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An Estimated DSGE Open-Economy Model of the Indian Economy with Financial Frictions

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An Estimated DSGE Open-Economy Model of the Indian Economy with Financial Frictions*

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Abstract

We develop an open-economy DSGE model of the Indian economy and estimate it by Bayesian Maximum Likelihood methods. We build up in stages to a model with a number of features important for emerging economies in general and the Indian economy in particular: a large proportion of credit-constrained consumers, a financial accelerator facing domestic firms seeking to finance their investment, 'liability dollarization' and incomplete exchange rate pass-through. Our estimation results support the inclusion of financial frictions in an otherwise standard small-open economy model. The simulation properties of the estimated model are examined under a generalized inflation targeting Taylor-type interest rate rule with forward and backward-looking components.

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Contents

1 Introduction

Recent episodes of financial turmoil have highlighted the need to understand how large external shocks are propagated in small open economies. This is particularly relevant in emerging market countries, since these economies face additional vulnerabilities in the form of imperfect access to capital markets. These include sudden and sharp reversals of capital inflows (the "sudden stops" highlighted in Calvo (1998)), the inability of firms to borrow in domestic currency only (a phenomenon dubbed "liability dollarization") or the presence of significant monitoring costs in credit markets, thus exacerbating finance premiums faced by borrowers (the "financial accelerator" mechanism).

These features may substantially amplify the effects of large external disturbances to the domestic economy. For example, a depreciation will deteriorate the balance sheets of borrowers relying on foreign currency denominated debt and increase the external finance premium accrued on top of the international interest rate. The ensuing fall in the demand for capital reduces the value of the borrowers' existing capital stock and corresponding net worth, further amplifying the increase in the costs of borrowing and the swings in investment and production.

While there is a substantial body of literature devoted to understanding business cycle dynamics (and financial frictions) in developed economies, research focusing on emerging economies is relatively sparser. Data limitations have often been identified as a cause, but the real challenge is to provide sensible explanations for the markedly distinct observed fluctuations in these economies. In fact, some stylized facts may be pointed out: *i*) output growth tends to be subject to larger swings in developing countries; *ii*) private consumption, relative to income, is substantially more volatile; *iii*) terms of trade and output are strongly positively correlated, while real interest rates and output/net exports display large countercyclicality relative to developed economies; *iv*) capital inflows are subject to dramatic "sudden stops" (see Agenor *et al.* (2000), Aguiar and Gopinath (2007) and Neumeyer and Perri (2005), for example).

By sharing some of these characteristics, India provides a particularly interesting challenge for macroeconomic modelling. From the early 90s, high growth rates were accompanied by a significant wave of trade and financial liberalization, with high-growth and highly-skilled services and exports sectors co-existing with a sizeable informal, low-skilled labour intensive sector. Given the stage of development of India's financial sector, frictions of this nature, affecting both firms and households, may be greatly exacerbated in adverse conditions. Such a scenario implies that policymakers, in their quest for price and financial stability, face extra significant trade-offs when setting monetary conditions in response to shocks. This, in turn, requires careful investigation of the mechanisms that contribute to the propagation and amplification of economic and financial shocks hitting the economy.

Indeed, many emerging economies conduct their monetary and fiscal policy according to the 'three pillars macroeconomic policy framework': a combination of a freely floating exchange rate, an explicit target for inflation over the medium run, and a mechanism that ensures a stable government debt-GDP ratio around a specified long run, but may allow for counter-cyclical adjustments of the fiscal deficit over the business cycle. By contrast, the Reserve Bank of India (henceforth RBI) intervenes in the foreign exchange market to prevent what it regards as excessive volatility of the exchange rate. On the fiscal side, Central Government has a rigid fiscal deficit target of 3% of GDP irrespective of whether the economy is in boom or recession (Shah (2008)). Therefore, understanding these differences and carefully modelling the transmission mechanism of internal and external shocks may be crucial to the assessment and design of stabilization programs and the conduct of economic policies in India.

The move to more flexible exchange rate regimes in emerging open economies has been accompanied by a variety of frameworks to conduct monetary policy, including inflation targeting. Over the next few years, the trend towards adoption of flexible exchange rate regimes, and inflation targeting in particular, is expected to continue. A recent IMF survey of 88 non-industrial countries found that more than half expressed a desire to move to explicit or implicit quantitative inflation targets. While there are undoubtedly countries where inflation targeting may not be a suitable framework, it is a flexible framework that can be adapted to particular needs of non-industrial countries, which face a number of challenges that differ in character or in degree from those faced in industrial economies. Since 2015, the RBI has entered into a formal flexible inflation targeting (FIT) agreement with the Ministry of Finance and is moving towards a FIT regime over the next two years with an explicit target of 4% within a band of $\pm 2\%$. The RBI's proposed stabilization objective combined with the change of its nominal anchor to headline CPI inflation under the FIT framework have strong implications for policy making in the presence of financial frictions. The transmission of monetary policy is stronger through the credit channel to affect asset prices since firms' external premiums are more sensitive to their financial leverage. The financial systems of emerging open markets are more vulnerable to external disturbances, which may be beyond the control of the monetary authorities – this may cause inflation to deviate from its target thus lowering the credibility of the FIT regime without the support from strong financial and monetary institutions (e.g. an effective MPC). Again understanding and modelling the transmission mechanism of the frictions is important for designing policy rules that are robust and can minimise agents' vulnerability to these shocks particularly those arising from international openness.

Gabriel *et al.* (2012), in a closed-economy setting, show that the introduction of financial frictions in the form of liquidity constrained consumers and a financial accelerator mechanism are not only realistic, but also conducive to a better empirical performance. Thus, in this paper we develop both closed and open-economy DSGE models of India as an emerging small open economy (SOE) interacting with the rest of the world and estimate them by Bayesian Maximum Likelihood methods using Dynare. We build up in stages to a model with a number of features important for emerging economies, small open economies in general and the Indian economy in particular: as a combination of producer and local currency pricing for exporters, a large proportion of credit-constrained consumers, a financial accelerator facing domestic firms seeking to finance their investment and 'liability dollarization'.[1]. As mentioned above, this intensifies the exposure of a SOE to internal and external shocks in a manner consistent with the stylized facts listed above. Papers close to ours include Gertler *et al.* (2003), Cespedes *et al.* (2004), Cook (2004), Devereux *et al.* (2006) and Elekdag *et al.* (2005).

Using data on five key macroeconomic variables (output, investment, inflation, nominal interest rates and the real exchange rate), the main purpose of the paper is to ascertain whether or not the data supports the inclusion of these financial frictions in an open-economy framework. We do so by employing Bayesian system estimation techniques, in the vein of Smets and Wouters (2003), Smets and Wouters (2007) and Fernandez-Villaverde and Rubio-Ramirez (2004) (for a survey, see Fernandez-Villaverde, 2009). We then examine the properties of the estimated model under a generalised inflation targeting Taylor-type interest rate rule with forward and backward-looking components.

We take a Bayesian approach for several reasons. First, these procedures, unlike full information maximum likelihood, for example, allow us to use prior information to identify key structural parameters. In addition, the Bayesian methods employed here utilise all the cross-equation restrictions implied by the general equilibrium set-up, which makes estimation more efficient when compared to the partial equilibrium approaches. Moreover, Bayesian estimation and model comparison are consistent even when the models are misspecified, as shown by Fernandez-Villaverde and Rubio-Ramirez (2004). Finally, this framework provides a straightforward method of evaluating the ability of the models in capturing the cyclical features of the data, while allowing for a fully structural approach to analyse the sources of fluctuations in the Indian economy.

The rest of the paper is organized as follows. In Appendix, we describe a baseline New Keynesian (NK) DSGE closed economy model, from which we subsequently build up our model in stages. In Section 2, we develop a standard open economy counterpart to the baseline model. Section 3 then introduces the financial frictions and, in addition, an open economy aspect, namely liability dollarization which outline the novel features that distinguish our SOE model from the standard open economy model. Up to this point the open economy models assume complete exchange rate pass-through. Section 4 relaxes this assumption. Section 5 describes the equilibrium. Section 6 shows the workings of the financial frictions and highlights the precise mechanism thought which the frictions affect the shocks and variables. Section 7 describes our empirical strategy and presents the estimation results. Section 8 studies the empirical applications for India and Section 9 discusses the implications for policy-making. The final section summarises our findings and points directions for further study.

[1]In a parallel paper, Gabriel *et al.* (2012) focuses on a further important feature of emerging economies, informality, but only in a closed-economy model.

2 A Standard Open-Economy NK Model

This is a model built on our baseline closed economy model with producer currency producers in the retail sector and therefore complete exchange rate pass-through. The law of one price therefore applies to each differentiated good. We first set up a model without financial frictions where UIP holds (see Gali (2008)). Then we assume households face a risk premium on international markets leading to a modified UIP condition.

First define composite Dixit-Stiglitz (D-S) consumption and investment indices consisting of home-produced (H) and foreign (F) goods:

$$C_t = \left[\mathrm{w}_C^{\frac{1}{\mu_C}} C_{H,t}^{\frac{\mu_C-1}{\mu_C}} + (1-\mathrm{w}_C)^{\frac{1}{\mu_C}} C_{F,t}^{\frac{\mu_C-1}{\mu_C}} \right]^{\frac{\mu_C}{\mu_C-1}} \tag{1}$$

$$I_t = \left[\mathrm{w}_I^{\frac{1}{\mu_I}} I_{H,t}^{\frac{\mu_I-1}{\mu_I}} + (1-\mathrm{w}_I)^{\frac{1}{\mu_I}} I_{F,t}^{\frac{\mu_I-1}{\mu_I}} \right]^{\frac{\mu_I}{\mu_I-1}} \tag{2}$$

The corresponding D-S price indices are

$$P_{C,t} = \left[\mathrm{w}_C (P_{H,t})^{1-\mu_C} + (1-\mathrm{w}_C)(P_{F,t})^{1-\mu_C} \right]^{\frac{1}{1-\mu_C}} \tag{3}$$

$$P_{I,t} = \left[\mathrm{w}_I (P_{H,t})^{1-\mu_I} + (1-\mathrm{w}_I)(P_{F,t})^{1-\mu_I} \right]^{\frac{1}{1-\mu_I}} \tag{4}$$

Let the proportions of differentiated goods produced in the home and foreign blocs be ν and $1-\nu$ respectively. With each variety produced by one firm and the number households proportional to the number of firm then ν and $1-\nu$ may be considered as measures of the relative size of the two blocs. Weights in the consumption baskets in the two blocs are then defined by

$$\mathrm{w}_C = 1-(1-\nu)(1-\omega_C)\,; \quad \mathrm{w}_C^* = 1-\nu(1-\omega_C^*) \tag{5}$$

In (5), ω_C, $\omega_C^* \in [0,1]$ are a parameters that captures the degree of 'bias' in the two blocs. If $\omega_C = \omega_C^* = 1$ we have $\mathrm{w}_C = \mathrm{w}_C^* = 1$, i.e., autarky, while $\omega_C = \omega_C^* = 0$ gives us the case of perfect integration with $\mathrm{w}_C = \nu$ and $\mathrm{w}_C^* = 1-\nu$, i.e., weights are in proportion to the proportions of goods produced in the two countries. In the limit, as the home country becomes small $\nu \to 0$. Hence $\mathrm{w}_C \to \omega_C$ and $\mathrm{w}_C^* \to 1$. Thus the foreign bloc becomes closed, but as long as there is a degree of home bias and $\omega_C > 0$, the home country continues to consume foreign-produced consumption goods. Exactly the same applies to the investment baskets where we define ω_I and ω_I^* by

$$\mathrm{w}_I = 1-(1-\nu)(1-\omega_I)\,; \quad \mathrm{w}_I^* = 1-\nu(1-\omega_I^*) \tag{6}$$

Then standard intra-temporal optimizing decisions for home consumers and firms lead to

$$
\begin{aligned}
C_{H,t} &= \mathrm{w}_C \left(\frac{P_{H,t}}{P_{C,t}}\right)^{-\mu_C} C_t && (7)\\
C_{F,t} &= (1-\mathrm{w}_C) \left(\frac{P_{F,t}}{P_{C,t}}\right)^{-\mu_C} C_t && (8)\\
I_{H,t} &= \mathrm{w}_I \left(\frac{P_{H,t}}{P_{I,t}}\right)^{-\mu_I} I_t && (9)\\
I_{F,t} &= (1-\mathrm{w}_I) \left(\frac{P_{F,t}}{P_{I,t}}\right)^{-\mu_I} I_t && (10)
\end{aligned}
$$

In the small open economy we take foreign aggregate consumption and investment, denoted by C_t^* and I_t^* respectively, as exogenous processes[2]. Define one real exchange rate as the relative aggregate consumption price $RER_{C,t} \equiv \frac{P_{C,t}^* S_t}{P_{C,t}}$ where S_t is the nominal exchange rate. Similarly define $RER_{I,t} \equiv \frac{P_{I,t}^* S_t}{P_{I,t}}$ for investment. Then foreign counterparts of the above defining demand for the export of the home goods are

$$
\begin{aligned}
C_{H,t}^* &= \mathrm{w}_C^* \left(\frac{P_{H,t}^*}{P_{C,t}^*}\right)^{-\mu_C^*} C_t^* = \mathrm{w}_C^* \left(\frac{P_{H,t}}{P_{C,t} RER_{C,t}}\right)^{-\mu_C^*} C_t^* && (11)\\
I_{H,t}^* &= \mathrm{w}_I^* \left(\frac{P_{H,t}^*}{P_{I,t}^*}\right)^{-\mu_I^*} I_t^* = \mathrm{w}_I^* \left(\frac{P_{H,t}}{P_{I,t} RER_{I,t}}\right)^{-\mu_I^*} I_t^* && (12)
\end{aligned}
$$

where $P_{H,t}^*$, $P_{C,t}^*$ and $P_{I,t}^*$ denote the price of home consumption, aggregate consumption and aggregate investment goods in foreign currency and we have used the law of one price for differentiated good, namely $S_t P_{H,t}^* = P_{H,t}$.

We incorporate financial frictions facing households as in Benigno (2001). There are two non-contingent one-period bonds denominated in the currencies of each bloc with payments in period t, $B_{H,t}$ and $B_{F,t}^*$ respectively in (per capita) aggregate. The prices of these bonds are given by

$$
P_{B,t} = \frac{1}{1+R_{n,t}}; \quad P_{B,t}^* = \frac{1}{(1+R_{n,t}^*)\phi(\frac{S_t B_{F,t}^*}{P_{H,t} Y_t})} \tag{13}
$$

where $\phi(\cdot)$ captures the cost in the form of a risk premium for home households to hold foreign bonds, $B_{F,t}^*$ is the aggregate foreign asset position of the economy denominated in home currency and $P_{H,t} Y_t$ is nominal GDP. We assume $\phi(0) = 0$ and $\phi' < 0$. $R_{n,t}$ and $R_{n,t}^*$ denote the nominal interest rate over the interval $[t, t+1]$.

