An Estimated Model with Macrofinancial Linkages for India

Rahul Anand, Shanaka Peiris, and Magnus Saxegaard
Cornell University and International Monetary Fund

Preliminary and Incomplete. Not to be Quoted

September 2009

Abstract

This paper develops a small open economy dynamic stochastic general-equilibrium model with macrofinancial linkages. The model includes a financial accelerator–entrepreneurs are assumed to partially finance investment using domestic and foreign currency debt–to assess the importance of financial frictions in the amplification and propagation of the effects of transitory shocks. We use Bayesian estimation techniques to estimate the model using India data. The model is used to assess the importance of the financial accelerator in India and to assess the optimality of monetary policy.

1 Introduction

The global financial crisis which erupted in September 2008 prompted the most severe economic slowdown of the world economy since the great depression. The crisis also served to highlight the link between financial distress and economic downturns. Evidence reported in a recent World Economic Outlook report (IMF 2008), for example, argues that recessions preceded by a financial crisis tend to be twice as severe in terms of lost output as recessions not preceded by financial distress. Among macroeconomic practitioners, this has prompted renewed interest in the so-called macro-financial linkages and, in particular, the role that balance sheets play in the transmissions of shocks to the economy through their impact on the cost of external finance. In a seminal paper, Bernanke and Gertler (1989) showed that the presence of asymmetric information in credit markets and monitoring costs would make the external finance premium faced by borrowers dependent on their net worth. Moreover, because of the procyclical nature of net worth, this premium would tend to fall during booms and rise during recessions. Bernanke, Gertler, and Gilchrist (1999) (BGG hereafter), Kiyotaki and Moore (1997), Carlstrom and Fuerst (1997), and others have since demonstrated that these financial frictions may significantly amplify both real and nominal shocks to the economy. In the literature, this link between the cost of borrowing and net worth has become know as the "financial accelerator".

Krugman (1999), Aghion, Bacchetta, and Banerjee (2001) and others have argued that exchange rate and interest rate fluctuations–through their effect on balance sheets–are likely to have more serious consequences in emerging market economies that in industrialized countries [check]. A contributing factor to this is–as noted by Elekdag, Justiniano, and Tchakarov (2005)–that emerging market economies who rely on foreign currency borrowing are likely to be particularly affected by the presence of financial accelerator. In particular, the net worth of borrowers in emerging markets are likely to be sensitive to exchange rate fluctuations. In this setting, a depreciation could trigger a deterioration in the balance sheets of borrowers with a negative net open position, thus eroding their net worth and increasing their leverage, thereby increasing the cost of borrowing. In the case of firms, this reduces the demand for capital, which puts downward pressure on the value of firms existing stock of capital and thus their net worth, thereby further increasing the cost of financing. Papers exploring the importance of the financial accelerator for emerging market economies dependent on foreign currency borrowing include Elekdag, Justiniano, and Tchakarov (2005) and Batini, Levine, and Pearlman (2009).

In this paper, we develop and estimate a small open-economy Dynamic Stochastic General Equilibrium (DSGE) model that incorporates the financial accelerator mechanism proposed by BGG in a setting where firms are able to borrow in both domestic and foreign currency. The model is estimated on post-1996 Indian data using Bayesian estimation techniques. As in Christensen and Dib (2006), we also estimate a constrained version of the model in which the financial accelerator is turned off. A comparison of the two models then allows us to evaluate the importance of the financial accelerator mechanism in India. India provides an interesting backdrop for our analysis. One the one hand the sharp increase in corporates' reliance on external financing–including foreign financing–suggests that a financial accelerator might play an important role in the propagation of shocks. On the other hand this is, to our knowledge, the first attempt at estimating a DSGE model for India [1]

Bayesian inference has a number of benefits which are worth highlighting. Firstly, it formalizes the use of prior empirical or theoretical knowledge about the parameters of interest. Secondly, Bayesian inference provides a natural framework for parameterizing and evaluating simple macroeconomic models that are likely to be fundamentally mis-specified. Thus, as pointed out by Fernandez-Villaverde and Rubio-Ramirez (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 regular features of the data. Finally, Bayesian inference provides a simple method for comparing and choosing between different mis-specified models that may not be nested on the basis of the marginal likelihood or the posterior probability of the model. In particular, Geweke (1998) shows that the marginal likelihood is directly related to the predictive performance of the model which provides a natural benchmark for assessing the usefulness of economic models for policy analysis and forecasting.

[Paragraph on main findings to be added]

The rest of this paper is structured as follows: Section 2 provides a brief overview of the Indian economy with a focus on the increasing importance

[1] Other India-specific DSGE models are under development (references to Rahul's work and Batini and Levine's work)

of debt financing– including in foreign currency–as a source of funds for corporates. Section 3 presents the main components of the model. Section 4 briefly describes the data and the estimation methodology before we present the results of the estimation in Section 5. In section 6 we employ the estimated model to analyse the optimality of monetary policy in India before a final section concludes.

2 The Indian Context

To be completed

3 The Model

The model is an expanded version of the small open-economy DSGE model outlined in Saxegaard (2006b). The augmented model features a financial accelerator mechanism similar to proposed by BGG to study the effect of financial frictions on the real economy. The model incorporates financial frictions by assuming that firms have to borrow at a premium over domestic and foreign interest rates to finance part of their capital acquisition cost as in Christensen and Dib (2006), and Gertler, Gilchrist, and Natalucci (2007). Under this framework, information asymmetry between lenders and borrowers creates the financial friction by establishing a link between the cost of borrowing and the financial health of the firms. The external finance premium, in turn, is inversely related to the net worth of the entrepreneurs.

The basic structure of model consists of four kind of agents - households, entrepreneurs, capital producers and retailers. Households consume a composite of domestic and imported goods and provide labor. They have access to foreign capital markets and make deposits which are used by entrepreneurs to purchase capital. Entrepreneurs produce intermediate goods using labor and capital purchased from capital producers. They finance the acquisition of capital partly through their net worth and partly through borrowing domestically and abroad. Entrepreneurs produce intermediate goods under perfect competition and sell their product to retailers who differentiate them at no cost and sell them either in domestic market or export overseas. Retailers operate in a monopolistically competitive environment and face a quadratic adjustment costs in changing prices à la Rotemberg (1982). Capital producers use a combination of the existing capital stock and investment goods purchased from retailers to produce capital. The markets for capital, labor and domestic loans are competitive. The model is completed with a description of the fiscal and monetary authority. Our model differs from BGG in its characterization of monetary policy using a modified Taylor-type rule. We assume that the Reserve Bank of India adjusts short-term interest rates in response to inflation, output, and nominal exchange rate changes.

In order to provide a rationale for monetary stabilization policy, three sources of inefficiency are included in the model: (a) monopolistically competitive retail markets; (b) sluggish price adjustment in retail sector. While relatively simple, the 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 India.

