increase in marginal costs caused by the higher interest rates associated with sterilization. The persistence of the rise in inflation reflects the persistent increase in the stock of government bonds. In terms of the real sector, GDP rises substantially more, largely because of the boost to exports resulting from the milder appreciation.

Optimal Response to Aid Shocks

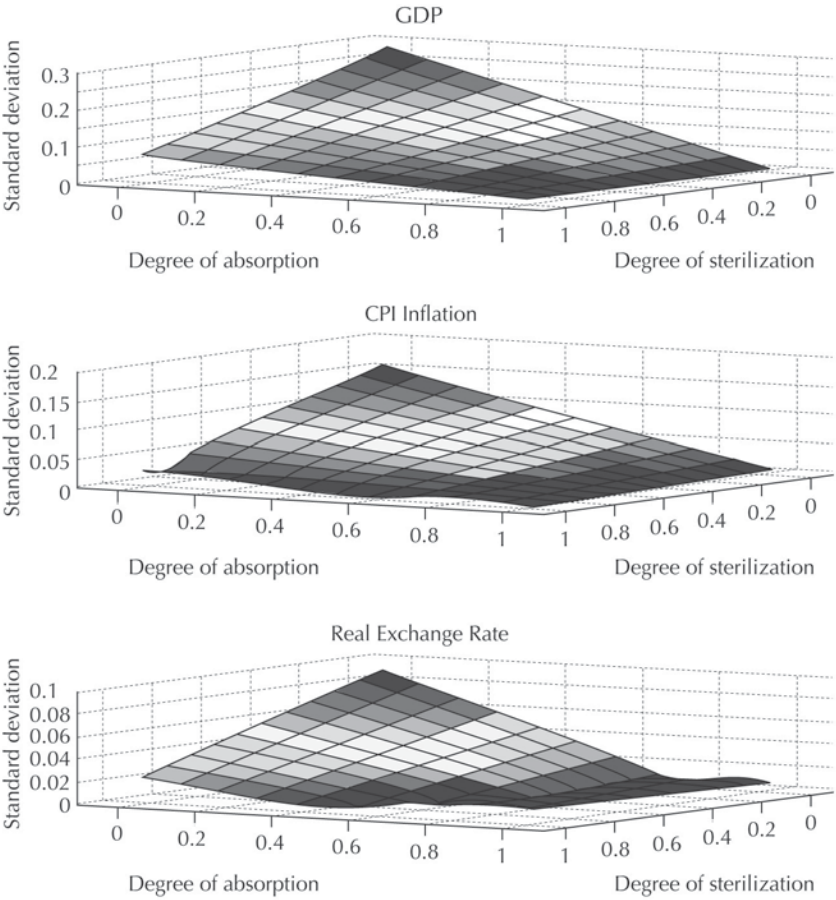
To summarize the insights from the above discussion of alternative responses to aid shocks in Mozambique, we plot the standard deviation of output, inflation, and the real exchange rate for different assumptions regarding the degree of absorption and sterilization of aid-financed fiscal expenditures. Figure 5.3 shows that with full absorption (the spend-and-absorb scenario), output is unambiguously less volatile than in any other scenario considered. If some of the aid-financed fiscal expenditure is not absorbed, Figure 5.3 confirms our findings that output is less volatile if the resulting monetary expansion is sterilized using open market operations.

However, the conclusions are not so clear-cut for CPI inflation and the real exchange rate. In particular, the volatility of CPI inflation is largely unchanged if only part of the aid is absorbed as long as the resulting increase in liquidity is sterilized. For the real exchange rate, volatility is slightly lower if only half of the aid is absorbed than if the entire amount is absorbed, assuming the country has a closed capital account, which is probable based on the relatively limited capital mobility we have observed in the countries in question. In particular, imposing uncovered interest parity would make the real exchange rate more sensitive to domestic interest rates and thus to sterilization. To the extent this is translated into nominal exchange rate volatility, it would also affect the volatility of CPI inflation. Hence, it is likely that opening the capital account would reduce the attractiveness of sterilization in terms of inflation and real exchange rate stability.[16]

In general, the results provide support for the assertion that "to *absorb and spend* the aid would appear to be the appropriate response under 'normal' circumstances" (IMF, 2005b, p. 15; emphasis added), at least in the case of Mozambique. However, it may also answer one of the conundrums identified in IMF (2005b); most of the countries in that sample—Mozambique, Uganda, and, initially, Tanzania—resisted absorb-

[16]Extending the model to include an open capital account is a topic of future research.