The representative household must obey a budget constraint:

$$
P_{C,t} C_t + P_{B,t} B_{H,t} + P_{B,t}^* S_t B_{F,t}^* + TL_t = W_t L_t + B_{H,t-1} + S_t B_{F,t-1}^* + \Gamma_t \tag{14}
$$

[2]Aggregate variables such as C_t and C_t^* are aggregates over varieties and in fact per capita measures. Relative total consumption in the two blocs is then given by $\frac{\nu C_t}{(1-\nu) C_t^*}$.

where $P_{C,t}$ is a Dixit-Stiglitz price index defined in (3), W_t is the wage rate, TL_t are lump-sum taxes net of transfers and Γ_t are dividends from ownership of firms. The intertemporal and labour supply decisions of the household are then

$$P_{B,t} = \beta E_t \left[\frac{\Lambda_{C,t+1}}{\Lambda_{C,t}\Pi_{t+1}} \right] \tag{15}$$

$$P^*_{B,t} = \beta E_t \left[\frac{\Lambda_{C,t+1} S_{t+1}}{\Lambda_{C,t}\Pi_{t+1} S_t} \right] \tag{16}$$

$$\frac{W_t}{P_{C,t}} = \frac{\Lambda_{L,t}}{\Lambda_{C,t}} = -\frac{\Lambda_{h,t}}{\Lambda_{C,t}} \tag{17}$$

where

$$\Lambda_{C,t} = (1-\varrho) C_t^{(1-\varrho)(1-\sigma)-1} (1-h_t)^{\varrho(1-\sigma)} \tag{18}$$

$$\lambda_{h,t} = -C_t^{(1-\varrho)(1-\sigma)} \varrho (1-h_t)^{\varrho(1-\sigma)-1} \tag{19}$$

$$\Pi_t \equiv \frac{P_{C,t}}{P_{C,t-1}} \tag{20}$$

Note that now in the open economy Π_t is consumer price inflation.

The retailer's and wholesaler's decisions are as before for the closed economy except Π_t is replaced with domestic price inflation $\Pi_{H,t} \equiv \frac{P_{H,t}}{P_{H,t-1}}$ which differs from consumer price inflation. Equilibrium and Foreign asset accumulation is given by

$$\begin{aligned} Y_t &= C_{H,t} + I_{H,t} + \frac{1-\nu}{\nu} \left[C^*_{H,t} + I^*_{H,t} \right] + G_t \\ &\equiv C_{H,t} + I_{H,t} + EX^*_t + G_t \end{aligned} \tag{21}$$

$$\begin{aligned} EX_t &= \frac{1-\nu}{\nu}(1-\mathrm{w}^*_C) \left(\frac{P_{H,t}}{P_{C,t} RER_{C,t}} \right)^{-\mu^*_C} C^*_t \\ &+ \frac{1-\nu}{\nu}(1-\mathrm{w}^*_I) \left(\frac{P_{H,t}}{P_{I,t} RER_{I,t}} \right)^{-\mu^*_I} I^*_t \end{aligned} \tag{22}$$

$$\frac{S_t}{S_{t-1}} = \frac{RER_{C,t}\,\Pi_t}{RER_{C,t-1}\,\Pi^*_t} \tag{23}$$

$$\frac{\mathcal{T}_t}{\mathcal{T}_{t-1}} = \frac{\Pi_{F,t}}{\Pi_{H,t}} \tag{24}$$

$$RER_{C,t} = \frac{\left[\mathrm{w}^*_C + (1-\mathrm{w}^*_C) \mathcal{T}_t^{\mu^*_C - 1} \right]^{\frac{1}{1-\mu^*_C}}}{\left[1 - \mathrm{w}_C + \mathrm{w}_C \mathcal{T}_t^{\mu_C - 1} \right]^{\frac{1}{1-\mu_C}}} \tag{25}$$

$$RER_{I,t} = \frac{\left[\mathrm{w}^*_I + (1-\mathrm{w}^*_I) \mathcal{T}_t^{\mu^*_I - 1} \right]^{\frac{1}{1-\mu^*_I}}}{\left[1 - \mathrm{w}_I + \mathrm{w}_I \mathcal{T}_t^{\mu_I - 1} \right]^{\frac{1}{1-\mu_I}}} \tag{26}$$

$$\Pi_t = \left[\mathrm{w}(\Pi_{H,t})^{1-\mu_C} + (1-\mathrm{w})(\Pi_{F,t})^{1-\mu_C} \right]^{\frac{1}{1-\mu_C}} \tag{27}$$

$$
\begin{aligned}
\log(1+R_{n,t})/(1+R_n) &= \rho_r \log(1+R_{n,t-1})/(1+R_n) + (1-\rho_r)(\theta_\pi E_t[\log \Pi_{t+1}]/\Pi \\
&+ \theta_s \log S_t/S) + \epsilon_{r,t+1} \qquad (28)
\end{aligned}
$$

For the SOE $\nu \to 0$, $\mathrm{w}_C \to \omega_C$ and $\mathrm{w}_C^* \to 1$; but $\frac{1-\nu}{\nu}(1-\mathrm{w}_C^*) \to 1-\omega_C^*$ so a large 'closed' economy imports consumption goods from the SOE. Similarly $\mathrm{w}_I \to \omega_I$ and $\mathrm{w}_I^* \to 1$; but $\frac{1-\nu}{\nu}(1-\mathrm{w}_I^*) \to 1-\omega_I^*$ and the same applies to investment goods.

The risk-sharing condition, foreign Euler and Fischer equations are

$$
\begin{aligned}
RER_t^r &= \frac{\Lambda_{C,t}^*}{\Lambda_{C,t}} \qquad (29) \\
\frac{1}{1+R_{n,t}^*} &= \beta E_t \left[\frac{\Lambda_{C,t+1}^*}{\Lambda_{C,t}^* \Pi_{t+1}^*} \right] \qquad (30) \\
1+R &= \frac{1+R_{n,t-1}}{1+\Pi_t} \qquad (31) \\
1+R_t^* &= \frac{1+R_{n,t-1}^*}{1+\Pi_t^*} \qquad (32)
\end{aligned}
$$

Then add a risk premium shock in period $t-1$, $\exp(\epsilon_{UIP,t})$ and use (16) and (30) to obtain

$$
\phi\left(\frac{S_t B_{F,t}^*}{P_{H,t} Y_t}\right) \exp(\epsilon_{UIP,t}) E_t \left[\frac{\Lambda_{C,t+1}^*}{\Lambda_{C,t}^* \Pi_{t+1}^*} \right] = E_t \left[\frac{\Lambda_{C,t+1} S_{t+1}}{\Lambda_{C,t} \Pi_{t+1} S_t} \right] \qquad (33)
$$

Noting that $\frac{S_{t+1}}{\Pi_{t+1} S_t} = \frac{S_{t+1} P_t}{P_{t+1} S_t} = \frac{RER_{C,t+1}}{RER_{C,t} \Pi_{t+1}^*}$, and using (29), we then obtain the consumption real exchange rate as

$$
RER_{C,t} = RER_t^d RER_t^r \qquad (34)
$$

where the deviation of the real consumption exchange rate from its risk-sharing value, RER_t^d is given by

$$
E_t \left[\frac{\Lambda_{C,t+1}}{\Lambda_{C,t}} \frac{RER_{t+1}^r}{RER_t^r} \frac{1}{\Pi_{t+1}^*} \left(\frac{1}{\phi(\frac{S_t B_{F,t}^*}{P_{H,t} Y_t}) \exp(\epsilon_{UIP,t})} - \frac{RER_{t+1}^d}{RER_t^d} \right) \right] = 0 \qquad (35)
$$

Current account dynamics are given by

$$
\begin{aligned}
\frac{1}{(1+R_{n,t}^*)\phi(\frac{S_t B_{F,t}^*}{P_{H,t} Y_t})} S_t B_{F,t}^* &= S_t B_{F,t-1}^* + TB_t \qquad (36) \\
\phi(\frac{S_t B_{F,t}^*}{P_{H,t} Y_t}) &= \exp\left(\frac{\phi_B S_t B_{F,t}^*}{P_{H,t} Y_t} \right) \; ; \; \chi_B < 0 \qquad (37) \\
TB_t &= P_{H,t} Y_t - P_{C,t} C_t - P_{I,t} I_t - P_{H,t} G_t \qquad (38)
\end{aligned}
$$

Exogenous shocks are assumed to follow AR(1) processes:

$$\log \frac{A_{t+1}}{A} = \rho_a \log \frac{A_t}{A} + \epsilon_{a,t+1} \tag{39}$$

$$\log \frac{G_{t+1}}{G} = \rho_g \log \frac{G_t}{G} + \epsilon_{g,t+1} \tag{40}$$

$$\log \frac{MS_{t+1}}{MS} = \rho_{ms} \log \frac{MS_t}{MS} + \epsilon_{ms,t+1} \tag{41}$$

$$\log \frac{UIP_{t+1}}{UIP} = \rho_{UIP} \log \frac{UIP_t}{UIP} + \epsilon_{uip,t+1} \tag{42}$$

There are now two ways to close the model. First, as is standard for models of the SOE, we can assume processes for foreign variables $R^*_{n,t}$, Π^*_t, C^*_t, I^*_t and Λ^*_t are exogenous and independent. Then assuming AR(1) processes for these as well the model is closed with

$$\log(1 + R^*_{n,t})/(1 + R^*_n) = \rho^*_r \log(1 + R^*_{n,t-1})/(1 + R^*_n) + \epsilon^*_{r,t+1} \tag{43}$$

$$\log \frac{\Pi^*_{t+1}}{\Pi^*} = \rho^*_\pi \log \frac{\Pi^*_t}{\Pi^*} + \epsilon^*_{\pi,t+1} \tag{44}$$

$$\log \frac{C^*_{t+1}}{C^*} = \rho^*_c \log \frac{C^*_t}{C^*} + \epsilon^*_{c,t+1} \tag{45}$$

$$\log \frac{I^*_{t+1}}{I^*} = \rho^*_I \log \frac{I^*_t}{I^*} + \epsilon^*_{i,t+1} \tag{46}$$

$$\log \frac{\Lambda^*_{t+1}}{\Lambda^*} = \rho^*_\Lambda \log \frac{\Lambda^*_t}{\Lambda^*} + \epsilon^*_{\lambda,t+1} \tag{47}$$

The second more satisfactory approach is to acknowledge that the foreign variables are interdependent and part of a model driven by the same form of shocks and policy rules as for the SOE. This model can be the closed economy baseline model fitted to World or US data.

3 An Open Economy NK Model with Financial Frictions

We now introduce two financial frictions to the SOE: liquidity constrained 'rule of thumb' consumers and a financial accelerator for firms. The inclusion of these features is particularly relevant, not only because it acknowledges powerful transmission mechanisms of shocks in emerging economies, but it also helps to conceptualize and understand events such as the 2008 global financial crisis and subsequent economic slowdown. Carlstrom and Fuerst (1997), Bernanke *et al.* (1999) and Gertler *et al.* (2003), for example, stress the importance of financial frictions in the amplification of both real and nominal shocks to the economy, namely in the form of the financial accelerator, linking the cost of borrowing and firms' net worth.

Consider first the existence of liquidity constrained consumers. Suppose that a proportion λ of consumers are credit constrained and have no income from monopolistic retail firms. They must consume out of wage income and their consumption is given by

$$C_{1,t} = \frac{W_t h_t}{P_t} \tag{48}$$

The remaining Ricardian consumers are modelled as in Appendix A and consume $C_{2,t}$. Total consumption is then

$$C_t = \lambda C_{1,t} + (1-\lambda)C_{2,t} \tag{49}$$

Note that, when taking the model to estimation, we reparameterize and define a now parameter λ_{C_1}, which measures the share of consumption consumed by the liquidity constrained consumers, such that $\lambda_{C_1} = \lambda\frac{C_1}{C} = 1-(1-\lambda)\frac{C_2}{C}$.

This model assumes that Ricardian and liquidity constrained consumers work the same hours h_t. Following Gali *et al.* (2004) we now relax this assumption. Liquidity constrained consumers now choose $C_{1,t}$ and $L_{1,t} = 1 - h_{1,t}$ to maximize $\Lambda_1(C_{1,t}, L_{1,t})$ subject to

$$C_{1,t} = \frac{W_t h_{1,t}}{P_t} \tag{50}$$

The first order conditions are now the same for both types

$$\frac{\Lambda_{L_1,t}}{\Lambda_{C_1,t}} = \frac{\Lambda_{L_2,t}}{\Lambda_{C_2,t}} = \frac{W_t}{P_t} \tag{51}$$

Together with (50) and the functional form $\Lambda_{1,t} = \Lambda(C_{1,t}, L_{1,t}) = \frac{(C_{1,t}^{(1-\varrho)}L_{1,t}^{\varrho})^{1-\sigma}-1}{1-\sigma}$ this leads to the first order condition. for the liquidity constrained consumers

$$\frac{\rho(1-L_{1,t})}{(1-\rho)L_{1,t}} = 1 \quad \Rightarrow \quad L_{1,t} = 1 - h_{1,t} = \rho \tag{52}$$

In other words hours worked by liquidity constrained consumers are constant. Aggregate hours are now

$$h_t = \lambda h_{1,t} + (1-\lambda)h_{2,t} \tag{53}$$

We can model the risk premium rigorously and financial stress by introducing a financial accelerator. The first ingredient of financial frictions in the open economy is liability dollarization. Wholesale firms borrow from home and foreign financial intermediaries in both currencies, with exogenously given proportion[3] of the former given by $\varphi \in [0,1]$, so

[3] We do not attempt to endogenize the decision of firms to partially borrow foreign currency; this lies outside the scope of this paper.

that this expected cost is

$$
\begin{aligned}
& \Theta_t \varphi E_t\left[(1+R_{n,t}) \frac{P_{C,t}}{P_{C,t+1}}\right]+\Theta_t(1-\varphi) E_t\left[(1+R_{n,t}^*) \frac{P_{C,t}^*}{P_{C,t+1}^*} \frac{RER_{C,t+1}}{RER_{C,t}}\right] \\
= \;& \Theta_t\left[\varphi E_t\left[(1+R_{t+1})\right]+(1-\varphi) E_t\left[(1+R_{t+1}^*) \frac{RER_{C,t+1}}{RER_{C,t}}\right]\right] \qquad (54)
\end{aligned}
$$

If $\varphi=1$ or if UIP holds this becomes $(1+\Theta_t)E_t\left[1+R_{t+1}\right]$. In (54), $RER_{C,t} \equiv \frac{P_{C,t}^* S_t}{P_{C,t}}$ is the real exchange rate, $R_t \equiv \left[(1+R_{n,t-1})\frac{P_{t-1}}{P_t}\right]-1$ is the *ex post* real interest rate over $[t-1,t]$ and $\Theta_t \geq 0$ is the external finance premium.

The second ingredient is an external finance premium Θ_t such that when the firm equates the expected return with the expected cost of borrowing we have

$$
E_t[1+R_{k,t+1}]=E_t\left[\Theta_{t+1}\left(\varphi E_t\left[(1+R_{t+1})\right]+(1-\varphi) E_t\left((1+R_{t+1}^*) \frac{RER_{C,t+1}}{RER_{C,t}}\right)\right)\right] \qquad (55)
$$

where

$$
\Theta_t=s\left(\frac{N_t}{Q_{t-1}K_t}\right)^{-\chi} \;;\; s'(\cdot)<0 \qquad (56)
$$

In (56), N_t is net worth and $Q_{t-1}K_t-N_t$ is the external financing requirement. Thus $\frac{Q_{t-1}K_t-N_t}{N_t}$ is the leverage ratio and thus (55) and (56) state that the cost of capital is an increasing function of this ratio. Bernanke *et al.* (1999), in a costly verification model, show that the optimal financial contract between a risk-neutral intermediary and entrepreneur takes the form of a risk premium given by (56). Thus the risk premium is an increasing function of leverage of the firm. Following these authors, in the general equilibrium we ignore monitoring costs.