3.1 Household

The economy is populated with a continuum of infinitely lived households with preferences defined over consumption, $C_t(j)$, and labor effort, $L_t(j)$. The objective of the household j is to maximize the expected value of a discounted sum of period utility functions:

$$E_0 \sum_{t=0}^{\infty} \beta^t U\left(C_t(j), L_t(j)\right) \tag{1}$$

$\beta \in (0,1)$ is the consumer subjective discount factor and U is a period utility function. We include habit persistence according to the specification:

$$U\left(C_t(j), L_t(j)\right) = \zeta_{c,t}(1-b)\ln\left(C_t(j) - bC_{t-1}\right) - \frac{\zeta_{L,t}}{\psi} L_t(j)^{\psi} \tag{2}$$

where C_{t-1} is lagged aggregate consumption and $b \in (0,1)$. $\zeta_{c,t}$ and $\zeta_{L,t}$ are preference shocks to the marginal utility of consumption and the supply of labour, respectively. Note that in symmetric steady-state where $C_t(j) = C_{t-1}$, marginal utility of consumption is independent of the habit persistence parameter b. The aggregate consumption bundle,$C_t(j)$, consists of domestically produced goods,$C_{H,t}$, and an imported foreign good, $C_{F,t}$, and is given by:

$$C_t(j) \equiv \left[\alpha^{\frac{1}{\eta}}(C_{H,t}(j))^{\frac{\eta-1}{\eta}} + (1-\alpha)^{\frac{1}{\eta}}(C_{F,t}(j))^{\frac{\eta-1}{\eta}}\right]^{\frac{\eta}{\eta-1}} \tag{3}$$

where $C_{H,t}$ is an index of consumption of domestic goods given by the constant elasticity of substitution (CES) function:

$$C_{H,t}(j) = \left(\int_0^1 C_{H,t}(s)^{\frac{\varepsilon_t-1}{\varepsilon_t}} ds\right)^{\frac{\varepsilon_t}{\varepsilon_t-1}} \tag{4}$$

where $s \in [0,1]$ denotes the variety of the domestic good. The parameter $\eta \in [0,\infty]$ is the elasticity of substitution between domestic and foreign good. The parameter $\varepsilon_t > 1$ is the elasticity of substitution between varieties produced within the country while $\alpha \in [0,1]$ can be interpreted as a measure of the home-bias.

We assume that households have access to foreign financial markets or nominal contingent claims that span all relevant household specific uncertainty about future income and prices, interest rates, exchange rates and so on. As a result each household faces a single intertemporal budget constraint:

$$\begin{aligned} P_tC_t(j) + e_tB_{t+1}(j) + P_t\tau_t + P_td_t(j) &= e_tB_t(j)(1+i^f_{t-1}) + \\ &\int_0^1 \pi_t(s)ds + W_tL_t(j) \\ &+(1+i_{t-1})P_td_{t-1}(j) \end{aligned} \tag{5}$$

where B_t is net holdings of a foreign currency one-period bond that mature in period t paying an interest rate of i^f_{t-1}. Household makes deposit d_t, which earns an interest of i_t. $\int_0^1 \pi_t(s)ds$ represents receipts of the profits from domestic retailers owned by the household in the economy. τ_t is the lump sum tax in the economy and W_t is the nominal wage rate per unit of labor. P_t is the CPI price index given by:

$$P_t \equiv \left[\alpha(P_{H,t})^{1-\eta} + (1-\alpha)(P_{F,t})^{1-\eta}\right]^{\frac{1}{1-\eta}} \tag{6}$$

where $P_{H,t}$ is the domestic price index given by:

$$P_{H,t} = \left[\int_0^{1_t} P_{H,t}(s)^{1-\varepsilon_t} ds\right]^{1/(1-\varepsilon_t)} \tag{7}$$

and $P_{F,t}$ is the price of imported goods.

The household chooses the paths of $\{C_t(j), L_t(j), d_t(j), B_{t+1}(j)\}_{t=0}^{\infty}$ to maximize expected lifetime utility (1) subject to the constraint (5) and initial value of B_0.The consumer's problem can therefore be written as:

$$\max_{C_t, d_t, B_{t+1}, L_t} E_t \sum_{t=0}^{\infty} \beta^t \left\{ \begin{array}{c} U\left(C_t\left(j\right), L_t\left(j\right)\right) \\ -\lambda_t \left[\begin{array}{c} A_{t+1}\left(j\right) + e_t B_{t+1}\left(j\right) - \\ A_t\left(j\right)\left(1+i_{t-1}\right) \\ -e_t B_t\left(j\right)\left(1+i_{t-1}^f\right) + P_t d_t \\ -(1+i_{t-1}) P_t d_{t-1} \\ +P_t \tau_t - W_t L_t\left(j\right) - \\ \int_0^1 \pi_t(s) ds + P_t C_t\left(j\right) \end{array} \right] \end{array} \right\} \tag{8}$$

Ruling out Ponzi type schemes, we get the following first order conditions:

$$\frac{(1-b)\,\zeta_{c,t}}{C_t\left(j\right) - bC_{t-1}} = \lambda_t P_t \tag{9}$$

$$\zeta_{L,t} L_t\left(j\right)^{\psi-1} = \lambda_t W_t \tag{10}$$

[Given the well documented departures from uncovered interest parity (UIP), we follow Kollman (2002) and introduce an exogenous shock into the consumers first-order condition for foreign currency bond holdings]. The first-order conditions for deposits and foreign currency bond holdings are therefore given by:

$$1 = (1+i_t) E_t \left\{ \rho_{t,t+1} \frac{P_t}{P_{t+1}} \right\} \tag{11}$$

$$1 = (1+i_t^f) E_t \left\{ \rho_{t,t+1} \frac{P_t}{P_{t+1}} \frac{e_{t+1}}{e_t} \right\} \tag{12}$$

where $\rho_{t,t+1} = \beta \frac{P_t \lambda_t}{P_{t+1}\lambda_{t+1}} = \frac{\zeta_{c,t}(C_{t+1}(j) - bC_t)}{\zeta_{c,t+1}(C_t(j) - bC_{t-1})}$ is the stochastic discount factor. Up to a log-linear approximation equations (11)and (12) imply $E_t \ln\left(e_{t+1}/e_t\right) \approx i_t - i_t^f$.Thus the optimum allocation of expenditures between domestic and imported goods is given by

$$C_{H,t}(j) = \alpha \left(\frac{P_{H,t}}{P_t}\right)^{-\eta} C_t(j) \tag{13}$$

$$C_{F,t}(j) = (1-\alpha)\left(\frac{P_{F,t}}{P_t}\right)^{-\eta} C_t(j) \tag{14}$$

and the demand for each variety of domestic good is given by:

$$C_{H,t}(s) = \left(\frac{P_{H,t}(s)}{P_t}\right)^{-\varepsilon_t} C_{H,t}(j) \tag{15}$$

For simplicity, we assume that changes in the exchange rate are passed through immediately to the import price so that $P_{F,t} = u_t^{tot} \frac{\varepsilon_t}{(\varepsilon_t - 1)} e_t P_t^*$ where u_t^{tot} is a shock to the terms of trade of the economy.

3.2 Production Sector

3.2.1 Entrepreneurs

We model the behavior of entrepreneurs as proposed by BGG . We follow the modeling framework of Gertler, Gilchrist, and Natalucci (2007) and Elekdag, Justiniano, and Tchakarov (2005) while introducing financial accelerator in an open economy context. Entrepreneurs combine labor, hired from households, and capital, purchased from capital producers, to produce intermediate good in a perfectly competitive setting . They are risk neutral and have a finite horizon for planning purposes. The probability that an entrepreneur will survive until the next period is ν,so the expected live horizon is $\frac{1}{1-\nu}$ [2]. New entrepreneurs enter the market each period equal to the amount that exit, implying a stationary population. To get started, new entrepreneurs receive a small transfer of funds from exiting entrepreneurs.