Figure 5.3. Impact of Absorption and Sterilization on GDP, CPI Inflation, and the Real Exchange Rate



Source: Authors' calculations.

ing the aid-financed spending, partly through domestic bond issuance. These countries may have placed a greater emphasis on real exchange rate stability than on the volatility of output and inflation.

Monetary Policy Rules in a Shock-Prone Economy

Having used the estimated model to analyze the optimal response to aid shocks, we now turn to the analysis of monetary policy in a more general

setting. The motivation for this analysis is the fact that while spend and absorb might provide a useful guide for macroeconomic policy in the event of an aid shock, it may not prove as useful when the economy is buffeted by a larger set of shocks. We investigate whether stabilizing CPI inflation or the nominal exchange rate in a shock-prone economy might provide a better recipe for macroeconomic policy, in terms of minimizing macroeconomic volatility, than spend and absorb.[17] While it is true that aid shocks are more clearly identifiable than other shocks, attempting to respond differently to various shocks complicates monetary policy management and could lead to greater instrument instability. Therefore, it makes sense to gauge the efficiency of a spend-and-absorb rule against more general monetary policy rules in the presence of a wider array of exogenous shocks.

Table 5.2 shows standard deviations of key macroeconomic variables for the spend-and-absorb rule, CPI inflation targeting, and the crawling exchange rate peg where the monetary policy authorities are assumed to target a rate of depreciation equal to the long-run inflation differential between Mozambique and the rest of the world.[18] The parameterization of the spend-and-absorb rule is as described above.[19] CPI inflation targeting assumes a weight ($\chi_4 = b_2 = 1$) on inflation stabilization in the bond and the foreign exchange reserves rules. The crawling exchange rate peg assumes a weight ($\chi_3 = 1$) on the exchange rate in the foreign exchange reserves rule. In all cases 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 sectors.

The results suggest that a spend-and-absorb rule is significantly less successful at stabilizing the economy than inflation and exchange rate targeting. This is particularly true with respect to the volatility of the nominal exchange rate, CPI inflation, consumption, and GDP, which is greater in spend-and-absorb scenarios. As expected, inflation is significantly less volatile under the CPI-inflation-targeting rule than under either the spend-and-absorb rule or the crawling-exchange-rate-peg rule,

[17]We have not conducted a full welfare analysis of alternative policy rules at this stage because we felt that macroeconomic volatility, rather than welfare, was a more useful metric for discussing different policies with the country authorities. A full welfare analysis can easily be incorporated into the analysis, however. This may be done at a later stage.

[18]It should be recognized, however, that the crawling exchange rate peg is not operational unless the trajectory of the equilibrium real exchange rate is known (as it is in this model).

[19]In the case of shocks other than an aid shock, a shock to government bonds, and a shock to foreign exchange reserves, spend and absorb simply implies keeping the stock of government bonds and the stock of foreign exchange reserves constant.

Table 5.2. Standard Deviations of Macroeconomic Variables

	Nominal exchange rate	Real exchange rate	Consumption	CPI inflation	Exports	GDP
Spend and absorb	0.1299	0.0238	0.1183	0.1317	0.0501	0.1823
CPI inflation targeting	0.0241	0.0225	0.0960	0.0177	0.0437	0.1330
Crawling exchange rate peg	0.0193	0.0256	0.1043	0.0331	0.0365	0.1448

Source: Authors' calculations.

although the nominal exchange rate is slightly more volatile under the CPI-inflation-targeting rule than under the crawling-exchange-rate-peg rule. As a result, exports are somewhat more volatile under the inflation targeting rule, although price stability helps stabilize nontradable output to the extent that GDP and consumption are less volatile under the inflation targeting rule than under the exchange-rate-targeting rule.