Assume that entrepreneurs exit with a given probability $1-\xi_e$. Then the net worth accumulates according to

$$
N_{t+1}=\xi_e V_t+(1-\xi_e)D_t^e \qquad (57)
$$

where D_t^e are exogenous transfer, consistent with a balanced growth path steady state, from exiting to newly entering entrepreneurs continuing, and V_t, the net value carried over from the previous period, is given by

$$
V_t = (1+R_{k,t})Q_{t-1}K_t-\Theta_t\left[\varphi(1+R_t)+(1-\varphi)(1+R_t^*)\frac{RER_{C,t}}{RER_{C,t-1}}\right](Q_{t-1}K_t-N_t) \qquad (58)
$$

where $R_{k,t}$ is the *ex post* return given by

$$
1+R_{k,t} = \frac{(1-\alpha)\frac{P_t^W}{P_t}\frac{Y_t^W}{K_t}+(1-\delta)Q_t}{Q_{t-1}} \qquad (59)
$$

Demand for capital is then given by

$$E_t[1 + R_{k,t+1}] \;=\; \frac{E_t\left[(1-\alpha)\frac{P^W_{t+1}}{P_{t+1}}\frac{Y^W_{t+1}}{K_{t+1}} + (1-\delta)Q_{t+1}\right]}{Q_t} \tag{60}$$

Finally, exiting entrepreneurs consume the residual equity so that their consumption

$$C^e_t = \frac{1-\xi_e}{\xi_e} N_t \tag{61}$$

must be added to total consumption. The full model is summarized in Appendices C and D with the closed economy baseline in A and B as a special case[4].

4 Incomplete Exchange Rate Pass-Through

We now provide a more general set-up in which a fixed proportion θ of retailers set export prices $P^{*p}_{H,t}$ in the Home currency (producer currency pricers, PCP) and a proportion $1-\theta$ set export prices $P^{*\ell}_{H,t}$ in the dollars (local currency pricers, LCP). Then the price of exports in foreign currency is given by

$$P^*_{H,t} = \theta P^{*p}_{H,t} + (1-\theta)P^{*\ell}_{H,t} \tag{62}$$

Putting $\theta = 0$ gets us back to the previous model with complete exchange rate pass-through.

4.1 PCP Exporters

Assume that there is a probability of $1-\xi_H$ at each period that the price of each good f is set optimally to $\hat{P}_{H,t}(f)$. If the price is not re-optimized, then it is held constant.[5] For each producer f the objective is at time t to choose $\hat{P}_{H,t}(f)$ to maximize discounted profits

$$E_t \sum_{k=0}^{\infty} \xi_H^k D_{t,t+k} Y_{t+k}(f) \left[\hat{P}_{H,t}(f) - P_{H,t+k}\mathrm{MC}_{t+k}\right]$$

where $D_{t,t+k}$ is the discount factor over the interval $[t, t+k]$, subject to a common[6] downward sloping demand from domestic consumers and foreign importers of elasticity ζ and $MC_t = \frac{P^W_{H,t}}{P_{H,t}}$ are marginal costs. The solution to this is

$$E_t \sum_{k=0}^{\infty} \xi_H^k D_{t,t+k} Y_{t+k}(f) \left[\hat{P}_{Ht}(f) - \frac{\zeta}{(\zeta-1)} P_{H,t+k}\mathrm{MC}_{t+k}\right] = 0 \tag{63}$$

[4] The closed economy model with financial frictions is a special case when $\varphi = 1$.

[5] Thus we can interpret $\frac{1}{1-\xi_H}$ as the average duration for which prices are left unchanged.

[6] Recall that we have imposed a symmetry condition $\zeta = \zeta^*$ at this point; i.e., the elasticity of substitution between differentiated goods produced in any one bloc is the same for consumers in both blocs.

and by the law of large numbers the evolution of the price index is given by

$$P_{H,t+1}^{1-\zeta} = \xi_H \left(P_{H,t}\right)^{1-\zeta} + (1-\xi_H)(\hat{P}_{H,t+1}(f))^{1-\zeta} \tag{64}$$

Monopolistic profits as a proportion of GDP are given by

$$\frac{\Gamma_t}{P_{H,t}Y_t} \equiv \frac{P_{H,t}Y_t - P_{H,t}^W Y_t^W}{P_{H,t}Y_t} = 1 - \mathrm{MC}_t\left(1+\frac{F}{Y}\right) \tag{65}$$

For good f imported by the home country from PCP foreign firms the price $P_{F,t}^p(f)$, set by retailers, is given by $P_{F,t}^p(f) = S_t P_{F,t}^*(f)$. Similarly $P_{H,t}^{*\,p}(f) = \frac{P_{H,t}(f)}{S_t}$.

4.2 LCP Exporters

Price setting in export markets by domestic LCP exporters follows is a very similar fashion to domestic pricing. The optimal price in units of domestic currency is $\hat{P}_{H,t}^{*\,\ell} S_t$, costs are as for domestically marketed goods so (63) and (64) become

$$E_t \sum_{k=0}^{\infty} \xi_H^k D_{t,t+k} Y_{t+k}^*(f)\left[\hat{P}_{H,t}(f)^{*\,\ell} S_{t+k} - \frac{\zeta}{(\zeta-1)} P_{H,t+k}\mathrm{MC}_{t+k}\right] = 0 \tag{66}$$

and by the law of large numbers the evolution of the price index is given by

$$(P_{H,t+1}^{*\,\ell})^{1-\zeta} = \xi_H (P_{H,t}^{*\,\ell})^{1-\zeta} + (1-\xi_H)(\hat{P}_{H,t+1}^{*\,\ell}(f))^{1-\zeta} \tag{67}$$

Foreign exporters from the large ROW bloc are PCPers so we have

$$P_{F,t} = S_t P_{F,t}^* \tag{68}$$

Table 1 summarizes the notation used. To obtain the non-linear dynamics for LCPers,

Origin of Good	Domestic Market	Export Market (PCP)	Export Market(LCP)
Home	P_H	$P_H^{*\,p} = \frac{P_H}{S_t}$	$P_H^{*\,\ell} \neq \frac{P_H}{S_t}$
Foreign	P_F^*	$P_F^p = S_t P_F^*$	non-existent

Table 1: Calibrated Parameters

rewrite (66) as

$$E_t \sum_{k=0}^{\infty} \xi_H^k D_{t,t+k} Y_{t+k}^*(f) S_{t+k}\left[\hat{P}_{H,t}(f)^{*\,\ell} - \frac{\zeta}{(\zeta-1)} P_{H,t+k}^{*\,\ell}\mathrm{MC}_{t+k}^{\ell}\right] = 0 \tag{69}$$

where

$$MC_t^{\ell} \equiv \frac{MC_t\, P_{H,t}}{S_t P_{H,t}^{*\,\ell}} \tag{70}$$

As before define the terms of trade for the home bloc (import/export prices in one currency) as $\mathcal{T}_t \equiv \frac{P_{F,t}}{P_{H,t}}$. Define the terms of trade for the foreign bloc as $\mathcal{T}_t^* \equiv \frac{P_{H,t}^*}{P_{F,t}^*}$. With PCPers only the law of one price holds and $\mathcal{T}_t^* = \frac{S_t P_{H,t}^*}{S_t P_{F,t}^*} = \frac{P_{H,t}}{P_{F,t}} = \frac{1}{\mathcal{T}_t}$, but with LCPers this no longer is the case. Now we have that

$$\mathcal{T}_t^* \equiv \frac{P_{H,t}^*}{P_{F,t}^*} = \frac{\theta P_{H,t}^{*p} + (1-\theta)P_{H,t}^{*\ell}}{P_{F,t}^*} = \frac{\theta \frac{P_{H,t}}{S_t} + (1-\theta)P_{H,t}^{*\ell}}{\frac{P_{F,t}}{S_t}} \tag{71}$$

It follows that

$$\mathcal{T}_t \mathcal{T}_t^* = \theta + (1-\theta)\frac{S_t P_{H,t}^{*\ell}}{P_{H,t}} \tag{72}$$

and hence from (70) and (72)

$$MC_t^\ell = \frac{(1-\theta)MC_t}{\mathcal{T}_t \mathcal{T}_t^* - \theta} \tag{73}$$

The system is completed with

$$\Pi_{H,t}^* = \theta \Pi_{H,t}^{*p} + (1-\theta)\Pi_{H,t}^{*\ell} \tag{74}$$

From $S_t P_{H,t}^{*p} = P_{H,t}$ and $RER_t \equiv \frac{S_t P_t^*}{P_t}$ we have that

$$\Pi_{H,t}^{*p} = \frac{RER_{t-1}\Pi_{H,t}\Pi_t^*}{RER_t \Pi_t} \tag{75}$$

Exporters from the foreign bloc are PCPers so $S_t P_{F,t}^* = P_{F,t}$. Therefore by analogy with (75) we have

$$\Pi_{F,t} = \frac{RER_t}{RER_{t-1}}\frac{\Pi_t}{\Pi_t^*}\Pi_{F,t}^* \tag{76}$$

and

$$\Pi_t = \left[\mathrm{w}(\Pi_{H,t})^{1-\mu} + (1-\mathrm{w})(\Pi_{F,t})^{1-\mu}\right]^{\frac{1}{1-\mu}} \tag{77}$$

From the definitions of $\mathcal{T}_t$ and $\mathcal{T}_t^*$ we have that

$$\begin{aligned}
\frac{\mathcal{T}_t}{\mathcal{T}_{t-1}} &= \frac{\Pi_{F,t}}{\Pi_{H,t}} && (78)\\
\frac{\mathcal{T}_t^*}{\mathcal{T}_{t-1}^*} &= \frac{\Pi_{H,t}^*}{\Pi_{F,t}^*} && (79)\\
H_t^\ell - \xi_H \beta E_t[(\Pi_{H,t+1}^{*\ell})^{\zeta-1} H_{t+1}^\ell] &= Y_t^* S_t U_{C,t} && (80)\\
J_t^\ell - \xi_H \beta E_t[(\Pi_{H,t+1}^{*\ell})^{\zeta} J_{t+1}^\ell] &= \frac{1}{1-\frac{1}{\zeta}} MS_t Y_t^* S_t U_{C,t} MC_t^\ell && (81)\\
1 &= \xi_H (\Pi_{H,t}^{*\ell})^{\zeta-1} + (1-\xi_H)\left(\frac{J_t^\ell}{H_t^\ell}\right)^{1-\zeta} && (82)
\end{aligned}$$

Equations (73) – (82) give us the new equations to describe imperfect exchange rate pass-though. As $\theta \to 1$ we get back to the previous model with complete exchange rate pass-through.

5 The Equilibrium, Fiscal Policy and Foreign Asset Accumulation

In equilibrium, goods markets, money markets and the bond market all clear. Equating the supply and demand of the home consumer good and assuming that government expenditure, taken as exogenous, goes exclusively on home goods, we obtain[7]

$$Y_t = C_{H,t} + C^e_{H,t} + I_{H,t} + \frac{1-\nu}{\nu}\left[C^*_{H,t} + C^{e*}_{H,t} + I^*_{H,t}\right] + G_t \tag{83}$$

Fiscal policy is rudimentary: a balanced government budget constraint given by

$$P_{H,t}G_t = T_t + M_{H,t} - M_{H,t-1} \tag{84}$$

Adjustments to the taxes, T_t, in response to shocks to government spending away from the steady state are assumed to be non-distortionary.

Let $\sum_{h=1}^{\nu} B_{F,t}(h) = \nu B_{F,t}$ be the net holdings by the household sector of foreign bonds. Summing over the household budget constraints (including entrepreneurs and capital producers), noting that net holdings of domestic bonds are zero (since home bonds are not held by foreign households) and subtracting (84), we arrive at the accumulation of net foreign assets:

$$\begin{aligned} P^*_{B,t}S_tB_{F,t} + S_tM_{F,t} &= S_tB_{F,t-1} + S_tM_{F,t-1} + W_tL_t + \Gamma_t + (1-\xi_e)P_tV_t \\ &+ P_tQ_t(1-S(X_t))I_t - P_tC_t - P_tC^e_t - P_{I,t}I_t - P_{H,t}G_t \\ &\equiv S_tB_{F,t-1} + S_tM_{F,t-1} + TB_t \end{aligned} \tag{85}$$

where the trade balance, TB_t, is given by the national accounting identity

$$P_{H,t}Y_t = P_tC_t + P_tC^e_t + P_{I,t}I_t + P_{H,t}G_t + TB_t \tag{86}$$

This completes the model. Given nominal interest rates $R_{n,t}, R^*_{n,t}$ the money supply is fixed by the central banks to accommodate money demand. By Walras' Law, we can dispense with the bond market equilibrium condition. Then the equilibrium is defined at $t = 0$ as stochastic sequences C_t, C^e_t, $C_{H,t}$, $C_{F,t}$, $P_{H,t}$, $P_{F,t}$, P_t, $M_{H,t}$, $M_{F,t}$, $B_{H,t}$, $B_{F,t}$, W_t, Y_t, L_t, $P^0_{H,t}$, P^I_t, K_t, I_t, Q_t, V_t, foreign counterparts C^*_t, etc, RER_t, and S_t, given the monetary instruments $R_{n,t}$, $R^*_{n,t}$ and exogenous processes.

[7] Note that all aggregates, Y_t, $C_{H,t}$, etc. are expressed in per capita (household) terms.

6 The Workings of the Financial Frictions

The SOE model makes explicit the operating mechanism of liability dollarization. This feature increases the susceptibility to external shocks since a potential depreciation can substantially inflate debt service costs, due to currency mismatches (i.e. debts are denominated in foreign currency when the value of production is denominated in domestic currency), and thus increase rollover risk. In other words, borrowers in this model may find that both interest and exchange rate fluctuations have large effect on their real net worth positions (see (57) and (58)), and so, through balance sheet constraints that affect investment spending, have much more serious macroeconomic consequences than for richer industrial economics.

To understand the precise mechanism through which the various financial frictions and dollarization magnify the shocks, and affect the other variables in the economy, we need first to take a step back and illustrate some of the mechanisms driving the real exchange rate, and the behaviour of net worth of the wholesale firms sector. Solving forward in time linearization of the modified UIP condition it is straightforward to see that the real exchange rate is a sum of future expected real interest rate differentials with the ROW plus a term proportional to the sum of future expected net liabilities plus a sum of expected future shocks, $\epsilon_{UIP,t}$. The real exchange will depreciate if the sum of expected future interest rate differentials are positive and/or the sum of expected future net liabilities are positive and/or a positive shock to the risk premium, $\epsilon_{UIP,t}$, occurs.

Also crucial to the understanding of the effects of the financial accelerator and liability dollarization is the behaviour of the net worth of the wholesale sector. Again in (58) we can see that net worth increases with the *ex post* return on capital, and and decreases with the financial accelerator risk premium and the *ex post* costs of capital in home currency and dollars: $\varphi(1 + R_t) + (1 - \varphi)(1 + R_t^*)\frac{RER_{C,t}}{RER_{C,t-1}}$. Note that $\frac{RER_{C,t}}{RER_{C,t-1}}$ is the real depreciation of the home currency, so net worth falls if Tobins Q falls and if some borrowing is in dollars ($\varphi < 1$). We see also that a *depreciation* of the real exchange rate brings about a further drop in net worth. However, an *appreciation* of the real exchange rate will offset the drop in net worth. Output falls through two channels: first, a drop in Tobins Q and a subsequent fall in investment demand and, second, through a reduction in consumption by entrepreneurs. For the analysis in the following sections, we parameterize the model according to two alternatives, Model no FF as the baseline open economy model (no frictions/dollarization) and Model FF that includes all the financial frictions discussed above and liability dollarization, assuming that firms borrow a fraction of their financing requirements $1 - \varphi \in [0, 1]$ in dollars.