At the end of each period t, entrepreneurs purchase capital k_{t+1}, to be used in the subsequent period at a price q_t.They finance capital acquisition partly by their net worth available at the end of period t, n_{t+1} , and partly by domestic borrowing and by raising foreign currency denominated debt. Total borrowing, L_t, given by:

$$L_t = q_t K_{t+1} - n_{t+1} \tag{16}$$

where q_t is the real price per unit of capital. The fraction of loan raised domestically, L_t^d is exogenous to the model and is given by ϖ. Thus,

$$L_t^d = \varpi * L_t = \varpi * (q_t K_{t+1} - n_{t+1}) \tag{17}$$

and

[2] This assumption ensures that entrepreneur's net worth (the firm equity) will never be enough to fully finance the new capital acquisition.

$$L_t^f = (1-\varpi) * (q_{t-1}K_t - n_t)) \tag{18}$$

Entrepreneurs use K_t units of capital and L_t units of labor to produce output, Y_t^W, using a constant returns to scale technology:

$$Y_t^W \leq \theta_t K_t^{\psi} L_t^{1-\psi}, \qquad \psi \in (0,1) \tag{19}$$

where θ_t is a stochastic disturbance to total factor productivity. The entrepreneur maximizes profit by choosing K_t and L_t subject to the production function given by eq(19). The first order conditions for this optimization problem are:

$$W_t = (1-\psi) P_{H,t}^W \frac{Y_t^W}{L_t} \tag{20}$$

$$r_{kt} = \frac{P_{H,t}^W}{P_t}(1-\psi)\frac{Y_t^W}{K_t} \tag{21}$$

where $P_{H,t}^W$ is the price of the wholesale good [3]. The expected marginal real return on capital, acquired at the beginning of period t, net of depreciation, over the period, r_t^k is given by:

$$E_t(1+r_{t+1}^k) = E_t\left[\frac{r_{kt+1} + (1-\delta)q_{t+1}}{q_t}\right] \tag{22}$$

Following BGG, we assume that there exists an agency problem which makes external finance more expensive than internal funds. While entrepreneurs costlessly observe their output, which is subject to random outcome, lenders can not verify output outcomes of entrepreneurs costlessly. After observing the outcome, entrepreneurs decide whether to repay their debt or to default. If they default, lenders audit the loan and recover the outcome, less monitoring costs. This agency problem makes loan riskier and thus lenders charge a premium over the risk free rate. Thus, entrepreneur's marginal external financing cost is the product of the gross premium and the gross real opportunity cost of funds (the riskless interest rate) that would arise in the absence of capital market frictions.

[3] Since the firms are perfectly competitive this is equivalent to saying that $P_{H,t}^W = MC_t^W$.

Therefore, expected marginal cost of borrowing, $E_t f_{t+1}$,is given by:

$$E_t f_{t+1} = \Theta\left(\frac{n_{t+1}}{q_t K_{t+1}}\right) E_t\left[\frac{(1+i_t)}{\pi_{t+1}}\right] + \Theta\left(\frac{n_{t+1}}{q_t K_{t+1}}\right) E_t\left[\frac{(1+i_t^f)}{\pi_{t+1}^*}\frac{RER_{t+1}}{RER_t}\right] \tag{23}$$
$$\Theta^{'} < 0 \text{ and } \Theta(1) = 1$$

where Θ is the gross finance premium which depends on the size of the borrower's equity stake in a project (or, alternatively, the borrower's leverage ratio). $\pi_t = \frac{P_t}{P_{t-1}}$, is the gross domestic inflation, $\pi_t^* = \frac{P_t^*}{P_{t-1}^*}$, is the gross world inflation and RER_t is the real exchange rate defined as[4]

$$RER_t = \frac{e_t P_t^*}{P_t} \tag{24}$$

As $\frac{n_{t+1}}{q_t K_{t+1}}$ falls, the entrepreneur relies on uncollateralized borrowing (higher leverage). Since this increases the incentive to misreport the outcome of the project, the loan becomes riskier and the cost of borrowing rises. Entrepreneurs demand for capital depends on the expected marginal return and the expected marginal cost of borrowing. Thus, the entrepreneur's demand for capital satisfies the following optimality condition:

$$\begin{aligned} E_t(1+r_{t+1}^k) &= \Theta\left(\frac{n_{t+1}}{q_t K_{t+1}}\right) E_t\left[\frac{(1+i_t)}{\pi_{t+1}}\right] \\ &+\Theta\left(\frac{n_{t+1}}{q_t K_{t+1}}\right) E_t\left[\frac{(1+i_t^f)}{\pi_{t+1}^*}\frac{RER_{t+1}}{RER_t}\right] \end{aligned} \tag{25}$$

Equation (25) provides the foundation for the financial accelerator. It links entrepreneur's financial position to the marginal cost of funds and, hence, to the demand for capital. Also, movements in the price of capital ,q_t , may have significant effects on the leverage ratio. In this way the model captures the link between asset price movements and collateral stressed in the Kiyotaki and Moore (1997) theory of credit cycles[5]. At the beginning of each period,

[4] We have assumed that law of one price holds for all differentiated goods.

[5] Though the behavior described above is true for an individual entrepreneur, we appeal to the assumptions in BGG that permit us to write it as an aggregate condition. See BGG and Carlstrom and Fuerst (1997) for details. It implies that gross finance premium may be expressed as a function of the aggregate leverage ratio, i.e. it is not entrepreneur specific.

entrepreneurs collect their returns from capital and honor their foreign debt obligations. Aggregate entrepreneurial net worth evolves according to

$$n_{t+1} = \nu V_t + (1-\nu) G_t \tag{26}$$

Where V_t is the net worth of the surviving entrepreneurs carried over from the previous period, $1-\nu$ is the share of new entrepreneurs entering and G_t (which is exogenous in the model) are the transfers from exiting to newly entering entrepreneurs. V_t is given by

$$V_t = \left[\begin{array}{c} \left(1+r_t^k\right) q_{t-1} K_t - \Theta\left(\frac{n_t}{q_{t-1}K_t}\right) \\ \left\{ \left[\frac{(1+i_{t-1})}{\pi_t}\right] (\varpi * (q_{t-1}K_t - n_t)) + \left[\frac{(1+i_{t-1}^f)}{\pi_t^*} \frac{RER_t}{RER_{t-1}}\right] (1-\varpi) * (q_{t-1}K_t - n_t)) \right\} \end{array} \right] \tag{27}$$