Overall, these findings confirm that spend and absorb may not be an appropriate guide for the conduct of monetary policy in countries that face a larger number of shocks, whereas the choice between inflation targeting and a crawling exchange rate peg will depend on which of the following the authorities prefer to stabilize: output, inflation, exports, or the exchange rate. It should be noted that, from a practical point of view, a crawling exchange rate peg as designed in the model is unlikely to be feasible given the uncertainties surrounding the equilibrium real exchange rate in practice, making the case for an inflation targeting regime stronger.

Lessons and Challenges

This chapter has considered what would be the monetary policy rule most likely to minimize macroeconomic volatility in a country facing aid-related expenditures and numerous other exogenous shocks. To our knowledge, ours is the first attempt to estimate a DSGE model for sub-Saharan Africa and low-income countries that could serve as a starting point for macroeconomic policy analysis. While the simulations of the policy experiments largely validate the assertion "to absorb and spend the aid would appear to be the appropriate response under 'normal' circumstances" (IMF, 2005b, p. 15), we also provide insights as to why some sub-Saharan African countries, including Mozambique, have, for the most part, been

reluctant to fully absorb aid shocks (IMF, 2005b). This reluctance may be related to a desire to smooth real exchange rate fluctuations—and thus the effects of Dutch disease, including its negative impact on long-term growth prospects.

It is worth reiterating the need to pay greater attention to the consistency of monetary and exchange rate policy in cases where the authorities spend but do not absorb aid—perhaps in an effort to safeguard export competitiveness. On the other hand, sub-Saharan African countries like Mozambique are prone to numerous exogenous shocks, and our simulations suggest that monetary authorities seeking to minimize overall macroeconomic volatility will be more successful if they place more weight on inflation (or exchange rate stabilization, if the authorities do not place a lot of weight on inflation stabilization) than if they apply simple rules such as spend and absorb. Monetary policy in economies subject to many exogenous shocks needs to be considered in a more general setting, and policymakers should avoid being narrowly focused on spending and absorbing foreign aid. "Lite" inflation targeting regimes, as depicted in Stone (2003), may thus be more suitable for countries in sub-Saharan Africa. Stone (2003) describes "lite" inflation targeting regimes as those that probably aim to bring inflation into the single digits and maintain financial stability, including through a relatively interventionist exchange rate policy.[20] The inflation targeting regime considered in this chapter was somewhat similar.

The model and policy rules discussed here are broadly applicable. For one thing, non-CFA sub-Saharan Africa is rich in petroleum (Angola, Nigeria, São Tóme and Príncipe, and, potentially, Uganda) and mineral resources (for example, the Democratic Republic of the Congo, Mozambique, Tanzania, and Zambia), with new producers coming on line each year. Although our model does not explicitly address oil-producing and mineral-extracting economies, the simulation evidence reported above bears directly on the monetary policy challenges facing these countries. Since most production is carried out by foreign firms, the principal linkages between volatile commodity prices and the domestic economy are fiscal (Adam and O'Connell, 2005). Variations in revenues from oil and mineral exports can therefore be treated in a manner that is directly analogous to our treatment of variations in aid, subject to the necessary

[20]Further, "lite" inflation targeting regimes employ monetary targets that are less market oriented, and the objectives of monetary policy, as well as the instruments used to conduct it, are relatively nontransparent in sub-Saharan Africa owing to shallow financial markets.

recalibration of the relevant model parameters. Many of the insights we develop in the context of managing aid flows (and a wider array of exogenous shocks) will therefore carry over to the monetary management of petroleum and mineral resource booms.