7 Posterior Estimation

We now present estimates of the model variants for the Indian economy. We linearize about a zero inflation balanced growth steady state. Next, we briefly describe the estimation methods used in this section.

7.1 Bayesian Methods

Bayesian estimation entails obtaining the posterior distribution of the model's parameters, say θ, conditional on the data. Using Bayes' theorem, the posterior distribution is obtained as:

$$p(\theta|Y^T) = \frac{L(Y^T|\theta)p(\theta)}{\int L(Y^T|\theta)p(\theta)d\theta} \tag{87}$$

where $p(\theta)$ denotes the prior density of the parameter vector θ, $L(Y^T|\theta/)$ is the likelihood of the sample Y^T with T observations (evaluated with the Kalman filter) and $\int L(Y^T|\theta)p(\theta)$ is the marginal likelihood. Since there is no closed form analytical expression for the posterior, this must be simulated.

One of the main advantages of adopting a Bayesian approach is that it facilitates a formal comparison of different models through their posterior marginal likelihoods, computed using the Geweke (1999) modified harmonic-mean estimator. For a given model $m_i \in M$ and common data set, the marginal likelihood is obtained by integrating out vector θ,

$$L\left(Y^T|m_i\right) = \int_\Theta L\left(Y^T|\theta, m_i\right) p\left(\theta|m_i\right) d\theta \tag{88}$$

where $p_i\left(\theta|m_i\right)$ is the prior density for model m_i, and $L\left(Y^T|m_i\right)$ is the data density for model m_i given parameter vector θ. To compare models (say, m_i and m_j) we calculate the posterior odds ratio which is the ratio of their posterior model probabilities (or Bayes Factor when the prior odds ratio, $\frac{p(m_i)}{p(m_j)}$, is set to unity):

$$PO_{i,j} = \frac{p(m_i|Y^T)}{p(m_j|Y^T)} = \frac{L(Y^T|m_i)p(m_i)}{L(Y^T|m_j)p(m_j)} \tag{89}$$

$$BF_{i,j} = \frac{L(Y^T|m_i)}{L(Y^T|m_j)} = \frac{\exp(LL(Y^T|m_i))}{\exp(LL(Y^T|m_j))} \tag{90}$$

in terms of the log-likelihoods. Components (89) and (90) provide a framework for comparing alternative and potentially misspecified models based on their marginal likelihood. Such comparisons are important in the assessment of rival models, as the model which attains the highest odds outperforms its rivals and is therefore favoured.

Given Bayes factors, we can easily compute the model probabilities $p_1, p_2, \cdots, p_n$ for n models. Since $\sum_{i=1}^n p_i = 1$ we have that $\frac{1}{p_1} = \sum_{i=2}^n BF_{i,1}$, from which p_1 is obtained. Then $p_i = p_1 BF(i, 1)$ gives the remaining model probabilities.

7.2 Data, Priors and Calibration

To estimate the system, we use five macroeconomic observables at quarterly frequency. We use measures of real GDP, real investment, the inflation rate, the nominal interest rate and the real exchange rate. All data are taken from the International Financial Statistics and RBI database and the sample period is 1996:1-2008:4. The inflation rate is calculated on the Wholesale Price Index (WPI), which includes food, fuel and manufacturing indices.[8] The interest rate is measured by the 91-day Treasury Bill rate, in order to capture the combined effect of the RBI policy rates and liquidity changes brought about by the Bank sterilization interventions (see Bhattacharya *et al.* (2010)). A time series for investment is only available at the annual frequency. Thus, we use the interpolation techniques suggested by Litterman (1983) to obtain quarterly data based on the Index of Industrial Production (IIP) for capital goods.[9] For GDP, data is available from 1996:4 onwards, so we interpolate the first few initial periods from annual data, using the IIP. Finally, We use the trade-weighted real effective exchange rate as a proxy for the real exchange rate.

Since the variables in the model are measured as deviations from a constant steady state, the GDP and investment series are de-trended against a linear quadratic trend in order to obtain approximately stationary data.[10] Real variables are measured in logarithmic deviations from the respective trends, in percentage points, while inflation and the nominal interest rate are demeaned and expressed as quarterly rates. The corresponding measurement equations for model are:

$$\begin{bmatrix} GDP_t \\ INV_t \\ log(WPI_t - WPI_{t-1}) \\ TBill_t/4 \\ REER_t \end{bmatrix} = \begin{bmatrix} log\left(\frac{Y_t}{Y}\right) \\ log\left(\frac{I_t}{I}\right) \\ log\left(\frac{\Pi_t}{\Pi}\right) \\ log\left(\frac{1+R_{n,t}}{1+R_n}\right) \\ log\left(\frac{REER_t}{REER}\right) \end{bmatrix} \tag{91}$$

In order to implement Bayesian estimation, it is first necessary to define prior distributions for the parameters. A few structural parameters are kept fixed in the estimation procedure, in accordance with the usual practice in the literature (see Table 2). This is done so that the calibrated parameters reflect steady state values of the observed variables. For instance, β is set at 0.9823, corresponding to an interest rate of 7% (matching its sample mean), while $\delta = 0.025$ is a common choice for the depreciation rate. In turn, the

[8]The WPI rather than the CPI was officially used by the RBI until 2014 (i.e. at the time we produced the paper), mainly because it was the broader measure and there were four different CPI measures, depending on the type of worker.

[9]The Bayesian system estimation techniques used in our study can easily handle variables measured with imprecision, by introducing stochastic measurement errors. Exploratory analysis revealed that measurement errors are a negligible source of uncertainty in our estimated models and we therefore focus on estimation results without measurement errors.

[10]Employing the Hodrick-Prescott filter instead delivers time series with similar behaviour and estimation results are qualitatively, and quantitatively, very close.

investment adjustment cost parameter ϕ_X is set at 2.

Calibrated parameter	Symbol	Value for India
Discount factor	β	0.9863
Depreciation rate	δ	0.069
Risk premium - scaling	k_B	1.00
Financial accelerator risk premium	Θ	1.01
Imported investment share	is_{import}	0.15
Imported consumption share	cs_{import}	0.10
Exported investment share	is_{export}	0.02
Exported consumption share	cs_{export}	0.23

Table 2: Calibrated Parameters

The choice of priors for the estimated parameters is usually determined by the theoretical implications of the model and evidence from previous studies. However, as noted in the introduction, estimated DSGE models for emerging economies, and India in particular, are scarce, though one might infer potential priors by comparing the features and stylized facts of developed and developing economies. In most cases, we use the same priors used in our earlier study (see (Gabriel *et al.*, 2012)).

In general, inverse gamma distributions are used as priors when non-negativity constraints are necessary, and beta distributions for fractions or probabilities. Normal distributions are used when more informative priors seem to be necessary. In some cases, we use same prior means as in previous studies (Levin *et al.* (2006), Smets and Wouters (2003) and Smets and Wouters (2007), for example), but choose larger standard deviations, thus imposing less informative priors and allowing for the data to determine the parameters' location. The first four columns of Table 3 provide an overview of the priors used for each model variant. For consistency and comparability, all priors are the same across different specifications.

The risk aversion parameter σ allows significant room for manoeuvre, with a normal prior defined with a mean of 2 and standard deviation of 0.5. The beta prior density for ϱ is centred in the midpoint of the unit interval with a standard deviation of 0.2, while the Calvo-pricing parameter ξ has a mean of 0.75 and standard deviation of 0.1 as in Smets and Wouters (2007), implying a contract length of 4 quarters. The labour share α has a normal prior with mean 0.8 (approximately its steady state value[11]), while ζ has a mean of 7 with a standard deviation of 0.5.

For the policy parameters, priors were chosen so that a large domain is covered, reflecting the lack of knowledge of the RBI reaction function. We choose beta distributions for the parameters that should be constrained between 0 and 1, namely the smoothing coefficient

[11] We chose not to calibrate α to its steady state value and instead freely estimate this parameter. The proximity of the estimated values for α will provide additional indications regarding the quality of the fit for each model.

ρ (centred around 0.75 with a standard deviation of 0.1) and the forward-backward looking parameters φ and τ, with a mean of 0.5 and a standard deviation of 0.2, a relatively diffuse prior. The feedback parameters θ and ϕ have normal priors with a mean of 2 and a standard error of 1, thus covering a relatively large parameter space.

The shock processes are the likeliest elements to differ from previous studies based on the developing economies. Adolfson *et al.* (2008), for example, argue for choosing larger prior means for shock processes when analyzing a small open developed economy (Sweden). In the case of India, it is natural to expect significantly larger swings in the macro observables and the prior means for the standard errors are therefore set at 3 (3.5 for the risk premium shock, higher than the US), using an inverse gamma distribution.

7.3 Posterior Estimates

The joint posterior distribution of the estimated parameters is obtained in two steps. First, the posterior mode and the Hessian matrix are obtained via standard numerical optimization routines. The Hessian matrix is then used in the Metropolis-Hastings algorithm to generate a sample from the posterior distribution. Two parallel chains are used in the MCMC-MH algorithm and in all the estimations reported in this paper, the univariate diagnostic statistics produced by Dynare indicate convergence by comparing between and within moments of multiple chains (Brooks and Gelman (1998)).

Thus, 100,000 random draws (though the first 30% 'burn-in' observations are discarded) from the posterior density are obtained via the MCMC-Metropolis Hastings algorithm (MH), with the variance-covariance matrix of the perturbation term in the algorithm being adjusted in order to obtain reasonable acceptance rates (between 20%-30%).[12] Table 3, reports posterior means of all estimated parameters, along with the approximate 95% confidence intervals based on the approximate posterior standard deviation obtained from the inverse Hessian at the posterior mode.

Table 3 reports the estimation results for the standard SOE with no financial frictions (No FF) and for a model incorporating a financial accelerator mechanism and liability dollarization (FF), assuming a policy rule that feedbacks on inflation and the nominal exchange rate (Equation (28)). In this rule the responses to both inflation deviations and exchange rate movements are direct, reflecting an open-economy interest rate rule that predominantly tracks variability of the two potential targets, as we discussed in Section 1[13]. The two bottom lines of Table 3 report the log marginal likelihood of the two models under study. A striking result is the substantial improvement in fit achieved by the model with financial frictions over the simpler SOE model. Indeed, the difference in the log likelihoods is remarkable, lending unequivocal support to the FF model.

The posterior estimates and confidence intervals for the two models are presented in the

[12] See Schorfheide (2000) for more details.

[13] Mallick (2011)) estimates a structural VAR with the exchange rate and provides evidence of exchange rate targeting by the RBI.

Parameter	Notation	Prior distribution			Posterior distribution$^{\diamond}$	
		Density	Mean	S.D/df	No FF	FF
Investment adjustment	ϕ_i	Normal	4.00	1.50	3.50 [1.60:5.47]	3.89 [1.71:5.84]
Risk aversion	σ	Normal	2.00	0.50	2.27 [1.53:2.96]	2.25 [1.19:3.08]
Consumption habit	h_C	Beta	0.60	0.20	0.81 [0.60:0.97]	0.63 [0.12:0.98]
Calvo prices	ξ	Beta	0.75	0.15	0.83 [0.77:0.90]	0.69 [0.56:0.83]
Labour share	α	Normal	0.68	0.10	0.66 [0.63:0.69]	0.63 [0.58:0.68]
Preference parameter	ϱ	Beta	0.80	0.20	0.09 [0.04:0.14]	0.27 [0.10:0.44]
Substitution elas. (H/F goods)	μ	Normal	1.50	0.50	0.50 [-0.25:1.26]	1.04 [0.02:1.89]
Investment substitution elas.	ρ_I	Inv. gamma	0.25	2.00	0.094 [0.056:0.133]	0.118 [0.061:0.177]
Risk premium elas.	χ_B	Inv. gamma	0.05	2.00	0.044 [0.013:0.084]	0.037 [0.013:0.064]
Substitution elas. (varieties)	ζ	Normal	7.00	0.50	7.07 [6.30:7.95]	7.11 [6.28:7.94]
Financial frictions						
Ext. finance premium elas. (F)	χ	Inv. gamma	0.03	4.00	-	0.025 [0.006:0.046]
Inverse of leverage (F)	n_k	Beta	0.50	0.15	-	0.49 [0.35:0.65]
Entrepreneurs survival rate (F)	ξ_e	Beta	0.93	0.05	-	0.88 [0.80:0.97]
Degree of liability dollarization	φ	Beta	0.50	0.10	-	0.22 [0.05:0.38]
Proportion of RT consumption	λ_{C1}	Beta	0.10	0.05	-	0.08✠ [0.01:0.18]
Interest rate rule						
Interest rate smoothing	ρ	Beta	0.65	0.10	0.85 [0.73:0.99]	0.88 [0.77:0.99]
Feedback from exp. inflation	θ_{ph}	Normal	2.00	1.00	2.91 [1.60:3.98]	2.68 [1.58:3.74]
Feedback from exchange rate	θ_{sh}	Normal	0.50	0.25	0.11 [0.00:0.21]	0.17 [0.01:0.29]
AR(1) coefficient						
Technology	ρ_A	Beta	0.5	0.10	0.38 [0.19:0.58]	0.51 [0.26:0.76]
Government spending	ρ_G	Beta	0.50	0.10	0.91 [0.84:0.97]	0.77 [0.52:0.94]
Price mark-up	ρ_{MS}	Beta	0.65	0.10	0.96 [0.92:0.99]	0.64 [0.34:0.94]
UIP	ρ_{uip}	Beta	0.65	0.10	0.73 [0.50:0.94]	0.87 [0.78:0.98]
Foreign interest rate	ρ_r	Beta	0.50	0.10	0.48 [0.17:0.81]	0.65 [0.40:0.87]
Foreign inflation rate	ρ_{pie}	Beta	0.65	0.10	0.52 [0.23:0.82]	0.67 [0.38:0.91]
Foreign consumption	ρ_c	Beta	0.65	0.10	0.65 [0.35:0.96]	0.78 [0.51:0.95]
Foreign investment	ρ_i	Beta	0.50	0.10	0.51 [0.18:0.83]	0.50 [0.17:0.82]
Foreign MUC	ρ_{muc}	Beta	0.65	0.10	0.72 [0.50:0.97]	0.73 [0.49:0.98]
Standard deviation of AR(1) innovations/I.I.D. shocks						
Technology	$sd(\epsilon_A)$	Inv. gamma	2.00	3.00	4.03 [2.28:5.76]	3.11 [1.57:4.99]
Government spending	$sd(\epsilon_G)$	Inv. gamma	2.00	3.00	16.04 [12.42:19.62]	8.54 [0.53:18.57]
Price mark-up	$sd(\epsilon_{MS})$	Inv. gamma	2.00	3.00	8.97 [5.54:12.44]	1.84 [0.58:3.44]
UIP	$sd(\epsilon_{UIP})$	Inv. gamma	2.00	3.00	1.32 [0.66:1.95]	1.29 [0.67:1.93]
Monetary policy	$sd(\epsilon_r)$	Inv. gamma	2.00	3.00	1.12 [0.82:1.39]	1.10 [0.82:1.35]
Foreign interest rate	$sd(\epsilon_{re})$	Inv. gamma	2.00	3.00	1.87 [0.58:3.36]	2.19 [0.58:3.90]
Foreign inflation rate	$sd(\epsilon_{pie})$	Inv. gamma	2.00	3.00	1.56 [0.52:2.72]	1.57 [0.63:2.64]
Foreign consumption	$sd(\epsilon_c)$	Inv. gamma	2.00	3.00	1.58 [0.55:2.56]	8.20 [0.61:14.19]
Foreign investment	$sd(\epsilon_i)$	Inv. gamma	2.00	3.00	2.04 [0.56:4.17]	1.98 [0.59:3.91]
Foreign MUC	$sd(\epsilon_{muc})$	Inv. gamma	2.00	3.00	2.16 [0.57:4.20]	1.51 [0.56:2.56]
LL					-529.07	-511.50

Table 3: Priors and Posterior Estimates

$\diamond$ Notes: we report posterior means and 95% probability intervals (in parentheses) based on the output of the Metropolis-Hastings Algorithm. Sample period: 1996:I to 2008:IV.
✠ λ is derived as follows: $\frac{C_2}{C} = \frac{C_2^*}{C^*} = 1.5$, then $\lambda_{C_1} = \lambda\frac{C_1}{C} = 1 - (1-\lambda)\frac{C_2}{C}$.

right-most column of Table 3. These results are plausible and are generally similar to those of Gabriel *et al.* (2012). One interesting aspect revealed by these estimates is that prices are estimated to be a lot stickier when financial frictions are absent, while under the second model, firms adjust prices quite frequently, between 1 and 3 quarters, implying only mild price stickiness. A similar result is obtained for consumption habits, with an estimated lower habit persistence for the FF model.