As equations (26) and (27) suggest, the principle source of movements in net worth stems from unanticipated movements in returns and borrowing costs. In this regard, unforecastable variations in the asset prices, q_t, is the principle source of fluctuations in $\left(1+r_t^k\right)$. On the cost side, unexpected movements in inflation and exchange rate are the major source of fluctuations in the net worth. An unexpected deflation or depreciation, for example, reduces entrepreneurial net worth, thus enhancing the financial accelerator mechanism. Entrepreneurs going out of business at time t consume and transfer some funds to new entrepreneurs out of the residual equity $(1-\nu)V_t$. Thus the consumption by the entrepreneurs is given by:

$$C_t^e = (1-\nu)(V_t - G_t) \tag{28}$$

3.2.2 Capital Producers

Capital producers combine existing capital stock and a fraction of final goods purchased from retailers as investment goods, I_t, to produce new capital, K_{t+1},sold at the end of period t. We assume that capital producers are subject to quadratic capital adjustment cost. The law of motion for capital is given by

$$K_{t+1} = (1-\delta)K_t + \zeta_{in,t} I_t - \left[\frac{\kappa}{2}\left(\frac{I_t}{K_t} - \delta\right)^2\right] K_t \tag{29}$$

where $\zeta_{I,t}$, is a shock to the marginal efficiency of investment (as in (Greenwood, Hercowitz, and Huffman 1988)). Capital producing firm maximizes expected profits

$$\underset{I_t}{Max} E_t \left\{ q_t \left[I_t - \left(\frac{\kappa}{2} \left(\frac{I_t}{K_t} - \delta \right)^2 \right) K_t \right] - \frac{P_{H,t} I_t}{P_t} \right\} \tag{30}$$

Corresponding first order condition is given by:

$$q_t \left[1 - \kappa \left(\frac{I_t}{K_t} - \delta \right) \right] = \frac{P_{H,t}}{P_t} \tag{31}$$

Quantity and price of capital is determined in the market for capital. Entrepreneurial demand for capital is determined by equation (22), and the supply is given by equation (31).

3.2.3 Retailers

There is a continuum of retailers $s \in [0, 1]$. They purchase wholesale goods at a price equal to the nominal marginal costs, MC_t^W (the marginal cost in the entrepreneurs' sector) [6], and differentiate them at no cost [7]. Then they sell their product in a monopolistically competitive domestic and export market. Final good domestic output, $Y_{H,t}$, is the CES composite of individual retail goods:

$$Y_{H,t} = \left(\int_0^1 Y_{H,t}(s)^{\frac{\varepsilon_t - 1}{\varepsilon_t}} ds \right)^{\frac{\varepsilon_t}{\varepsilon_t - 1}} \tag{32}$$

The corresponding price of the composite consumption good, $P_{H,t}$, is given by eq(7). Domestic households, exiting entrepreneurs, capital producers, and government, and foreign country buy final goods from retailers. In particular the economy wide resource constraint is given by.

$$Y_{H,t} = C_{H,t} + C_{H,t}^e + I_t + G_t + Q_t^x \tag{33}$$

[6] The entreprenuers sell their goods in a perfectly competitive market, so $P_t^W = MC_t^W$.

[7] The retail sector is used only to introduce nominal rigidity into the economy. Since they differentiate goods costlessly, ihe marginal cost of producing final goods is same as MC_t^W.

where Q_t^x is the quantity exported. Given the index , eq(32) that aggregates individual retail goods into final goods, the demand curve facing each retailer is given by

$$Y_{H,t}(s) = \left(\frac{P_{H,t}(s)}{P_t}\right)^{-\varepsilon_t} Y_{H,t} \tag{34}$$

For simplicity we assume that the aggregate export demand function: $Q_t^x = [P_{X,t}/P_t^*]^{-\eta_t}$, $\eta_t > 0$.

Price Setting by Retailers Following Ireland (2001) and Rotemberg (1982), there is sluggish price adjustment to make the intermediate goods pricing decision dynamic. This ensures that monetary policy has real effects on the economy. Following, Julliard, Karam, Laxton, and Pesenti (2004) the cost of price adjustment is related to the change in inflation relative to the past observed inflation rate. This allows for more realistic inflation dynamics in the model with a backward looking term in the solved-out Phillips curve. Hence we assume that firms in the monopolistically competitive sector face an explicit cost of price adjustment given by:

$$\frac{\vartheta}{2}\left[\frac{P_{i,t}(s)/P_{i,t-1}(s)}{P_{i,t}/P_{i,t-1}} - 1\right]^2 \text{ for } i = H, X \tag{35}$$

where $\vartheta \succeq 0$ is the parameter determining the cost of price adjustment relative to last period's price level and last periods inflation, respectively. Following Saxegaard (2006), real profits is given by:

$$\begin{aligned} \pi_t\left[P_{H,t}(s), P_{X,t}(s)\right] &= \left[\frac{P_{H,t}(s)}{P_t} - \frac{MC_t^W}{P_t}\right]\left[\frac{P_{H,t}(s)}{P_{H,t}}\right]^{-\varepsilon_t} Q_t^d \\ &\quad + \left[\frac{e_t P_{X,t}(s)}{P_t} - \frac{MC_t^W}{P_t}\right]\left[\frac{P_{X,t}(s)}{P_{X,t}}/\right]^{-\varepsilon_t} Q_t^x \\ &\quad - \frac{\vartheta}{2}\left[\frac{P_{H,t}(s)/P_{H,t-1}(s)}{P_{H,t}/P_{H,t-1}} - 1\right]^2 \end{aligned} \tag{36}$$

Q_t^d is the total domestic demand and Q_t^x is the total exports. e_t is the nominal exchange rate, expressed as the domestic currency price of foreign currency, so that an increase in e_t implies a depreciation of the domestic currency. Note also that we allow for a shock to the elasticity of substitution between differentiated goods ε_t which determines the size of the markup of intermediate good firms. Alternatively, the shock to ε_t can be interpreted as a cost-push shock of the kind introduced into the New Keynesian model by Clarida, Gali, and Gertler (1999).

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

$$\begin{aligned} P_{H,t} \quad = \quad & \frac{\varepsilon_t}{(\varepsilon_t - 1)} MC_t^W - \frac{\vartheta}{(\varepsilon_t - 1)} \frac{P_t}{Q_t^d} \frac{\Pi_{H,t}}{\Pi_{H,t-1}} \left[\frac{\Pi_{H,t}}{\Pi_{H,t-1}} - 1 \right] \\ & + \frac{\vartheta}{(\varepsilon_t - 1)} P_t E_t \left\{ \rho_{t,t+1} \frac{Q_{t+1}^d}{Q_t^d} \frac{\Pi_{H,t+1}}{\Pi_{H,t}} \left[\frac{\Pi_{H,t+1}}{\Pi_{H,t}} - 1 \right] \left[1 + \frac{Q_t^x}{Q_t^d} \right] \right\} \end{aligned} \tag{37}$$

where we have used the fact that all retailer firms are alike to impose symmetry and where we assume that the law of one price holds in the export market so that $P_{X,t} = P_{H,t}/e_t$. Equation (37) reduces to the well-known result that prices are set as a markup over marginal costs if the cost of price adjustment $\vartheta = 0$. In general however, the goods price will follow a dynamic process and the firm's actual markup will differ from, but gravitate towards, the desired markup. Profits from the retail activity is rebated lump-sum to households (i.e. households are the ultimate owners of retail outlets).