At this point, it is important to note that we have discussed the monetary policy rules that are most appropriate in response to spending aid (or revenues from natural resources) and numerous exogenous shocks mainly from the viewpoint of minimizing macroeconomic volatility,[21] which the economic literature and experience of fast-growing Asian economies have revealed to be important for growth and poverty reduction. It could, however, be the case that policymakers view the level of macroeconomic variables (for example, the inflation and real exchange rates) and the degree of volatility, even in an absorb-and-spend aid scenario or "lite" inflation targeting regime, to be too high from the point of view of consumer welfare and long-term growth. This could be relevant, particularly if the aid (or commodity price) shock is significantly larger or less persistent than the typical shock considered here. A broader look at the appropriate pattern of government spending and absorption in response to aid would need to consider (1) the beneficial effects of aid-related spending on the level of consumption or investment and (2) the costs in terms of forgone growth due to the absence of learning by doing in the export sector. To do so, one could alter the assumption in this chapter that all of the aid (or export windfall) is spent to achieve the MDGs and evaluate alternative fiscal policy rules.[22] In addition, if the possible impact of Dutch disease on macroeconomic variables, such as the real exchange rate, is of greater concern, it could be illustrative to consider the sensitivity of the impact of learning by doing in the tradable sector and of productivity spillovers from government investment expenditure. These are subjects for future research.

[21]Given the firm microfoundations of the model, we could also have easily shown the ranking of the rules in terms of maximizing a specific social-welfare function.

[22]Fiscal policy trade-offs of a longer-term nature are covered in more detail in Chapter 6.

Appendix I. Calibration

Parameter	Value	Description
ϑ	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 expenditure
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	Ratio of currency to M2
$(M^0 + D)/Y$	0.7	Ratio of M2 to GDP
T/Y	0.15	Ratio of steady-state tax to GDP
A/Y	0.15	Ratio of steady-state aid to GDP
$\mathcal{Z}$	4.6 months of imports	Steady-state level of foreign currency reserves
α^r	0.11	Required reserves ratio

Appendix II. Estimation Results

		Prior			Posterior		
Parameter	Description	Density	Mean	SD	Mean	90%	Interval
ϕ	Cost of nontradable goods price adjustment	normal	100.000	10.000	103.453	89.091	121.621
b	Habit persistence	beta	0.400	0.100	0.302	0.177	0.454
ϕ_1	Capital-stock adjustment costs	normal	1.000	0.100	0.996	0.850	1.180
ϕ_2	Investment-level adjustment costs	normal	80.000	10.000	81.810	64.043	98.575
ω	Share of aid spent	normal	1.000	0.100	0.844	0.687	1.036
ι	Share of aid spent by public sector	normal	1.000	0.100	0.655	0.446	0.836
ϖ_1	Commercial-bank-reserve smoothing (bonds)	gamma	0.200	0.100	0.165	0.104	0.224
ϖ_2	Commercial-bank-reserve smoothing (lending)	gamma	0.200	0.100	0.145	0.083	0.197
ϖ_3	Commercial-bank-reserve smoothing (deposits)	gamma	0.200	0.100	0.093	0.035	0.143
η	Interest-rate-spread markup factor	normal	10.000	1.000	9.924	8.237	11.461
$\varkappa_1$	International reserves stabilization	normal	0.001	0.100	0.067	–0.013	0.140
$\varkappa_2$	Exchange rate stabilization	normal	0.500	0.100	0.323	0.149	0.461
$\varkappa_3$	Absorption	normal	0.500	0.100	0.566	0.415	0.714
b_1	International reserves sterilization	normal	0.500	0.100	0.472	0.330	0.652
b_2	Inflation stabilization	normal	0.500	0.100	0.592	0.438	0.727