As in Gabriel *et al.* (2012), both estimated models undershoot α, suggesting a labour share around two thirds. Structural parameters like σ and ζ deviate little from their prior means, in fact the posterior distributions overlap with the prior ones, which might suggest that the data is not very informative about these parameters. ϱ, on the other hand, is pinned down with better precision at around 0.3, much lower than the prior mean of 0.8. On the other hand, estimates of μ are very imprecise and not significantly different from zero, which may suggest some identification problems. Our estimation delivers, based on the posterior estimates of λ_{C1}, a relatively low share of liquidity constrained consumers in the Indian economy. Around 38% of the households is liquidity constrained. These households do not trade on asset markets and consume entirely their disposable income each period. Although this figure seems low for a country where 27.5% of the population live below the poverty line this is in line with the finding in Gabriel *et al.* (2012), which finds that $\lambda = 0.30$, and may present some important implications to the fiscal policy making in India.

The estimated parameters capturing the policy response to inflation suggest that the RBI appears to be quite aggressive in preempting inflationary pressures, with θ_{ph} close to 3. However, the response for fluctuations in the exchange rate is estimated to be quite feeble and not statistically different from zero. On the other hand, the degree of policy inertia is similar to that obtained in Gabriel *et al.* (2012), with ρ estimated above 0.85.

The estimation of the shock processes shows some persistence, but less so that results for developed economies such as the US and the Euro Area. Interestingly, the external shocks are even less persistent. Secondly, the estimated standard deviations are larger than the the values commonly found for developed economies, in accordance with the macro volatility stylized facts typically associated with emerging economies. Most strikingly, the standard errors associated with the government spending and price mark-up shocks reach very large values for the No-FF model. Results for the FF model are less pronounced, although in this case, estimations pick up a large standard deviation coming from foreign consumption. The remaining standard deviations are somewhat below the specified priors.

8 Empirical Applications

Having shown the model estimates and the assessment of relative model fit between the two alternative variants, we now use them to investigate a number of key macroeconomic issues in India. The model favoured in the space of competing models may still be poor (potentially misspecified) in capturing the important dynamics in the data. To further evaluate the absolute performance of one particular model against data, it is necessary to compare the model's implied characteristics with those of the actual data. Also in this section, we address the following questions: (i) can the models capture the underlying characteristics of the actual data? (ii) what are the impacts of the structural shocks on the main macroeconomic time series?

8.1 Standard Moment Criteria

To assess the contributions of assuming different specifications in our estimated models, i.e. Models with and without financial frictions (FF), we compute some selected second moments and present the results in this subsection. Table 4 presents the second moments implied by the above estimations and compares with those in the actual data. In particular, we compute these model-implied statistics by solving the models at the posterior means obtained from estimation. The results of the model's second moments are compared with the second moments in the actual data to evaluate the models' empirical performance.

	Standard Deviation				
	Output	Inflation	Interest rate	Investment	Exchange rate
Data	1.50	0.97	1.93	6.15	3.56
Model no FF	6.58	**1.60**	1.72	17.74	6.71
Model FF	**2.67**	1.75	**1.80**	**10.84**	**6.23**
	Cross-correlation with Output				
Data	1.00	0.11	0.26	0.57	0.05
Model no FF	1.00	-0.08	**0.18**	0.84	0.82
Model FF	1.00	**0.19**	0.12	**0.49**	**0.16**
	Autocorrelations (Order=1)				
Data	0.59	0.13	0.83	0.91	0.65
Model no FF	0.97	0.27	**0.84**	0.99	0.95
Model FF	**0.83**	**0.23**	0.86	**0.97**	**0.92**

Table 4: Selected Second Moments$^{\diamondsuit}$

$^{\diamondsuit}$ All the second moments are theoretical moments computed from the model solutions (order of approximation = 1). The results are based on the models' posterior distribution.

In terms of the standard deviations, almost all models generate relative high volatility compared to the actual data (except for the interest rate). Both model variants can successfully replicate the stylized fact that investment is more volatile than output. Inflation volatility is practically unchanged owing to the higher responsiveness (and volatility) of the interest rate. Overall, the estimated model with FF is able to reproduce acceptable volatility for the main variables of the DSGE model. The inflation volatilities implied by the model with no FF is close to that of the data. In line with the Bayesian model comparison, the NK model with financial frictions fits the data better in terms of implied volatilities of output, investment, real exchange rate and interest rate, getting closer to the data in this dimension. Note that our 'better' model with FF clearly outperforms its rival in capturing the volatilities of output and investment and does well at matching the interest rate volatility in the data.

Table 4 also reports the cross-correlations of the five observable variables vis-a-vis output. All models perform successfully in generating the positive contemporaneous correlations observed in the data (the only exception is the predicted correlation between output and inflation generated by the model without financial frictions). It is worth noting that our 'preferred' model, NK model with FF, does well at capturing the contemporaneous cross-correlation of the inflation rate and output, suggesting that the financial accelerator and liquidity-constrained consumption help fitting the Indian data in this dimension.

The NK model with FF outperforms its counterpart at capturing the autocorrelations (order=1) of all variables apart from the interest rate. Using this model, output is more autocorrelated while inflation seems to be less autocorrelated than those in the data at order 1. Also Note, as suggested by Castillo *et al.* (2013), that the 'preferred' model does a better job at matching the data autocorrelations in terms of the the real exchange rate inertia and this is generated by the endogenous persistence induced by partial liability dollarization. In other words, the additional Phillips curves that arises from the dollarization mechanism seems to be supported by the data. This provides additional evidence explaining why the inclusion of liability dollarization helps a model to outperform rivals. Nevertheless, the NK FF model, in general, is able to capture the main features of the data in most dimensions and strengthens the argument that the presence of financial friction mechanisms is supported by the data.

8.2 Autocorrelation Functions

To further illustrate how the estimated models capture the data statistics, we plot the unconditional autocorrelations of the actual data and those of the endogenous variables generated by the model variants in Figure 1. In general, all models match reasonably well the autocorrelations of output, interest rate and investment shown in the data within a shorter period horizon. The data report that these three variables are positively and very significantly autocorrelated over short horizons. At lags of one-two quarters, both of the estimated models are able to generate the observed autocorrelations of interest rate and investment as noted above. Output, investment and the real exchange rate are more autocorrelated in both models than in the data, but the NK model with FF gets closer to the data towards the end of sample period. When it comes to matching inflation, all models exhibit the shortcoming of the inability of predicting the dynamics in the data.

Of particular interest is that, when assuming the absence of financial frictions, the implied autocorrelograms produced by the NK model fit very well the observed autocorrelation of interest rate, while the NK FF model generates slightly more sluggishness and is less able to match the autocorrelation observed in the data as the period horizon increases. However the performance of the two models tends to converge towards the end of the sample period. Perhaps the main message to emerge from this RBC type of model validity exercise is that it can be misleading to assess model fit using a selective choice of second moment comparisons. LL comparisons provide the most comprehensive form of assessment that will still leave trade-offs in terms of fitting some second moments well, at the expense of others. The NK model incorporating FF outperforms in terms of getting closer to the autocorrelation observed in the Indian GDP, investment and investment. Overall, the results in this exercise generally show again that the estimated DSGE models are able to capture the some important features of Indian data and the presence of financial frictions helps improve the model fit to data.

8.3 Impulse Response Analysis

In this section we study (the estimated posterior) impulse responses for two selected shocks: a domestic technology shock (a_t) and a shock to the country's external risk premium ($\epsilon_{UIP,t}$). The aim of this exercise is two-fold. First, we are interested in comparing the transmission of the two key internal and external shocks when the accelerator mechanism is 'turned on' and 'turned off'. This way, we assess the impact of imposing the financial accelerator, dollerization and the credit constrained consumption on different model dynamics. Second, we investigate the importance of shocks to the endogenous variables of interests in order to gain a better understanding of the innovation and forecasting uncertainties and, thus, the model uncertainties faced by monetary policymakers. This exercise is performed for our models with and without the financial frictions. The endogenous variables of interest are the observable variables in the estimation and each response is for a 20 period (5 years) horizon.

Figures 2-3 plot the mean responses corresponding to a positive one standard deviation of the shocks' innovation. The impulse response functions show the percentage deviation of variables from their steady state. A technology (TFP) shock a_t has a positive impact on output, investment, real exchange rate and the terms of trade and implies an immediate fall in inflation, real wage and interest rate. Nevertheless, the effect dies out relatively rapidly (about 1 year) when affecting output, real exchange rate, the terms of trade and the price level. This shock appears to be fairly persistent when affecting investment, as confirmed by the AR(1) coefficient estimate.

The plots also suggest that a positive technology shock in India acts as a labour demand shifter: higher productivity shrinks labour demand, pushing marginal cost down, lowers prices and interest rate, but its effect on prices is not persistent: inflation returns to pre-shock levels after about one year. When all firms experience a decline in their marginal cost as a result of a shock in technology, they will adjust prices downwards only partially in the short run. In addition, a technology shock also depreciates the currency in response to the lowering of the interest rate, thereby increasing the terms of trade, which improves goods' competitiveness. Output also jumps upwards in response to the lower future expected real interest rate.

Consider now the labour market and the behaviour of the real wage. With sticky prices, the increase in demand for output is less than the productivity increase; so the demand for labour falls, shifting the demand curve in (real-wage, quantity) space inwards. This puts an initial downward pressure on the real wage. On the supply-side of the labour market, since the marginal utility of consumption for the household falls as consumption rises, there is an increase in leisure (i.e. a reduction in hours), shifting the supply-of-labour curve outward, thus tending to raise the real wage. The demand effect dominates, and we find that the real wage falls on impact of the productivity improvement. This finding is in line with the closed-economy model analysis in Gabriel *et al.* (2012). With the credit frictions in place a productivity shock translates into a larger change in the wage if workers are more credit constrained because of more inelastic labor supply from such workers.

We find that the addition of financial market frictions in India does not substantially affect the post-shock behaviours of inflation exchange rate and terms of trade. However, there are amplifications of the output, employment, investment, nominal interest rate and real wage responses in the presence of the financial accelerator. The amplification seems to be much more substantial for the real wage, employment and investment responses. This result is found to be generally consistent with those from Bernanke *et al.* (1999)'s simulations with a monetary policy shock. When there is an unanticipated positive shock in factor productivity, the demand for capital is stimulated, which in turn raises investment and the price of capital. The increase in asset prices pushes up net worth, forcing down the external finance premium and this, as a result, helps to further stimulate private investment. The decline in inflation, however, is relatively marginal with a financial accelerator.

In Figure 3, we evaluate the responses from a one standard deviation increase in the domestic country external risk premium. Most responses are consistent with the findings of Bernanke *et al.* (1999), using calibrated models. In particular, the models with and without FF predict that a positive risk premium shock immediately depreciates the real exchange rate. As expected, there is an immediate drop in investment because the increase in the cost of capital drives Tobin's Q down. The initial fall in net worth is exacerbated rather than attenuated by balance sheet effects, and the external risk premium rises by more. Investment further falls with the effects of the financial frictions. The nominal interest rate jumps on impact and the interest rate differential relative to abroad is rapidly closed and the exchange rate depreciation is short-lived because of the monetary policy tightening. Indeed, we expect to observe an interest rate increase when there is an increase in the external borrowing premium. Almost all the responses are short-lived, as suggested by the parameter estimates. The immediate implication is that, through the modified interest-exchange rate UIP channel, the monetary policy can trigger a further balance sheet effect that has the effect of returning net worth back to its steady state faster with the effects of FF, following the exchange rate appreciation, and this way bring investment and hence output faster back to equilibrium. Most significantly, we find that in the model with FF the presence of the financial accelerator and dollarization magnifies the effects of a shock to the country's external risk premium on investment, the real wage and nominal interest rate. There is a long-stabilising effect as investment and output are 'accelerated' faster back to potential.

Overall, the results from the estimated posterior impulse responses following unanticipated shocks confirm the findings discussed above, that there is substantial evidence in the data to support the presence of a financial accelerator mechanism and the various other financial frictions. More precisely, the inclusion of the accelerator along with the dollarized borrowers affects the transmission mechanism of monetary policy and significantly magnifies the effects of both internal and external shocks on most of the key macroeconomic variables in the estimated economy. Nonetheless, it produces only a relatively modest initial impact on output following a UIP shock and this contradicts to the findings from Gertler *et al.* (2003)'s model simulation. The mild response perhaps implies some distinct compositional effects to components of output from various frictions. Given that financial frictions tend to impact more directly fluctuations in investment via capital perhaps there are offsetting effects among the individual output components, coming from various frictions (e.g. a delayed response of consumption). In Figure 3, The initial rise of output falls sharply following the fall in investment demand. With the frictions operative the contraction in output is nearly doubled at longer horizons.

9 Policy Discussions with Financial Imperfections

The RBI's proposed stabilization objective combined with the change of its nominal anchor to headline CPI inflation under the FIT framework have strong implications for policy making/transmission in the presence of financial frictions. For example, imperfect access to financial markets implies that the demand of credit-constrained consumers is insensitive to interest rate movements. Because their demand depends only on real wages, relative price changes, through the effects on real wages, also influence aggregate demand. This has implications on the effectiveness of monetary policy, and inflation targets as a nominal anchor that helps stabilize inflationary expectations in an uncertain future. Currency mismatch due to liability dollarization may be reduced by stabilized low inflation Mishkin (2006). With the features that are especially relevant to India and other emerging economies, there are more important challenges to FIT in emerging economies: weak public sector financial management and inflation control, getting compounded by low policy credibility and degree of central bank independence, can lead to sudden stops of capital inflows thus making emerging economies such as India vulnerable to financial crises (Calvo and Mishkin (2003)). The transmission of policy operation to inflation and aggregate demand may be affected by weak financial sector institutions and markets. Transition to FIT is complicated in emerging economies and should be combined with reforms of improving institutional framework and prudential supervision of the financial system. The interesting results from the IRF analysis show that some movements including output are more persistent when the financial frictions are present. This extra inertial in output suggests that agents are more responsive to current financial conditions. This, consequently, requires active behaviours of policy that respond to financial conditions. When markets are subject to significant financial imperfections, monetary policy at the RBI needs to be rather aggressive to stablisze/prevent persistent fluctuations. Our results in terms of monetary policy predict aggressive expected inflation targeting stance which seems to be consistent with the behaviour of the monetary authorities.