3.3 The Government

The fiscal authority is assumed to purchase an exogenous stream G_t of the final good which is financed by the collection of lump-sum taxes[8]. For simplicity, we do not assume that the fiscal authority has access to domestic or international capital markets. Its period-by-period budget constraint is given by:

$$G_t = \tau_t \tag{38}$$

In choosing a specification for the monetary policy reaction function, we assume a simple Taylor rule time function given by:

$$i_t = \rho_i (i_{t-1}) + (1 - \rho_i) \bar{i} + \rho_\pi \log(\frac{\pi_t}{\bar{\pi}}) + \rho_Y \log(\frac{Y_t}{\bar{Y}}) + \rho_e \log(\frac{e_t}{\bar{e}}) + \zeta_{i,t} \tag{39}$$

[8] We assume for simplicity that government only consumes domestic goods.

where ρ_π, ρ_Y and ρ_e are the weights on inflation, output and nominal exchange rate. Parameter ρ_i captures interest rate smoothing, and where $\bar{i}$ is the steady state interest rate. $\zeta_{i,t}$, is a monetary policy shock to capture unanticipated increase in the nominal interest rate . Equation (39) is essentially a simple Taylor rule with partial adjustment. We interpret this rule as being a form of flexible inflation targeting in the sense of Bernanke and Mishkin (1997).

3.4 Market Clearing and Aggregation

We assume that the total government spending is on domestic goods and also capital producers buy investment goods only domestically. Markets for the wholesale goods clear:

$$Y_t^W = Y_{H,t} \tag{40}$$

where $Y_{H,t}$ is the aggregate final good sold by retailers and is given by eq(32).

The national accounting equation is given by

$$Y_t = C_t + C_t^e + I_t + G_t + Q_t^x - Q_t^m + \frac{\vartheta}{2}\left[\frac{P_{H,t}(s)}{\Pi_{P_{H,t-1}(s)}} - 1\right]^2 \tag{41}$$

where Q_t^m, is the total imports [9].

The model allows for a non-zero holdings of foreign currency bonds by households and foreign currency denominated debt by entrepreneurs. In particular, it is well known (see inter alia Schmitt-Grohe and Uribe (2003)) that unless adjustments are made to the standard model, the steady state of an small open-economy model with foreign currency bonds will depend upon initial conditions and will display dynamics with random walk properties. In particular, if the domestic discount rate exceeds the real rate of return on foreign currency bonds, then domestic holdings of foreign currency bonds will increase perpetually. Beyond the obvious conceptual problems of such an outcome our analysis is constrained by the fact that the available techniques used to solve non-linear business cycle models of the type considered here are only valid locally around a stationary path.

[9] It is given by $(1-\alpha)\left(\frac{P_{F,t}}{P_t}\right)^{-\eta}(C_t + C_t^e)$

Fortunately, a number of modifications to the standard model are available which enable us to overcome this issue. In this paper we follow Schmitt-Grohe and Uribe (2003) and specify a foreign debt elastic risk-premium whereby holders of foreign debt are assumed to face an interest rate that is increasing in the country's net foreign debt. In particular, i_t^f, the interest rate at which households and entrepreneurs can borrow foreign currency equals the exogenous world interest rate plus a spread that is a decreasing function of economy's net foreign asset position:

$$(1+i_t^f) = (1+i_t^*) - \chi_d \left[((B_t + L_t^f)/P_t^* - \vartheta_t) - ((B + L^f)/P^* - \vartheta) \right] / \Omega, \quad \chi_d \succ 0 \tag{42}$$

where χ_d is a parameter which captures the degree of capital mobility in the market for foreign-currency borrowing and lending by households and Ω is the steady-state value of exports. As in Schmitt-Grohe and Uribe (2003) we include the steady-state level of debt so that the risk-premium is nil in steady-state. Note that under perfect capital mobility ($\chi_d = 0$), the country would face an infinite supply or demand of foreign capital and the model would not have well-defined steady state. Kollmann (2002) points out, the model in this case becomes a version of the permanent income theory of consumption, with non-stationary consumption and net assets.

3.5 Specification of the Stochastic Processes

We include a number of shocks 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 ten structural shocks: three shocks to technology and preferences (θ_t, $\zeta_{c,t}$, $\zeta_{l,t}$), two foreign shocks to world interest rates and world inflation (i_t^*, Π_t^*), two shocks to investment and firms markup $\left(\zeta_{in,t}, \upsilon_t\right)$, two policy shocks to monetary policy and government spending $\left(\zeta_{i,t}, G_t\right)$ and a UIP shock $\left(\zeta_{uip,t}\right)$. With the exception of the price markup shock, which is assumed to be a white noise process, all shocks are assumed to follow a first-order autoregressive process.[10]

[10] In addition to our ten structural shocks, we follow the approach adopted in Julliard, Karam, Laxton, and Pesenti (2004) of allowing for measurement errors in the data. The

4 Data and Estimation Strategy

We estimate the model using the Bayesian estimation module in DYNARE Juillard (2001). Bayesian estimation requires construction of the posterior density of the parameters of interest given the data. If we denote the set of parameters to be estimated as θ using observations on a set of variables X, the posterior density can be written as $p(\theta|X)$. The posterior density is thus the probability distribution of θ, conditional on having observed the data X. It forms the basis for inference in the Bayesian framework. Following Bayes law the posterior density is proportional to the product of the prior density of the parameters $p(\theta)$ and the distribution of the data given the parameter set $f(X|\theta)$:

$$p(\theta|X) = \frac{p(\theta) f(X|\theta)}{f(X)} \tag{43}$$

where $f(X)$ is the marginal distribution of the data. The conditional distribution function of the data given the parameter set $f(X|\theta)$ is equivalent to the likelihood function of the set of parameters given the data $L(\theta|X)$ .The likelihood function can be calculated from the state-space representation of the model using the Kalman filter (see Ljungqvist and Sargent (2004) for details). Bayesian inference therefore requires (i) the choice of prior densities for the parameters of interest, and (ii) construction of the posterior from the prior densities and the likelihood function. The remainder of this section discusses briefly how to construct the posterior distribution. The choice of prior is discussed later, together with the estimation results.

Given the likelihood function and a set of prior distributions, an approximation to the posterior mode of the parameters of interest can be calculated using a Laplace approximation. The posterior mode obtained in this way is used as the starting value for the Metropolis-Hastings algorithm (see Bauwens, Lubrano, and Richard (1999) for details). This algorithm allows us to generate draws from the posterior density $p(\theta|X)$. At each iteration, a proposal density (a normal distribution with mean equal to the previously accepted draw) is used to generate a new draw which is accepted as a draw from the posterior density $p(\theta|X)$ with probability p. The probability p depends on the value of the posterior and the proposal density at the candidate draw, relative to the previously accepted draw. We generate 100000 draws in 4 chains in this manner, discarding the first 50000 draws to reduce the

inclusion of measurement errors is discussed in more detail in the next section.

importance of the starting values.

4.1 Data

To estimate the model we use information on 9 key macroeconomic variables for India running from 1996Q2 to 2009Q1: real GDP, real private consumption expenditure, real government expenditure, real investment, real exports, real imports, the real exchange rate, the rate of depreciation of the nominal exchange rate, wholesale price inflation, and the nominal interest rate. The 3-month Treasury Bill rate is used as a proxy of the nominal interest rate and the real effective exchange rate calculated by the IMF is used as proxy for the real exchange rate. With the exception of the real and nominal exchange rates, wholesale price inflation, and the nominal interest rate, all variables are seasonally adjusted using the X12 filter and expressed as deviations from a Hodrick-Prescott time trend. All data are taken from the CEIC database.