Parameter	Description	Prior			Posterior		
		Density	Mean	SD	Mean	90%	Interval
b_3	Output stabilization	normal	0.500	0.100	0.159	0.078	0.230
b_4	Bond stabilization	normal	0.001	0.100	0.075	0.008	0.133
ρ^{θ}	Technology shock persistence	beta	0.800	0.100	0.856	0.770	0.957
ρ^{π^*}	Foreign inflation shock persistence	beta	0.800	0.100	0.726	0.623	0.848
ρ^{L}	Labor supply shock persistence	beta	0.800	0.100	0.760	0.589	0.912
ρ^{C}	Consumption shock persistence	beta	0.800	0.100	0.727	0.574	0.883
ρ^{A}	Aid shock persistence	beta	0.800	0.100	0.699	0.519	0.897
ρ^{i^*}	Foreign interest rate shock persistence	beta	0.800	0.100	0.738	0.628	0.840
ρ^{μ}	Government investment shock persistence	beta	0.800	0.100	0.740	0.596	0.897
ρ^{γ}	Learning-by-doing shock persistence	beta	0.800	0.100	0.770	0.641	0.939
ρ^{I}	Investment shock persistence	beta	0.800	0.100	0.720	0.578	0.906
ρ^{i}	Interest rate spread shock persistence	beta	0.800	0.100	0.826	0.732	0.944
ρ^{B}	Bond shock persistence	beta	0.800	0.100	0.674	0.534	0.799
ρ^{tot}	Terms of trade shock persistence	beta	0.800	0.100	0.849	0.749	0.940
ρ^{z}	International reserves shock persistence	beta	0.800	0.100	0.753	0.592	0.899
u^{θ}	Size of technology shock	invgamma	0.002	Inf	0.009	0.005	0.015

Parameter	Description	Prior			Posterior		
		Density	Mean	SD	Mean	90%	Interval
$u^{\pi*}$	Size of foreign inflation shock	invgamma	0.002	Inf	0.014	0.008	0.018
u^{L}	Size of labor supply shock	invgamma	0.100	Inf	0.032	0.021	0.042
u^{C}	Size of consumption shock	invgamma	0.200	Inf	0.083	0.053	0.108
u^{A}	Size of aid shock	invgamma	0.100	Inf	0.015	0.012	0.017
u^{μ}	Size of government investment shock	invgamma	0.050	Inf	0.024	0.012	0.039
u^{γ}	Size of learning-by-doing shock	invgamma	0.100	Inf	0.051	0.026	0.077
u^{B}	Size of bond shock	invgamma	0.050	Inf	0.015	0.010	0.018
u^{I}	Size of investment shock	invgamma	5.000	Inf	3.200	1.321	5.421
u^{i}	Size of interest rate spread shock	invgamma	10.000	Inf	3.266	2.479	3.898
u^{tot}	Size of terms of trade shock	invgamma	0.050	Inf	0.019	0.013	0.025
u^{z}	Size of international reserves shock	invgamma	0.050	Inf	0.009	0.006	0.012
u^{i*}	Size of foreign interest rate shock	invgamma	0.050	Inf	0.021	0.016	0.026
u^{v}	Size of price markup shock	invgamma	10.000	Inf	2.286	1.652	2.860

Appendix III. Model Structure

The model used in this chapter can be described as follows.

Household Behavior

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

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

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

$$\begin{aligned} &M_t^c(j)+D_t(j)+P_t(C_t(j)+I_t(j)) \\ &=M_{t-1}^C(j)+D_{t-1}(j)(1+i_{t-1})+\prod_t^f \\ &+\int_0^1\prod_t^d(s)ds+W_tL_t(j)+R_tK_t(j)-T_t\,, \end{aligned} \tag{2}$$

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

$$K_{t+1}=(1-\delta)K_t+\Psi_tK_t\,, \tag{3}$$

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

$$\Psi_t\equiv\frac{I_t(j)}{K_t(j)}-\frac{\phi_1}{2}\left[\frac{I_t(j)}{K_t(j)}-\delta(1+u_t^I)\right]^2-\frac{\phi_2}{2}\left[\frac{I_t(j)}{K_t(j)}-\frac{I_{t-1}}{K_{t-1}}\right]^2, \tag{4}$$

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 way of accounting for the low correlation between labor productivity and hours observed in the data.