There are also welfare outcomes to the monetary policy frameworks of inflation stabilization objective with financial frictions. Since we find that the various forms of financial imperfections are significant amplifier of the effects of financial stress in the Indian macroeconomy, the policy questions here are (a) how do financial frictions affect the conduct of monetary policy? (b) because of extensive liability dollarization, should the exchange rate play a special role in monetary policy? There is a growing body of literature that compares alternative monetary-policy regimes by their ability to stabilize emerging economies when faced with external shocks and financial frictions. In Batini *et al.* (2010a), the paper sets out the two-bloc SOE model calibrated using Indian/US data and studies the effectiveness of macroeconomic policy under two monetary interest rate regimes: domestic Inflation targeting with a floating exchange rate and a managed exchange rate. The main result is that flexible-exchange-rate regimes outperform a pegging one. In Batini *et al.* (2010b), the model with FF is further calibrated to India and other emerging economies. An important feature of their work is the introduction of a zero lower bound into the construction of policy rules and they compare these regimes with the optimal policy. The paper first reaffirms the finding in the literature that financial frictions, especially when coupled with liability dollarization, severely increase the costs of a pegging regime. It also recommends that central banks with these frictions should not explicitly target the exchange rate; nor should they implicitly do so by choosing a CPI inflation target. With frictions, the zero lower bound constraint on the nominal interest rate makes simple Taylor-type rules perform much worse in terms of stabilization performance than fully optimal monetary policy. The main message is that monetary policymakers should consider adopting the "twin pillars" of flexible exchange rate and inflation targeting, as opposed to their more traditional use of active exchange rate management, to accommodate fluctuations in capital inflows and anchor the inflation rate, and that future research should examine alternative simple rules that mimic the fully optimal rule more closely.

Before the financial crisis of 2008 there was another main approach in the literature to modelling the interaction between banking distress and the real economy. This was modelled as 'Collateral Constraints', going back to Kiyotaki and Moore (2007) and was subsequently developed and incorporated into a DSGE model by Iacoviello (2005) and Brozoza-Brzezina *et al.* (2013). In this setting agents face endogenous credit limits determined by the value of collateralized assets. Collateral constraints always bind but default never occurs. In the financial accelerator scenario the propagation and amplification come from the fluctuation of agents' net worth while in the collateral constraint scenario from fluctuations in asset prices. The significance of such credit frictions, which are particularly relevant for emerging markets such as India, presents implications for monetary policy and housing prices (see, for example, K. Aoki and Vlieghe (2004) and Iacoviello (2005)). From 2008 onwards the literature on financial frictions and macroeconomic fluctuations has expanded considerably and focused both on improving the existing approaches and on developing new theories to model the interactions between the financial sector and the real economy focusing mainly on how monetary policy should react to financial crisis. Cúrdia and Woodford (2010) extend the financial accelerator approach to investigate the implications of time-varying interest rate spreads for the conduct of monetary policy. Adrian and Shin (2009) analyze how balance-sheet quantities of marked-based financial intermediaries are important macroeconomic state variables for the conduct of monetary policy. Gertler and Karadi (2011) and Gertler and Kiyotaki (2012) extend the financial accelerator approach to analyze the conduct of 'Unconventional' Monetary Policy.

10 Conclusions and Future Research

Overall, the estimated models reveal some useful insights. By extending our analysis to a small open-economy framework, we now include important sources of fluctuations. Moreover, the introduction of financial frictions in the form of liquidity constrained consumers, a financial accelerator mechanism and liability dollarization are not only realistic, but also conducive to a better empirical performance. Indeed, model fit is significantly improved, thus providing a more consistent explanation for the fluctuations exhibited by the data. This intensifies the exposure of a SOE to internal and external shocks in a manner consistent with the stylized facts discussed in Section 1.

The results correctly predict that the Indian economy is subject to more volatile shocks and that prices appear to be relatively flexible for India. In terms of monetary policy, an aggressive expected inflation targeting stance seems to be consistent with the behaviour of the monetary authorities. Overall, these results suggest that a great deal of volatility is is being transmitted by the demand side of the economy. One possible explanation is that all sorts of exogenous uncertainty, and potential misspecifications (particularly on the demand side) are being picked up by these shock processes. Note that we do not explicitly model fiscal policy and we are not using observables for the foreign sector. This suggests that careful modelling of fiscal policy might be required to understand this result better.

Nevertheless, there are limitations to our study and a number of directions for future research. First, we believe that in the case of emerging economies, the role of trends in the data requires special attention. Andrle (2008), for example, argues that assumptions on trending behaviour should be explicitly modelled, rather than side-stepped by means of an ad-hoc filtering procedure. Alternatively, one can take an agnostic view regarding de-trending in DSGE models by following the one-step approach recently suggested by Ferroni (2011), in which filtering parameters are jointly estimated with structural parameters, thus allowing for formal statistical comparisons among different de-trending procedures.

Second, there is some discrepancy in matching some moments between the model and data. Figure 1 highlights the inability of the model to satisfactorily account for the observed autocorrelations in investment, output and real exchange rate, whereas Table 4 shows that the model over predicts volatilities of all variables except the interest rate. As discussed, part of this could be a result of mis-specification of the trend when the data is detrended. This could also be due to the influence of the priors used in the estimation. The latest development in this area is employing endogenous priors in DSGE estimations, in which the priors are selected endogenously based on pre-samples to optimise the model's ability in matching the moments of the endogenous variables (see Christiano *et al.* (2011), Del Negro and Schorfheide (2008) and Chin *et al.* (2015). Perhaps the main message to emerge from this RBC type of model validity exercise in this paper is that it can be misleading to assess model fit using a selective choice of second moment comparisons. Likelihood comparisons provide the most comprehensive form of assessment that will still leave trade-offs in terms of fitting some second moments well, at the expense of others. An alternative way of validating the model performance is to follow Del Negro and Schorfheide (2004) and Del Negro *et al.* (2007) and to compare the DSGE model with a hybrid model that is a combination of an unrestricted VAR and the VAR implied by the estimated DSGE model (DSGE priors). These DSGE-VAR routines can also be used to test model mis-specification in a more formal way as the empirical performance of a DSGE-VAR depends on the tightness of the DSGE prior and is used as a benchmark for validation.

Third, several recent papers have documented the importance of the cost channel of monetary policy transmission, in which nominal interest rate fluctuations affect the cost of financing working capital, impacting on firms marginal cost and pricing decisions. This monetary friction could be incorporated and tested for its empirical relevance, as an addition friction in our Indian SOE model. Employment frictions in the labour market, wage stikiness and other form of financial frictions discussed in the previous section may be the other features worth testing in the current model. A formal comparison with all these approaches would be of some interest.

Finally, it would also be interesting to learn to what extent the different shocks are important in accounting for fluctuations in the Indian economy. Which are the main frictions and driving forces of business cycle dynamics in this small open economy? The analysis can be done by parameterizing the model according to alternative variants, ordered by increasing degrees of frictions and extending the estimation results to compute variance decompositions. Again this suggests directions for future research.

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A A Closed Economy Model

This section develops a standard New Keynesian (NK) DSGE model without any features we associate with emerging economies. To give us a preliminary insight into what is different about an emerging economy such as India. Every NK DSGE model has at its core a real business cycle model, describing the intertemporal problems facing consumers and firms and defining what would happen in the absence of the various Keynesian frictions. We first define a single-period utility for the representative agent in terms of consumption, C_t, and leisure, L_t, as

$$\Lambda_t = \Lambda(C_t, L_t) = \frac{((C_t - h_C C_{t-1})^{(1-\varrho)} L_t^{\varrho})^{1-\sigma} - 1}{1-\sigma} \quad \text{(A.1)}$$

In this utility function $\sigma \geq 1$ is a risk-aversion parameter which is also the inverse of the intertemporal rate of substitution. h_C is a habit parameter for private consumption C_t[14]. The parameter $\varrho \in (0, 1)$ defines the relative weight households place on consumption and this form of utility is compatible with a balanced growth steady state for for all $\sigma \geq 1$.[15] For later use, we write down the marginal utilities of consumption and leisure as, respectively,

$$\begin{aligned} \Lambda_{C,t} &= (1-\varrho)(C_t - h_C C_{t-1})^{(1-\varrho)(1-\sigma)-1} L_t^{\varrho(1-\sigma)} && \text{(A.2)} \\ \Lambda_{L,t} &= -\varrho(C_t - h_C C_{t-1})^{(1-\varrho)(1-\sigma)} L_t^{\varrho(1-\sigma)-1} && \text{(A.3)} \end{aligned}$$

The value function at time t of the representative household is given by

$$\Omega_t = E_t \left[\sum_{s=0}^{\infty} \beta^s \Lambda(C_{t+s}, L_{t+s}) \right] \tag{A.4}$$

where β is the discount factor. In a stochastic environment, the household's problem at time t is to choose state-contingent plans for consumption $\{C_t\}$, leisure, $\{L_t\}$ and holdings of financial savings to maximize Ω_t given its budget constraint in period t

$$B_{t+1} = B_t(1 + R_t) + W_t h_t - C_t \tag{A.5}$$

where B_t is the net stock of real financial assets at the beginning of period t, W_t is the real wage rate and R_t is the real interest rate paid on assets held at the beginning of period t. Hours worked are $h_t = 1 - L_t$ and the total amount of time available for work or leisure is normalized at unity. Government spending is financed by lump-sum non-distortionary taxes throughout. The first-order conditions for this optimization problem are

$$\begin{aligned} \Lambda_{C,t} &= \beta E_t \left[(1 + R_{t+1}) \Lambda_{C,t+1} \right] && \text{(A.6)} \\ \frac{\Lambda_{L,t}}{\Lambda_{C,t}} &= W_t && \text{(A.7)} \end{aligned}$$

Equation (A.6) is the Euler consumption function: it equates the current marginal utility of consumption with the discounted marginal of consumption of a basket of goods in period $t + 1$ enhanced by the interest on savings. Thus, the household is indifferent as between consuming 1 unit of income today or $1 + R_{t+1}$ units in the next period. Equation (A.7) equates the marginal rate of substitution between consumption and leisure with the real

[14] An alternative preference specification is the Jaimovich-Rebelo preferences (Jaimovich and Rebelo (2009)), that allows for flexible parameterization of the strength of wealth effects on the labour supply decision. The preference takes the following form and habit evolves according to $H_t = C_t^{\kappa} H_{t-1}^{1-\kappa}$. In the case with the wealth elasticity of labour supply $\kappa = 0$ there is no wealth effect on labour supply. This flexible specification links agents' habits with their consumption decisions and can account for the high volatility of wage and consumption relative to output that characterises developing countries. This feature may be important to study the effect of income on labour supply for emerging markets like India in adverse financial conditions: rising interest rate can induce larger short run wealth effects on labour supply despite of a significant drop in wages.

[15] See Barro and Sala-i-Martin (2004), chapter 9.

wage, the relative price of leisure. This completes the household component of the RBC model.

Turning to the production side, we assume that output Y_t is produced using hours, h_t and beginning-of-period capital K_t with a Cobb-Douglas production function

$$Y_t \;=\; F(A_t, h_t, K_t) = (A_t h_t)^{\alpha} K_t^{1-\alpha} \tag{A.8}$$

where A_t is a technology parameter and Y_t, h_t and K_t are all in per-capita (household) units. Assume first that capital can adjust instantly without investment costs. Then equating the marginal product of labour with the real wage and the marginal product of capital with the cost of capital (given by the real interest rate plus the depreciation rate, $R_t + \delta$), we have

$$F_{h,t} \;=\; \alpha \frac{Y_t}{h_t} = W_t \tag{A.9}$$

$$F_{K,t} \;=\; (1-\alpha)\frac{Y_t}{K_t} = R_t + \delta \tag{A.10}$$

Let investment in period t be I_t. Then capital accumulates according to

$$K_{t+1} = (1-\delta)K_t + I_t \tag{A.11}$$

The RBC model is then completed with an output equilibrium equating supply and demand

$$Y_t = C_t + I_t + G_t \tag{A.12}$$

where G_t is government spending on services assumed to be formed out of the economy's single good and by a financial market equilibrium. In this model, the only asset accumulated by households as a whole is capital, so the latter equilibrium is simply $B_t = K_t$. Substituting into the household budget constraint (A.5) and using the first-order conditions (A.9) and (A.10), and (A.11) we end up with the output equilibrium condition (A.12). In other words, equilibrium in the two factor markets and the output market implies equilibrium in the remaining financial market, which is simply a statement of Walras' Law.

Now let us introduce investment costs. It is convenient to introduce capital producing firms that at time t convert I_t of output into $(1 - S(X_t))I_t$ of new capital sold at a real price Q_t and at a cost (that was absent before) of $S(X_t)$. Here, $X_t \equiv \frac{I_t}{I_{t-1}}$ and the function $S(\cdot)$ satisfies S', $S'' \geq 0$; $S(1+g) = S'(1+g) = 0$. Thus, investment costs are convex and disappear along in the balanced growth steady state. They then maximize expected discounted profits

$$E_t \sum_{k=0}^{\infty} D_{t,t+k} \left[Q_{t+k}(1 - S\left(I_{t+k}/I_{t+k-1}\right))I_{t+k} - I_{t+k} \right]$$

where $D_{t,t+k} \equiv \beta \frac{\Lambda_{C,t+k}}{\Lambda_{C,t}}$ is the real stochastic discount rate and

$$K_{t+1} = (1-\delta)K_t + (1 - S(X_t))I_t \tag{A.13}$$

This results in the first-order condition

$$Q_t(1 - S(X_t) - X_t S'(X_t)) + E_t \left[\frac{1}{(1+R_{t+1})} Q_{t+1} S'(X_{t+1}) \frac{I_{t+1}^2}{I_t^2} \right] = 1 \tag{A.14}$$

Demand for capital by firms must satisfy

$$E_t[(1+R_{t+1})RPS_{t+1}] = \frac{E_t \left[(1-\alpha) \frac{P_{t+1}^W Y_{t+1}}{K_{t+1}} + (1-\delta)Q_{t+1} \right]}{Q_t} \tag{A.15}$$

In (A.15) the right-hand-side is the gross return to holding a unit of capital in from t to $t+1$. The left-hand-side is the gross return from holding bonds, the opportunity cost of capital and includes an exogenous risk-premium shock RPS_t, which, for now, we leave unmodelled. We complete the set-up with investment costs by defining the functional form

$$S(X) = \phi_X (X_t - (1+g))^2 \tag{A.16}$$

where g is the balanced growth rate. The RBC model we have set out defines a equilibrium in output, Y_t, consumption C_t, investment I_t, capital stock K_t and factor prices, W_t for labour and R_t for capital, and the price of capital Q_t, given exogenous processes for technology A_t, government spending G_t and the risk premium shock RPS_t.