4.2 Calibration of Steady-state Parameters

As in Saxegaard (2006a) we calibrate the parameters in the model that determine the steady-state based on findings from previous studies and the data. We then estimate the parameters that determine the dynamic properties of the model away from the steady-state. The list of calibrated parameters include the rate of time preference, β, the depreciation rate of capital, δ, the cost share of capital, ψ, the price elasticity of aggregate non-tradables and imports, η, the price elasticity of exports, ς, the share of non-tradables in the WPI, α, the steady-state markup for retailers, $\varepsilon/(\varepsilon-1)$, in addition to several steady-state ratios which are set so as to replicate the average in the data. The calibrated parameter values and the implied steady-state ratios are summarized in table 1.

The substitution elasticity between imported and domestically produced goods is set at 1.5, close to the value used by Saxegaard (2006a) for the Philippines, while the elasticity of substitution of exports, ς, was set to 2.4, a value consistent with the steady-state export to GDP ratio. With the share of non-tradables in the WPI, α, set at 0.8, this corresponds to a steady-state export to GDP ratio of 19 percent and a steady-state import to GDP ratio of 21 percent. The share of government expenditure in GDP is set at 11 percent as in the data. The steady-state markup factor is set to 9 percent so that $\varepsilon = 12$. The technology parameter ψ is set at 0.33 which is consistent

Table 1: Calibrated Parameters

Parameter	Value	Description
η	1.5	Price elasticity of non-tradables and imports
ς	2.4	Price elasticity of exports
α^d, $1-\alpha^m$	0.8	Share of non-tradables in CPI
$\upsilon/(\upsilon-1)$	1.09	Steady state markup factor for intermediary goods
ψ	0.33	Cost share of capital
δ	0.025	Quarterly depreciation rate of capital
Π	$1.045^{1/4}$	Steady state inflation
$1+i$	$1.07^{1/4}$	Steady state domestic interest rate
Π^*	$1.025^{1/4}$	Steady state inflation
s_g	0.27	Steady state government absorption

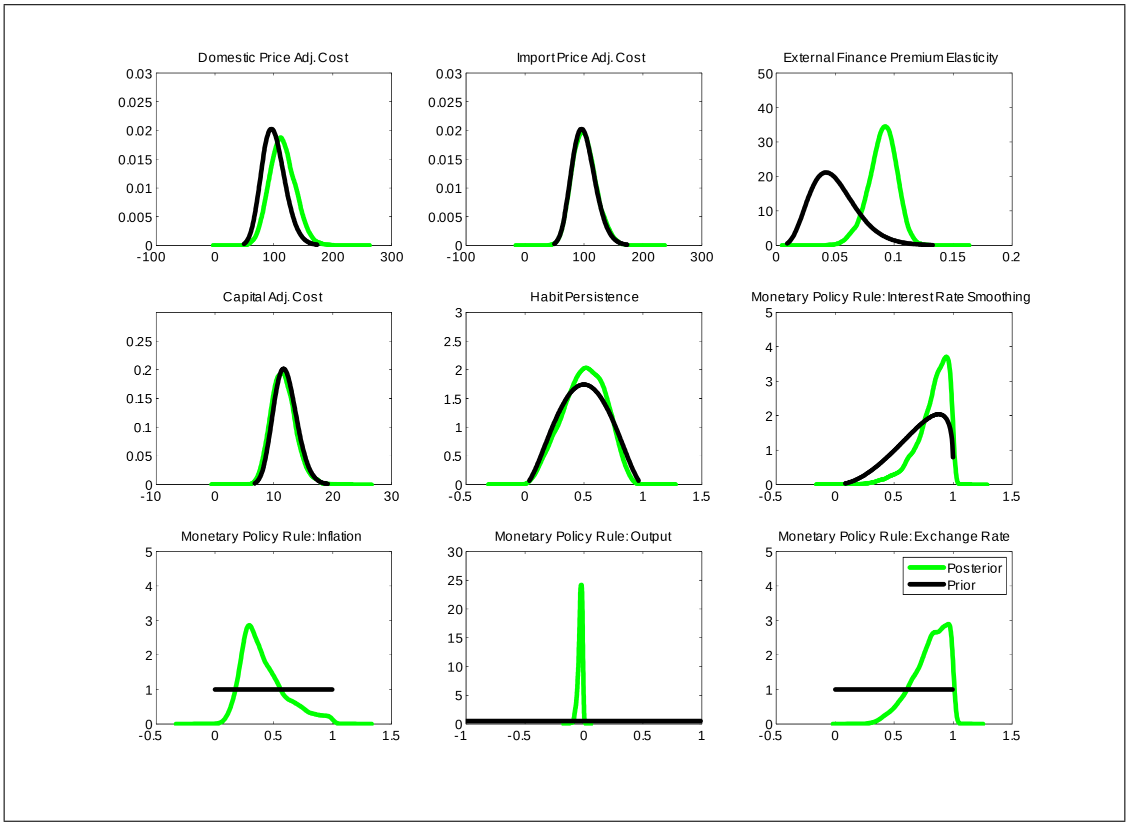
with much of the literature. As in much of the literature, the depreciation rate is set at 10 percent per annum, implying a value of δ of 0.025.

We set the steady-state annual nominal interest rate at 7 percent which corresponds to the annualized average quarterly rate for the period we have data on. Similarly, steady-state inflation was set equal to 4.5 percent which corresponds to the average seasonally adjusted quarterly WPI inflation over the period on an annualized basis. Intertemporal optimization by consumers implies that the subjective discount rate, β, is set equal to 0.994 which is the inverse of the quarterly real steady-state interest rate. We set world inflation equal to 2.5 percent on an annual basis which implies a steady-state depreciation rate of the nominal exchange rate of 2 percent on an annual basis and a world interest rate of 5 percent per annum.

4.3 Prior Distribution of Estimated Parameters

Our choice of prior distributions for the estimated parameters is guided both by theoretical considerations and empirical evidence. Given the lack of significant empirical evidence, however, we choose relatively diffuse priors that cover a wide range of parameter values. For the structural parameters, we choose either *gamma* distributions or *beta* distributions in the case when a parameter–such as the autoregressive shock processes–is restricted by theoretical considerations to lie between zero and one. Given the lack of evidence regarding the policy reaction function of the Reserve Bank of India, we use *uniform* distributions for the parameters of the monetary policy rule. Fi-

Figure 1: Prior and Posterior Distributions



nally, as in much of the literature the inverted *gamma* distribution is used for the standard errors of the shock processes. This distribution guarantees a positive variance but with a large domain. The choice of priors for the parameters to be estimated is summarized in table [to be added].

5 Empirical Results

Table [to be added] reports the estimated posterior model together with the 90 percentile of the posterior distribution. Figure 1 provides a visual representation of this information by plotting the prior and posterior distribution for each parameter that is estimated, together with the posterior mode.