The consumer's problem can be written thus:

$$\max_{C_t,M_t^c,D_t,L_t,K_{t+1},I_t} \sum_{t=0}^{\infty}\beta^t\left\{\begin{array}{l} U(C_t(j),L_t(j),M_t^c(j)) \\ -\lambda_t\left[\begin{array}{l} M_t^c(j)+D_t(j) \\ +P_t(C_t(j)+I_t(j))-M_{t-1}^c(j) \\ -D_{t-1}(j)(1+i_{t-1})\Pi_t^f \\ -\int_0^1\Pi_t^d(s)ds-W_tL_t(j) \\ -R_tK_t(j)+T_t \end{array}\right] \\ +\omega_t[(1-\delta)K_t+\Psi_tK_t-K_{t+1}\end{array}\right\}, \tag{5}$$

where λ_t and ω_t are Lagrange multipliers.

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

$$\frac{u_t^C(1-b)}{C_t(j)-bC_{t-1}} = \lambda_t P_t \tag{6}$$

$$u_t^L L(j)_t^{\psi-1} = \lambda_t W_t \tag{7}$$

$$\frac{\kappa}{P_t}\left(\frac{M_t^C(j)}{P_t}\right)^{-\varepsilon} = \lambda_t - \beta E_t(\lambda_{t+1}) \tag{8}$$

$$\lambda_t = \beta Et[\lambda_{t+1}(1+i_t)]. \tag{9}$$

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

$$E_t\left\{\beta\lambda_{t+1}R_{t+1}-\omega_t+\beta\omega_{t+1}\left[(1-\delta)+\Psi_{t+1}\frac{I_{t+1}(j)}{K_{t+1}(j)}\Psi'_{t+1}\right]\right\}=0, \tag{10}$$

$$P_t\lambda_t = \omega_t\Psi'_t, \tag{11}$$

where

$$\Psi'_t = \frac{\partial\Psi_t}{\partial I_t(j)/\partial K_t(j)} = 1-\phi_1[\frac{I_t(j)}{K_t(j)}-\delta(1+u_t^l)]-\phi_2[\frac{I_t(j)}{K_t(j)}-\frac{I_{t-1}}{K_{t-1}}]. \tag{12}$$

Final Goods Production

Producers of final goods 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:

$$Z_t = [(\alpha^d)^{1/\vartheta}(Q_t^d)^{(\vartheta-1)/\vartheta}+(1-\alpha^d)^{1/\vartheta}(Q_t^m)^{(\vartheta-1)/\vartheta}]^{\vartheta/(\vartheta-1)} \tag{13}$$

for some elasticity of substitution $\vartheta > 1$. The CES indices of domestic and imported intermediate goods are Q_t^d and Q_t^m:

$$Q_t^i = \left[\int_0^1 q_t^i(s)^{(\nu-1)/\nu}\right]^{\nu/(\nu-1)} \tag{14}$$

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

$$Q_t^i = \alpha^i[P_t^i/P_t]^{-\vartheta} Z_t, \tag{15}$$

with an associated cost-minimizing price index and where $\alpha^d + \alpha^m = 1$.

Intermediate Goods Production

Following Prati 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-goods firms use an input ϑ_t that is funded by borrowing from a financial intermediary. The production technology is Cobb-Douglas:

$$Y_t = \theta_t \vartheta_t^{\varsigma}(L_t^{\alpha} K t^{1-\alpha})^{1-\varsigma}, \tag{16}$$

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:

$$\theta_t = (1 - \rho^{\theta})[h(G_t^K) + u_t^{\gamma} Q_t^x] + \rho^{\theta}\theta_{t-1} + u_t^{\theta}\,, \tag{17}$$