The NK framework combines the DSGE characteristics of RBC models with frictions such as monopolistic competition - in which firms produce differentiated goods and are price-setters, instead of Walrasian determination of prices -, and nominal rigidities, in which firms face constraints on the frequency with which they are able to adjust their prices. Therefore, we now introduce a *retail sector* that uses a homogeneous wholesale good to produce a basket of differentiated goods for consumption

$$C_t = \left(\int_0^1 C_t(m)^{(\zeta-1)/\zeta} dk \right)^{\zeta/(\zeta-1)} \tag{A.17}$$

where ζ is the elasticity of substitution. This implies a set of demand equations for each intermediate good m with price $P_t(m)$ of the form

$$C_t(m) = \left(\frac{P_t(m)}{P_t} \right)^{-\zeta} C_t \tag{A.18}$$

where $P_t = \left[\int_0^1 P_t(m)^{1-\zeta} dm \right]^{\frac{1}{1-\zeta}}$. P_t is the aggregate price index.

Conversion of good m from a homogeneous output requires a cost $cY_t^W(m)$ where wholesale production uses the production technology (A.8). Thus

$$\begin{aligned} Y_t(m) &= (1-c)Y_t^W(m) && \text{(A.19)} \\ Y_t^W &= (A_t h_t)^\alpha K_t^{1-\alpha} && \text{(A.20)} \end{aligned}$$

To introduce price stickiness, we assume that there is a probability of $1-\xi$ at each period that the price of each intermediate good m is set optimally to $P_t^0(m)$. If the price is not re-optimized, then it is held fixed.[16] For each intermediate producer m the objective is at time t to choose $\{P_t^0(m)\}$ to maximize discounted profits

$$E_t \sum_{k=0}^{\infty} \xi^k D_{t,t+k} Y_{t+k}(m) \left[P_t^0(m) - P_{t+k} MC_{t+k}\right] \qquad \text{(A.21)}$$

subject to (A.18), where $D_{t,t+k}$ is now the nominal stochastic discount factor over the interval $[t, t+k]$. The solution to this is

$$E_t \sum_{k=0}^{\infty} \xi^k D_{t,t+k} Y_{t+k}(m) \left[P_t^0(m) - \frac{1}{(1-1/\zeta)} P_{t+k} MC_{t+k} MS_{t+k}\right] = 0 \qquad \text{(A.22)}$$

In (A.22) we have introduced a mark-up shock MS_t to the steady state mark-up $\frac{1}{(1-1/\zeta)}$. By the law of large numbers, the evolution of the price index is given by

$$P_{t+1}^{1-\zeta} = \xi P_t^{1-\zeta} + (1-\xi)(P_{t+1}^0)^{1-\zeta} \qquad \text{(A.23)}$$

In setting up the model for simulation and estimation, it is useful to represent the price dynamics as difference equations. Using the fact that for any summation $S_t \equiv \sum_{k=0}^{\infty} \beta^k X_{t+k}$, we can write

$$\begin{aligned} S_t &= X_t + \sum_{k=1}^{\infty} \beta^k X_{t+k} = X_t + \sum_{k'=0}^{\infty} \beta^{k'+1} X_{t+k'+1} \text{ putting } k' = k+1 \\ &= X_t + \beta S_{t+1} && \text{(A.24)} \end{aligned}$$

and defining here the nominal discount factor by $D_{t,t+k} \equiv \beta \frac{\Lambda_{C,t+k}/P_{t+k}}{\Lambda_{C,t}/P_t}$, inflation dynamics

[16] Thus we can interpret $\frac{1}{1-\xi}$ as the average duration for which prices are left unchanged.

are given by

$$\begin{aligned}
\frac{P_t^0}{P_t} &= \frac{H_t}{J_t} && \text{(A.25)}\\
H_t - \xi\beta E_t[\Pi_{t+1}^{\zeta-1} H_{t+1}] &= Y_t \Lambda_{C,t} && \text{(A.26)}\\
J_t - \xi\beta E_t[\Pi_{t+1}^{\zeta} J_{t+1}] &= \left(\frac{1}{1-\frac{1}{\zeta}}\right) Y_t \Lambda_{C,t} MC_t MS_t && \text{(A.27)}\\
\Pi_t: \quad 1 &= \xi \Pi_t^{\zeta-1} + (1-\xi)\left(\frac{J_t}{H_t}\right)^{1-\zeta} && \text{(A.28)}
\end{aligned}$$

Real marginal costs are no longer fixed and are given by

$$MC_t = \frac{P_t^W}{P_t} \tag{A.29}$$

Nominal and real interest rates are related by the Fischer equation

$$E_t[1 + R_{t+1}] = E_t\left[\frac{1 + R_{n,t}}{\Pi_{t+1}}\right] \tag{A.30}$$

where the nominal interest rate is a policy variable, typically given in the literature by a standard Taylor-type rule:

$$\log\left(\frac{1+R_{n,t}}{1+R_n}\right) = \rho \log\left(\frac{1+R_{n,t-1}}{1+R_n}\right) + \theta_\pi \log\left(\frac{\Pi_t}{\Pi}\right) + \theta_y \log\left(\frac{Y_t}{Y}\right) \tag{A.31}$$

In fact, we will model monetary policy in a more general way by formulating a Calvo-type forward-backward interest rate rule in inflation targets as in Levine *et al.* (2007) and Gabriel *et al.* (2009). This is defined by

$$\log\left(\frac{1+R_{n,t}}{1+R_n}\right) = \rho \log\left(\frac{1+R_{n,t-1}}{1+R_n}\right) + \theta_\pi \log\frac{\Theta_t}{\Theta} + \phi_\pi \log\frac{\Phi_t}{\Phi} + \theta_y \log\left(\frac{Y_t}{Y}\right) + \epsilon_{MPS,t} \tag{A.32}$$

where $\epsilon_{MPS,t}$ is a monetary policy shock and

$$\begin{aligned}
\log \Phi_t &= \log \Pi_t + \tau \log \Phi_{t-1} && \text{(A.33)}\\
\varphi E_t[\log \Theta_{t+1}] &= \log \Theta_t - (1-\varphi)\log(\Pi_t) && \text{(A.34)}
\end{aligned}$$

The Calvo rule can be interpreted as a feedback from expected inflation (the $\theta \log \frac{\Theta_t}{\Theta}$ term) and past inflation (the $\phi \log \frac{\Phi_t}{\Phi}$ term) that continues at any one period with probabilities φ and τ, switching off with probabilities $1-\varphi$ and $1-\tau$. The probability of the rule lasting for h periods is $(1-\varphi)\varphi^h$, hence the mean forecast horizon is $(1-\varphi)\sum_{h=1}^{\infty} h\varphi^h = \varphi/(1-\varphi)$. With $\varphi = 0.5$, for example, we would have a Taylor rule with one period lead in inflation ($h = 1$). Similarly, τ can be interpreted as the degree of backward-lookingness of the monetary authority.

This rule can also be seen as a special case of a Taylor-type rule that targets h-step-ahead (back) expected rates of inflation and past inflation rates (with $h = 1, 2, ..., \infty$)

$$i_t = \rho i_{t-1} + \theta_0 \pi_t + \theta_1 E_t \pi_{t+1} + \theta_2 E_t \pi_{t+2} + ... + \gamma_1 \pi_{t-1} + \gamma_2 \pi_{t-2} + ..., \tag{A.35}$$

albeit one that imposes a specific structure on the θ_i's and γ_i's (i.e., a weighted average of future and past variables with geometrically declining weights). This has an intuitive appeal and interpretation, reflecting monetary policy in an uncertain environment: the more distant the h-step ahead forecast, the less reliable it becomes, hence the less weight it receives. In turn, past inflation has a typical Koyck-lag structure.

Note that we are approximating the behaviour of the central bank with an instrument rule, rather than assuming that the monetary authority optimises a specific loss function. Despite the lack of a substantial body of evidence for the Indian case, the forward-backward-looking Calvo-type formulation can be useful to analyse the RBI's interest rate setting behaviour. Bhattacharya *et al.* (2010), using VAR methods, find monetary policy in India to have weak transmission channels. On the other hand, however, Virmani (2004) reports on the potential forward/backward looking behaviour of the RBI using instrumental rules, suggesting that a backward-looking rule explains the data well. Our proposal nests both types of behaviour and can therefore shed light on their relative importance.

The structural shock processes in log-linearised form are assumed to follow AR(1) processes

$$\begin{aligned}
\log A_t - \log \bar{A}_t &= \rho_A(\log A_{t-1} - \log \bar{A}_{t-1}) + \epsilon_{A,t} \\
\log G_t - \log \bar{G}_t &= \rho_G(\log G_{t-1} - \log \bar{G}_{t-1}) + \epsilon_{G,t} \\
\log MS_t - \log MS &= \rho_{MS}(\log MS_{t-1} - \log MS) + \epsilon_{MS,t} \\
\log RPS_t - \log RPS &= \rho_{RPS}(\log RPS_{t-1} - \log RPS) + \epsilon_{RPS,t}
\end{aligned}$$

where $MS = RPS = 1$ in the steady state (so $\log MS = \log RPS = 0$), while the monetary policy shock $\epsilon_{MPS,t}$ is assumed to be i.i.d with zero mean. This completes the specification of the benchmark NK model.

B Summary of Closed Economy Model

The following summarizes the dynamic model for the closed economy which applies to the foreign bloc. Note that the baseline model in Appendix A puts $\lambda = 0$ and shuts down the financial accelerator.

$$
\begin{aligned}
\Lambda_{2,t} &= \Lambda(C_{2,t}, L_t) = \frac{(C_{2,t}^{(1-\varrho)} L_{2,t}^{\varrho})^{1-\sigma} - 1}{1-\sigma} \\
\Lambda_{C_{2},t} &= (1-\varrho) C_{2,t}^{(1-\varrho)(1-\sigma)-1} (1-h_{2,t})^{\varrho(1-\sigma)}) \\
\Lambda_{L_{2},t} &= \varrho C_{2,t}^{(1-\varrho)(1-\sigma)} L_{2,t}^{\varrho(1-\sigma)-1} \\
\Lambda_{C_{2},t} &= \beta E_t \left[(1+R_{t+1}) \Lambda_{C_{2},t+1} \right] \\
\frac{\Lambda_{L_{2},t}}{\Lambda_{C_{2},t}} &= \frac{W_t}{P_t} \\
L_{2,t} &\equiv 1 - h_{2,t} \\
h_{1,t} &= 1 - \rho \\
C_{1,t} &= \frac{W_t h_{1,t}}{P_t} \\
h_t &= \lambda h_{1,t} + (1-\lambda) h_{2,t} \\
C_t^e &= \frac{1-\xi_e}{\xi_e} N_t \\
C_t &= \lambda C_{1,t} + (1-\lambda) C_{2,t} + C_t^e \\
Y_t^W &= F(A_t, h_t, K_t) = (A_t h_t)^{\alpha} K_t^{1-\alpha} \\
Y_t &= (1-c) Y_t^W \\
\frac{P_t^W}{P_t} F_{h,t} &= \frac{P_t^W}{P_t} \frac{\alpha Y_t^W}{h_t} = \frac{W_t}{P_t} \\
P_t &= \frac{1}{1-\frac{1}{\zeta}} P_t^W \\
K_{t+1} &= (1-\delta) K_t + (1 - S(X_t)) I_t \\
X_t &\equiv \frac{I_t}{I_{t-1}} \\
Q_t(1 - S(X_t) - X_t S'(X_t)) &+ E_t \left[\frac{1}{(1+R_{t+1})} Q_{t+1} S'(Z_{t+1}) \frac{I_{t+1}^2}{I_t^2} \right] = 1 \\
E_t[(1+R_{t+1})\Theta_{t+1}] &= E_t[1 + R_{k,t+1}] \\
1 + R_{k,t} &= \frac{(1-\alpha_I) \frac{P_t^W}{P_t} \frac{Y_t^W}{K_t} + (1-\delta) Q_t}{Q_{t-1}} \\
\Theta_t &= s \left(\frac{N_t}{Q_{t-1} K_t} \right) RP_t = k \left(\frac{N_t}{Q_{t-1} K_t} \right)^{-\chi} RPS_t \\
N_{t+1} &= \xi_e V_t + (1-\xi_e) D_t^e \\
D_t^e &= \bar{D}_t^e \text{ (BGP steady state)} \\
V_t &= (1 + R_{k,t}) Q_{t-1} K_t - \Theta_t (1 + R_t)(Q_{t-1} K_t - N_t)
\end{aligned}
$$

$$
\begin{aligned}
S(X_t) &= \phi_X(X_t-(1+g))^2 \\
Y_t &= C_t+G_t+I_t \\
H_t-\xi\beta E_t[\Pi_{t+1}^{\zeta-1}H_{t+1}] &= Y_t\Lambda_{C,t} \\
J_t-\xi\beta E_t[\Pi_{t+1}^{\zeta}J_{t+1}] &= \left(\frac{1}{1-\frac{1}{\zeta}}\right)Y_t\Lambda_{C,t}MS_tMC_t \\
1 &= \xi\Pi_t^{\zeta-1}+(1-\xi)\left(\frac{J_t}{H_t}\right)^{1-\zeta} \\
MC_t &= \frac{P_t^W}{P_t} \\
1+R_t &= \frac{1+R_{n,t-1}}{\Pi_t} \\
\log A_t-\log\bar{A}_t &= \rho_A(\log A_{t-1}-\log\bar{A}_{t-1})+\epsilon_{A,t} \\
\log G_t-\log\bar{G}_t &= \rho_G(\log G_{t-1}-\log\bar{G}_{t-1})+\epsilon_{G,t} \\
\log MS_t-\log MS &= \rho_{MS}(\log MS_{t-1}-\log MS)+\epsilon_{MS,t} \\
\log RPS_t-\log RPS &= \rho_{RPS}(\log RPS_{t-1}-\log RPS)+\epsilon_{RPS,t} \\
\log\left(\frac{1+R_{n,t}}{1+R_n}\right) &= \rho\log\left(\frac{1+R_{n,t-1}}{1+R_n}\right)+\theta\log\frac{\Theta_t}{\Theta}+\phi\log\frac{\Phi_t}{\Phi}+\epsilon_{MPS,t} \\
\log\Phi_t &= \log\Pi_t+\tau\log\Phi_{t-1} \\
\varphi E_t[\log\Theta_{t+1}] &= \log\Theta_t-(1-\varphi)\log(\Pi_t)
\end{aligned}
$$

The steady state is given by the following:

$$\bar{N}_t = \frac{(1-\xi_e)\bar{D}_t}{(1-\xi_e(1+R_k))} \tag{B.36}$$

$$1+R_k = (1+R)\, s\left(\frac{\bar{N}_t}{\bar{K}_t}\right) \tag{B.37}$$

$$\frac{\bar{K}_t}{\bar{Y}_t^W} = \frac{1-\alpha}{R_k+\delta} \tag{B.38}$$

Choose a functional form

$$s\left(\frac{\bar{N}_t}{Q\bar{K}_t}\right)=k\left(\frac{\bar{N}_t}{Q\bar{K}_t}\right)^{-\chi}$$