5.1 Cross-validation with alternative models

As suggested by Christensen and Dib (2006) we compare the fit of our model, the Estimated FA model, against an alternative model without a financial accelerator. The alternative model, which we call the Estimated No-FA model, is identical to the FA model with the exception that the parameter that captures the elasticity of the external finance premium with respect to firm leverage is constrained to equal zero. In addition, as suggested by Schorfheide (2000) we compare the fit our estimated model against a less restrictive non-structural reduced for Bayesian vector autogression (BVAR) estimated using the popular Litterman prior (Sims and Zha 1998). This provides a stringent test of the ability of our model to replicate the dynamics in the data and thus of its usefulness as a tool for policy analysis. Indeed, it is partly evidence presented by inter alia Smets and Wouters (2005), Julliard, Karam, Laxton, and Pesenti (2004), and Lubik and Schorfheide (2005) suggesting that empirical DSGE models with a sufficient number of structural shocks compare favorably with BVARs which have prompted the increased interest in DSGE models in policy making.

Bayesian econometrics provides a natural framework for assessing the empirical performance of different mis-specified models. Using Bayes Law again we can write the posterior probability of a model M_i as:

$$p(M_i|X) = \frac{p(M_i)L(M_i|X)}{f(X)}$$

where $p(M_i)$ is the prior belief attached to model i and $L(M_i|X)$ is the likelihood of the model given the data. Bayesian model selection is based on the posterior odds ratio of a particular model M_1 against another model M_2 which is given by:

$$\frac{p(M_1|X)}{p(M_2|X)} = \frac{p(M_1)L(M_1|X)}{p(M_2)L(M_2|X)}$$

where $\frac{L(M_1|X)}{L(M_2|X)}$–the ratio of marginal likelihoods for different models–represents a summary measure of the evidence provided by the data for choosing between two competing models.

Table 2 reports the marginal likelihood of the Estimated FA model, the Estimated No-FA model, and BVARs estimated on the same data set at lags 1 to 4. The higher marginal likelihood in the Estimated FA model relative to the Estimated No-FA Model suggest that the introduction of a financial accelerator mechanism does improve the model's ability to capture the

Table 2: Model Comparison

	Marginal Likelihood
Estimated FA model	1029.83
Estimated No-FA model	1011.26
BVAR(1)	1314.22
BVAR(2)	604.14
BVAR(3)	845.36
BVAR(4)	892.55

movements observed in the data. As in Elekdag, Justiniano, and Tchakarov (2005), however, the Estimated FA model does not compare favorably to a BVAR with one lag although it dominates BVARs with more lags. This is not particularly surprising as the marginal likelihood falls with increasing model complexity and increases with model fit: The improved fit of our Estimated FA model relative to a BVAR with one lag does not compensate for its higher complexity. Nevertheless, the fact that the Estimated FA model outperforms BVARs with more than one lag does provide some evidence in support of the Estimated FA model as a tool of policy analysis.

5.2 Impulse Responses

A useful way to illustrate the dynamics of the estimated model and the importance of the financial accelerator is to consider the impulse response functions of the Estimated FA model and the Estimated No-FA model. The response of some key macroeconomic variables to a 100 bps increase in the nominal interest rate are shown in figure 2 and to a positive technology shock in figure 3.

The increase in the nominal interest rate raises the cost of domestic borrowing for consumers and thus leads to a contraction in consumption. It also raises the demand for domestic bonds and thus appreciates the domestic currency. Output contracts both as a result of decreased domestic demand and a result of decreased competitiveness as a result of the appreciation of the real exchange rate. The contraction in demand in turn leads to a fall in inflation.

In the presence of financial accelerator, high interest rates and low inflation increases the real borrowing cost for entrepreneurs. This puts downward pressure on investment and capital and thus output. Reduced demand for

Figure 2: The Economy's Response to a Tightening Monetary Policy Shock

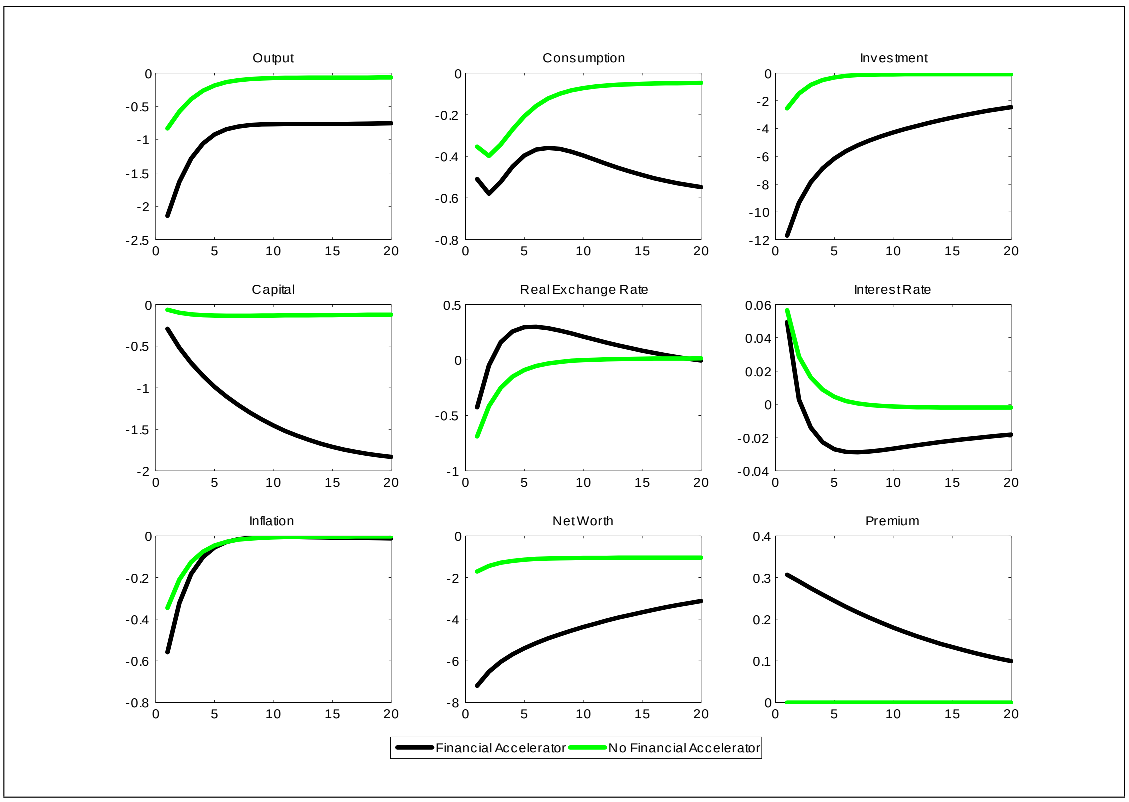
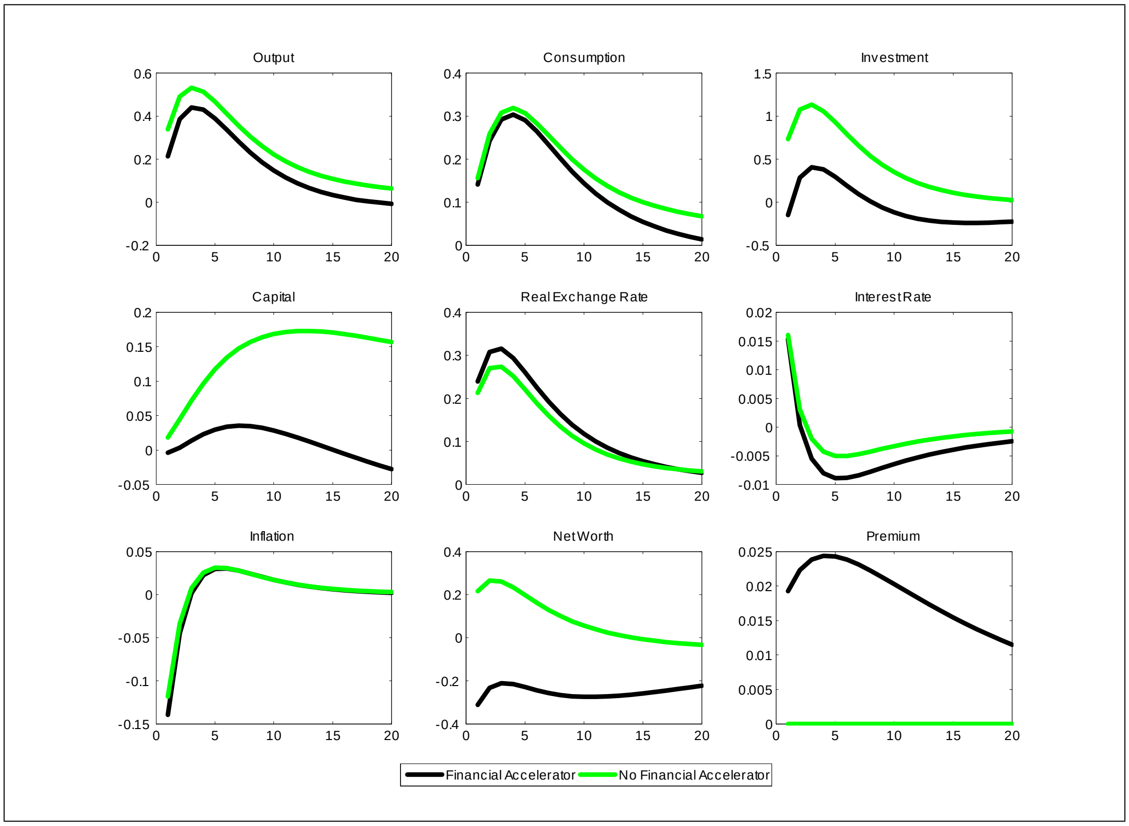