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

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

$$\min_{K_t, L_t, \vartheta_t^{\varsigma}} W_t L_t + R_t K_t + (1 + i_t^L) P_t \vartheta_t + P_t \lambda_t [Y_t - \theta_t \vartheta_t^{\varsigma}(L_t^{\alpha} K_t^{1-\alpha})^{1-\varsigma}], \tag{18}$$

where we assume that the firm takes prices as given. The first-order conditions for K_t, L_t and ϑ_t^{ς} are

$$R_t = (1 - \varsigma)(1 - \alpha)\lambda_t P_t \theta_t \vartheta_t^{\varsigma}(L_t^{\alpha} K_t^{1-\alpha})^{-\varsigma} K_t^{-\alpha} \tag{19}$$

$$W_t = (1 - \varsigma)\alpha\lambda_t P_t \theta_t \vartheta_t^{\varsigma}(L_t^{\alpha} K_t^{1-\alpha})^{-\varsigma} L_t^{\alpha-1} \tag{20}$$

$$(1 + i_t^L) = \lambda_t \varsigma \theta_t \vartheta_t^{\varsigma-1}(L_t^{\alpha} K_t^{1-\alpha})^{1-\varsigma}\,. \tag{21}$$

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

$$MC_t = \frac{W_t}{(1-\varsigma)\alpha_t\theta_t\vartheta_t^{\varsigma}(L_t^{\alpha}K_t^{1-\alpha})^{-\varsigma}L_t^{\alpha-1}}. \quad (22)$$

We assume that each domestic firm sells its output on both the domestic and the export markets 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:

$$Q_t^x = [P_t^x/P_t^*]^{-n}, \quad (23)$$

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

Price-Setting by Intermediate-Goods Producers

Intermediate-goods producers face quadratic adjustment costs in setting prices measured in terms of the intermediate good and given by

$$\frac{\phi}{2}\left[\frac{P_t^d/P_{t-1}^d}{P_{t-1}^d/P_{t-2}^d}-1\right]^2 Q_t^d. \quad (24)$$

Hence, we assume that the cost of price adjustment is related to the change in inflation relative to the past observed inflation rate. Juillard and others (2006) argue 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

$$P_t^d = \frac{\nu}{(\nu-1)}MC_t - \frac{\phi}{(\nu-1)}P_t\frac{\pi_t^d}{\pi_{t-1}^d}\left[\frac{\pi_t^d}{\pi_{t-1}^d}-1\right] + \frac{\phi}{(\nu-1)}P_tE_t\left\{\rho_{t,t+1}\frac{Q_{t+1}^d}{Q_t^d}\frac{\pi_{t+1}^d}{\pi_t^d}\left[\frac{\pi_{t+1}^d}{\pi_t^d}-1\right]\right\}, \quad (25)$$

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

Financial Intermediary

The financial sector is assumed to convert deposits from households into loans to intermediate-goods firms and the public sector, and reserves, similar to Agénor and Montiel (2006):

$$D_t = B_t^P + \vartheta_t + R_t \,. \tag{26}$$

For a given level of reserves, an increase in the volume of deposits at the financial intermediary reduces the amount of money in circulation and hence the utility from liquidity services.

Deposits are assumed to earn the same interest rate as government bonds. Loans to intermediate-goods firms earn an interest rate that represents a markup over the interest rate on deposits. This markup is a function $g(.)$ of firms' beginning-of-period net worth (the ratio of their liabilities to the value of their capital stock), as in Agénor and Montiel (2006):

$$\frac{i_t^L + u_t^i}{i_t} = g(\eta; P_t K_t / \vartheta_{t-1}), \tag{27}$$

where u_t^i is a mean 0 shock to the lending rate. Commercial banks are assumed to maintain reserves equal to required reserves in the steady state and to use reserves to smooth movements in net liabilities:

$$R_t = \alpha^r D_t + \varpi_1 \Delta B_t^P + \varpi_2 \Delta \vartheta_t - \varpi_3 \Delta D_t \tag{28}$$

The Public Sector

The central bank's balance sheet is:

$$\Delta M_t^c + \Delta R_t = e_t \Delta \mathcal{Z}_t + \Delta B_{t+1}, \tag{29}$$

where e_t is the nominal exchange rate, $\mathcal{Z}_t$ are international reserves, and B_{t+1} are government securities maturing in the next period and held by the central bank. We assume for simplicity that no interest is earned on international reserves. Different assumptions about aid absorption are characterized by the response of reserves to aid inflows. Assuming that profits of the central bank are transferred to the fiscal agent, the public sector's budget constraint takes the form

$$\Delta B_{t+1} + \Delta B_{t+1}^P = P_t G_t + i_{t-1} B_t^P - T_t - e_t A_t \,, \tag{30}$$

where A_t is aid and B_t^P are bonds issued to the financial sector. We assume that these bonds earn the same rate of interest as household deposits. A

share μ_t of government spending is spent on a productivity-enhancing investment good:

$$G_t = \mu_t G_t^K + (1 - \mu_t) G_t^C. \tag{31}$$

The consolidated budget constraint is then

$$M_t^0 + B_{t+1}^P - e_t Z_t = M_{t-1}^0 + (1 + i_{t-1}) B_t^P - e_t Z_{t-1} + P_t G_t - T_t - e_t A_t, \tag{32}$$

where M_t^0 is base money defined as $M_t^0 = M_t^C = R_t$.

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

$$\begin{aligned} T_t &= T - (1 - \iota)\omega(e_t A_t - eA) \\ P_t G_t &= PG + \iota\omega(e_t A_t - eA), \end{aligned} \tag{33}$$

where ω and ι determine the portion of aid used to reduce taxes and increase expenditure and thus increase the primary fiscal deficit (before grants). An ω less than 1 unambiguously lowers the primary deficit after grants. If ω equals 0, the primary deficit after grants falls by the amount of aid. If ω is between 0 and 1 so that part of the aid is spent, ι determines the allocation of that spending between the private and public sectors. If ι equals 0, the increased spending is carried out by the government, whereas if ι is 1 the increased spending is done by the private sector.

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

$$\begin{aligned} \Delta Z_t = {} & \gamma_1(\bar{Z} - Z_{t-1}) + (1 - \gamma_2\omega)(A_t - A) + \\ & \gamma_3 \log\left(\frac{e_t/e_{t-1}}{\pi/\pi^*}\right) + \gamma_4 \log\left(\frac{\pi_t}{\pi}\right) + u_t^Z, \end{aligned} \tag{34}$$

where γ_1 governs the authorities' commitment to a constant level of reserves, and γ_2 determines the commitment to an absorb-as-you-spend scenario in which the sale of foreign exchange is conducted in line with government

spending increases financed by aid inflows. The commitment to a crawling peg determined by the steady-state inflation differential ($\pi - \pi^*$) between at home and the rest of the world is represented by z_3. Finally, z_4 determines the extent to which the sale of foreign exchange reserves is used to achieve a given target of the inflation rate π , and 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

$$\Delta B_t^P = b_1 e_t \Delta Z_t + b_2 \log(\frac{\pi_t}{\pi}) + b_3(Y_{t-1} - Y) + b_4(B^P - B_{t-1}^P) + u_t^B, \qquad (35)$$

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; $b_4>0$ shows that all bond operations are unwound over time; and $u_t^{B^P}$ is a shock to domestic bonds.

Market Clearing and Aggregation

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

$$Y_t = Q_t^d + Q_t^x$$

$$Z_t = C_t + I_t + G_t + \vartheta_t - \frac{\phi}{2}\left[\frac{P_t^D/P_{t-1}^D}{P_{t-1}^D/P_{t-2}^D} - 1\right]^2 Q_t^d. \qquad (36)$$

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

$$e_t \Delta Z_t = e_t A_t + e_t P_t^x Q_t^x - P_t^m Q_t^m. \qquad (37)$$

Stochastic Shocks

A number of stochastic shocks are included in the model to ensure that the model is not stochastically singular and more capable of reproducing the dynamics in the data. In particular, the number of exogenous shocks must be at least as large as the number of observed variables to allow us 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; a shock to the markup (u_t^θ, 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^{i*}, u_t^{tot}); 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 white noise, all shocks are assumed to follow a first-order process.

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