Figure 3: The Economy's Reponse to a Postive Technology Shock



capital also lowers the price of capital, thus reducing the net worth. This reduction in net worth leads to a further increase in the cost of borrowing (premium goes up), thus reducing capital, investment and output further (second round effects). This mechanism amplifies the magnitude and the persistence of transitory monetary policy shock as evident from the impulse responses.

[Discussion of technology shock to be added]

6 Optimal Policy

To be added

7 Concluding Remarks

To be added

References

Aghion, P., P. Bacchetta, and A. Banerjee (2001). Currency crises and monetary policy in an economy with credit constraints. *European Economic Review 47*, 1121–1150.

Batini, N., P. Levine, and J. Pearlman (2009). Monetary and fiscal rules in an emerging small open economy. Working paper WP/09/22, International Monetary Fund.

Bauwens, L., M. Lubrano, and J.-F. Richard (1999). *Bayesian Inference in Dynamic Econometric Models*. Princeton: Oxford University Press.

Bernanke, B. and M. Gertler (1989). Agency costs, net worth, and business fluctuations. *American Economic Review 79*, 14–31.

Bernanke, B., M. Gertler, and S. Gilchrist (1999). The financial accelerator in a quantitative business cycle framework. In *Handbook of Macroeconomics*. Amsterdam: North Holland.

Bernanke, B. S. and F. S. Mishkin (1997, Spring). Inflation targeting: A new framework for monetary policy? *Journal of Economic Perspectives 11*(2), 97–116.

Carlstrom, G. and T. Fuerst (1997). Agency costs, net worth, and business fluctuations. *American Economic Review 87*, 893–910.

Christensen, I. and A. Dib (2006). Monetary policy in an estimated dsge model with a financial accelerator. Technical report.

Clarida, R., J. Gali, and M. Gertler (1999). The science of monetary policy: A new Keynesian perspective. *Journal of Economic Literature XXXVII*.

Elekdag, S., A. Justiniano, and I. Tchakarov (2005). An estimated small open economy model of the financial accelerator. Working paper WP/05/44, International Monetary Fund.

Fernandez-Villaverde, J. and J. Rubio-Ramirez (2004). Comparing dynamic equilibrium models to data: A Bayesian approach. *Journal of Econometrics 123*, 153–187.

Gertler, M., S. Gilchrist, and F. M. Natalucci (2007, 03). External constraints on monetary policy and the financial accelerator. *Journal of Money, Credit and Banking 39*(2-3), 295–330.

Geweke, J. (1998). Using simulation methods for Bayesian econometric models: Inference, development and communication. *Staff Report 249*. Federal Reserve Bank of Minneapolis.

Greenwood, J., Z. Hercowitz, and G. W. Huffman (1988, June). Investment, capacity utilization, and the real business cycle. *American Economic Review 78*(3), 402–17.

IMF (2008, October). *World Economic Outlook*. Washington: International Monetary Fund.

Ireland, P. (2001). Sticky-price models of the business cycle: Specification and stability. *Journal of Monetary Economics 47*, 3–18.

Juillard, M. (2001, April). Dynare: A program for the simulation of rational expectation models. Computing in Economics and Finance 2001 213, Society for Computational Economics.

Julliard, M., P. Karam, D. Laxton, and P. Pesenti (2004). Welfare-based monetary policy rules in an estimated DSGE model of the U.S. economy. mimeo. Federal Reserve Bank of New York.

Kiyotaki, N. and J. Moore (1997, April). Credit cycles. *Journal of Political Economy 105*(2), 211–48.

Kollmann, R. (2002). Monetary policy rules in the open economy: Effects on welfare and business cycles. *Journal of Monetary Economics 49*, 989–1015.

Krugman, P. (1999). Balance sheets, the transfer problem, and financial crises. *International Tax and Public Finance 6*, 459–472.

Ljungqvist, L. and T. J. Sargent (2004, January). *Recursive Macroeconomic Theory, 2nd Edition*, Volume 1 of *MIT Press Books*. The MIT Press.

Lubik, T. and F. Schorfheide (2005). A Bayesian look at new open economy. mimeo.

Rotemberg, J. (1982). Sticky prices in the United States. *Journal of Political Economy 90*, 1187–1211.

Saxegaard, M. (2006a). Fiscal and monetary policy in an estimated model of the philippine economy. Manuscript.

Saxegaard, M. (2006b). Monetary policy rules in a small open economy with external liabilities. Manuscript.

Schmitt-Grohe, S. and M. Uribe (2003). Closing small open economy models. *Journal of International Economics 61*, 163–185.

Schorfheide, F. (2000). Loss function-based evaluation of DSGE models. *Journal of Applied Econometrics 15*, 645–670.

Sims, C. A. and T. Zha (1998, November). Bayesian methods for dynamic multivariate models. *International Economic Review 39*(4), 949–68.

Smets, F. and R. Wouters (2005). Comparing shocks and frictions in U.s. and Euro area business cycles: A Bayesian DSGE approach. *Journal of Applied Econometrics 20(2)*, 161–183.