We obtain χ from econometric studies and we have data on the risk premium $\Theta=\frac{1+R_k}{1+R}$ and leverage (= borrowing/net worth)

$$\ell=\frac{QK-N}{N}=\frac{QK}{N}-1=\frac{1}{n_k}-1$$

defining $n_k\equiv\frac{N}{QK}$. Then we can set the scaling parameter k from (B.37) as

$$k=\Theta n_k^{\chi}$$

Then in the baseline steady state used to calibrate parameters, we put $\bar{N}_t = n_k \bar{K}_t$ and calibrate $\bar{D}^e$ from (B.36). The non-zero-inflation steady state and the calibrated k are given by

$$
\begin{aligned}
1+R &= \frac{(1+g)^{1+(\sigma-1)(1-\varrho)}}{\beta} \\
1+R_n &= \Pi(1+R) \\
Q &= 1 \\
\bar{Y}_t &= (1-c)(h_t\bar{A}_t)^{\alpha}\bar{K}_t^{1-\alpha} \\
\frac{\varrho\bar{C}_{2,t}}{(1-\varrho)(1-h)} &= \bar{W}_t \\
\bar{C}_{1,t} &= \bar{W}_t h \\
\frac{\alpha P^W \bar{Y}_t^W}{Ph} &= \bar{W}_t \\
\frac{\bar{K}_t}{\bar{Y}_t^W} &= \frac{1-\alpha}{R_k+\delta} \\
1+R_k &= (1+R)\Theta \\
\Theta &= k\, n_k^{-\chi} = k\left(\frac{\bar{N}_t}{Q\bar{K}_t}\right)^{-\chi} \\
\bar{I}_t &= (\delta+g)\bar{K}_t \\
\bar{Y}_t &= \bar{C}_t + \bar{I}_t + \bar{G}_t \\
1 &= \frac{1}{1-\frac{1}{\zeta}}\frac{P^W}{P} \\
\bar{N}_t &= n_k\bar{K}_t = \frac{(1-\xi_e)\bar{D}_t^e}{(1-\xi_e(1+R_k))} \text{ (determines } \bar{D}_t^e\text{)}
\end{aligned}
$$

C Summary of Standard Open Economy Model

For the small open economy as $\nu \to 0$ and $\mathrm{w}_C^* \to 1$, from (5) we have that $\frac{1-\nu}{\nu}(1-\mathrm{w}_C^*) \to 1-\omega_C^*$. Similarly, $\frac{1-\nu}{\nu}(1-\mathrm{w}_I^*) \to 1-\omega_I^*$.

$$
\begin{aligned}
\Lambda_{C,t}: \quad \frac{1}{1+R_{n,t}} &= \beta E_t\left[\frac{\Lambda_{C,t+1}}{\Lambda_{C,t}\Pi_{t+1}}\right] && \text{(C.39)} \\
\frac{W_t}{P_{C,t}} &= \frac{\Lambda_{L,t}}{\Lambda_{C,t}} = -\frac{\Lambda_{h,t}}{\Lambda_{C,t}} && \text{(C.40)} \\
C_{2,t}: \quad \Lambda_{C,t} &= (1-\varrho)C_{2,t}^{(1-\varrho)(1-\sigma)-1}(1-h_t)^{\varrho(1-\sigma)} && \text{(C.41)} \\
\lambda_{h,t} &= -C_{2,t}^{(1-\varrho)(1-\sigma)}\varrho(1-h_t)^{\varrho(1-\sigma)-1} && \text{(C.42)} \\
C_{1,t} &= \frac{W_t h_t}{P_{C,t}} && \text{(C.43)} \\
C_t &= \lambda C_{1,t} + (1-\lambda)C_{2,t} && \text{(C.44)}
\end{aligned}
$$

$$
\begin{aligned}
\left(\frac{P_{F,t}}{P_{C,t}}\right): \quad 1 &= \left[\mathrm{w}_C \left(\frac{P_{H,t}}{P_{C,t}}\right)^{1-\mu_C} + (1-\mathrm{w}_C)\left(\frac{P_{F,t}}{P_{C,t}}\right)^{1-\mu_C}\right]^{\frac{1}{1-\mu_C}} && \text{(C.45)}\\
\frac{P_{H,t}}{P_{C,t}} &= \frac{1}{[\mathrm{w}_C + (1-\mathrm{w}_C)\mathcal{T}_t^{1-\mu_C}]^{\frac{1}{1-\mu_C}}} && \text{(C.46)}\\
\text{where } \mathcal{T}_t &\equiv \frac{P_{F,t}}{P_{H,t}}\\
C_{F,t} &= \mathrm{w}_C \left(\frac{P_{H,t}}{P_{C,t}}\right)^{-\mu_C} C_t && \text{(C.47)}\\
C_{F,t} &= (1-\mathrm{w}_C)\left(\frac{P_{F,t}}{P_{C,t}}\right)^{-\mu_C} C_t && \text{(C.48)}\\
C_{H,t}{}^* &= (1-\omega_C^*)\left(\frac{P_{H,t}}{P_{C,t}RER_{C,t}}\right)^{-\mu_C^*} C_t{}^* && \text{(C.49)}\\
H_t: \quad H_t - \xi_H \beta E_t[\Pi_{H,t+1}^{\zeta-1} H_{t+1}] &= Y_t \Lambda_{C,t} && \text{(C.50)}\\
J_t: \quad J_t - \xi_H \beta E_t[\Pi_{H,t+1}^{\zeta} J_{t+1}] &= \frac{1}{1-\frac{1}{\zeta}} MS_t Y_t \Lambda_{C,t} MC_t && \text{(C.51)}\\
\Pi_{H,t}: \quad 1 &= \xi_H \Pi_{H,t}^{\zeta-1} + (1-\xi_H)\left(\frac{J_t}{H_t}\right)^{1-\zeta} && \text{(C.52)}\\
MC_t &= \frac{P_{H,t}^W}{P_{H,t}} = \frac{P_{H,t}^W/P_{C,t}}{P_{H,t}/P_{C,t}} = \frac{\frac{W_t}{P_{C,t}} h_t}{\alpha Y_t \frac{P_{H,t}}{P_{C,t}}} && \text{(C.53)}\\
h_t: \quad Y_t^W &= (A_t h_t)^\alpha K_t^{1-\alpha} && \text{(C.54)}\\
Y_t &= (1-c) Y_t^W && \text{(C.55)}\\
\frac{P_{H,t}^W}{P_{C,t}}: \quad \frac{P_{H,t}^W}{P_{C,t}} &= MC_t \frac{P_{H,t}}{P_{C,t}} && \text{(C.56)}\\
Q_t: E_t\left[1+R_{t+1}\right] &= \frac{E_t\left[\frac{P_{H,t+1}^W}{P_{t+1}}(1-\alpha)\frac{Y_{t+1}}{K_{t+1}} + (1-\delta)Q_{t+1}\right]}{Q_t} && \text{(C.57)}\\
R_t: \quad 1+R_t &= \frac{1+R_{n,t-1}}{1+\Pi_t} && \text{(C.58)}\\
K_{t+1} &= (1-\delta)K_t + (1-S(X_t))I_t\\
S',\, S'' &\geq 0\,;\; S(1+g) = S'(1+g) = 0 && \text{(C.59)}\\
X_t &= \frac{I_t}{I_{t-1}} && \text{(C.60)}\\
S(X_t) &= \frac{\phi_I}{2}(X_t - (1+g))^2 && \text{(C.61)}\\
I_t: \quad \frac{P_{I,t}}{P_{C,t}} &= Q_t(1 - S(X_t) - X_t S'(X_t)) + E_t\left[\frac{Q_{t+1}S'(X_{t+1})}{(1+R_{t+1})}\frac{I_{t+1}^2}{I_t^2}\right] && \text{(C.62)}\\
I_{H,t} &= \mathrm{w}_I \left(\frac{P_{H,t}/P_{C,t}}{P_{I,t}/P_{C,t}}\right)^{-\mu_I} I_t && \text{(C.63)}\\
I_{F,t} &= (1-\mathrm{w}_I)\left(\frac{P_{F,t}/P_{C,t}}{P_{I,t}/P_{C,t}}\right)^{-\mu_I} I_t && \text{(C.64)}
\end{aligned}
$$

$$I^*_{H,t} = (1-\omega^*_I)\left(\frac{P_{H,t}/P_{C,t}}{P_{I,t}/P_{C,t}RER_{I,t}}\right)^{-\rho^*_I} I^*_t \tag{C.65}$$

$$\frac{P_{I,t}}{P_{C,t}} = \left[\mathrm{w}_I\left(\frac{P_{H,t}}{P_{C,t}}\right)^{1-\mu_I} + (1-\mathrm{w}_I)\left(\frac{P_{F,t}}{P_{C,t}}\right)^{1-\mu_I}\right]^{\frac{1}{1-\mu_I}} \tag{C.66}$$

$$Y_t: \quad Y_t = C_{H,t} + I_{H,t} + C^*_{H,t} + I^*_{H,t} + G_t \tag{C.67}$$

$$\frac{S_t}{S_{t-1}} = \frac{RER_{C,t}\,\Pi_t}{RER_{C,t-1}\,\Pi^*_t} \tag{C.68}$$

$$\Pi_{F,t}: \quad \frac{\mathcal{T}_t}{\mathcal{T}_{t-1}} = \frac{\Pi_{F,t}}{\Pi_{H,t}} \tag{C.69}$$

$$\mathcal{T}_t: \quad RER_{C,t} = \frac{1}{\left[1-\mathrm{w}_C + \mathrm{w}_C\mathcal{T}_t^{\mu_C-1}\right]^{\frac{1}{1-\mu_C}}} \tag{C.70}$$

$$RER_{I,t} = \frac{1}{\left[1-\mathrm{w}_I + \mathrm{w}_I\mathcal{T}_t^{\mu_I-1}\right]^{\frac{1}{1-\mu_I}}} \tag{C.71}$$

$$\Pi_t = [\mathrm{w}_C(\Pi_{H,t})^{1-\mu_C} + (1-\mathrm{w}_C)(\Pi_{F,t})^{1-\mu_C}]^{\frac{1}{1-\mu_C}} \tag{C.72}$$

$$\begin{aligned}\log(1+R_{n,t})/(1+R_n) &= \rho_r \log(1+R_{n,t-1})/(1+R_n) + (1-\rho_r)(\theta_\pi E_t[\log\Pi_{t+1}]/\Pi \\ &+ \theta_s \log S_t/S) + \epsilon_{r,t+1}\end{aligned} \tag{C.73}$$

$$RER^r_t = \frac{\Lambda^*_{C,t}}{\Lambda_{C,t}} \tag{C.74}$$

$$1+R^*_t = \frac{1+R^*_{n,t-1}}{1+\Pi^*_t} \tag{C.75}$$

$$\frac{1}{(1+R^*_{n,t})\phi(\frac{S_tB^*_{F,t}}{P_{H,t}Y_t})}S_tB^*_{F,t} = S_tB^*_{F,t-1} + TB_t \tag{C.76}$$

$$\phi(\frac{S_tB^*_{F,t}}{P_{H,t}Y_t}) = \exp\left(\frac{\phi_B S_tB^*_{F,t}}{P_{H,t}Y_t}\right)\ ;\ \phi_B < 0 \tag{C.77}$$

$$TB_t = P_{H,t}Y_t - P_{C,t}C_t - P_{I,t}I_t - P_{H,t}G_t \tag{C.78}$$

Then the real exchange rate is given by

$$RER_{C,t} = RER^d_t RER^r_t \tag{C.79}$$

$$RER^d_t : 0 = E_t\left[\frac{\Lambda_{C,t+1}}{\Lambda_{C,t}}\frac{RER^r_{t+1}}{RER^r_t}\frac{1}{\Pi^*_{t+1}}\left(\frac{1}{\phi(\frac{S_tB^*_{F,t}}{P_{H,t}Y_t})\exp(\epsilon_{UIP,t+1})} - \frac{RER^d_{t+1}}{RER^d_t}\right)\right]$$

Shocks:

$$\log\frac{A_{t+1}}{A} = \rho_a \log\frac{A_t}{A} + \epsilon_{a,t+1} \tag{C.80}$$

$$\log\frac{G_{t+1}}{G} = \rho_g \log\frac{G_t}{G} + \epsilon_{g,t+1} \tag{C.81}$$

$$\log\frac{MS_{t+1}}{MS} = \rho_{ms} \log\frac{MS_t}{MS} + \epsilon_{ms,t+1} \tag{C.82}$$

$$\log \frac{UIP_{t+1}}{UIP} = \rho_{UIP} \log \frac{UIP_t}{UIP} + \epsilon_{uip,t+1} \quad \text{(C.83)}$$

If the ROW is not modelled explicitly we close the model with exogenous AR(1) shocks

$$\begin{aligned}
\log(1+R^*_{n,t})/(1+R^*_n) &= \rho^*_r \log(1+R^*_{n,t-1})/(1+R^*_n) + \epsilon^*_{r,t+1} && \text{(C.84)}\\
\log \frac{\Pi^*_{t+1}}{\Pi^*} &= \rho^*_\pi \log \frac{\Pi^*_t}{\Pi^*} + \epsilon^*_{\pi,t+1} && \text{(C.85)}\\
\log \frac{C^*_{t+1}}{C^*} &= \rho^*_c \log \frac{C^*_t}{C^*} + \epsilon^*_{c,t+1} && \text{(C.86)}\\
\log \frac{I^*_{t+1}}{I^*} &= \rho^*_i \log \frac{I^*_t}{I^*} + \epsilon^*_{i,t+1} && \text{(C.87)}\\
\log \frac{\Lambda^*_{t+1}}{\Lambda^*} &= \rho^*_\Lambda \log \frac{\Lambda^*_t}{\Lambda^*} + \epsilon^*_{\lambda,t+1} && \text{(C.88)}
\end{aligned}$$

Otherwise $R^*_{n,t}$, Π^*_t, C^*_t and I^*_t are modelled as before. First assume zero growth in the steady state: $g = g^* = 0$ and non-negative inflation. Then we have

$$\begin{aligned}
R_n: \quad 1+R_n &= (1+R^*_n)\phi\left(\frac{SB}{P}\right) && \text{(C.89)}\\
\frac{W}{P} &= -\frac{U_L}{U_C} && \text{(C.90)}\\
U_C &= (1-\varrho)C_2^{(1-\varrho)(1-\sigma)-1}(1-L)^{\varrho(1-\sigma)} && \text{(C.91)}\\
U_L &= -C_2^{(1-\varrho)(1-\sigma)}\varrho(1-L)^{\varrho(1-\sigma)-1} && \text{(C.92)}\\
C_1 &= \frac{WL}{P_C} && \text{(C.93)}\\
C &= \lambda C_1 + (1-\lambda)C_2 && \text{(C.94)}\\
P_F/P_C: \quad 1 &= \left[\mathrm{w}_C\left(\frac{P_H}{P_C}\right)^{1-\mu_C} + (1-\mathrm{w}_C)\left(\frac{P_F}{P_C}\right)^{1-\mu_C}\right]^{\frac{1}{1-\mu_C}} && \text{(C.95)}\\
\frac{P_H}{P_C} &= \frac{1}{[\mathrm{w}_C + (1-\mathrm{w}_C)\mathcal{T}^{1-\mu_C}]^{\frac{1}{1-\mu_C}}} && \text{(C.96)}\\
C_H &= \mathrm{w}_C\left(\frac{P_H}{P_C}\right)^{-\mu_C} C && \text{(C.97)}\\
C_F &= (1-\mathrm{w}_C)\left(\frac{P_F}{P_C}\right)^{-\mu_C} C && \text{(C.98)}\\
{C_H}^* &= (1-\omega^*_C)\left(\frac{P_H}{P_C RER_C}\right)^{-\mu^*_C} C^* && \text{(C.99)}\\
H(1-\xi_H\beta) &= YU_C && \text{(C.100)}\\
J(1-\xi_H\beta) &= \frac{1}{1-\frac{1}{\zeta}}YU_C MC && \text{(C.101)}\\
MC: \quad H &= J && \text{(C.102)}\\
MC &= 1-\frac{1}{\zeta} = \frac{C_2}{\alpha Y \frac{P_H}{P_C}} && \text{(C.103)}
\end{aligned}$$

$$
\begin{aligned}
Y &= (1-c)(AL)^{\alpha}K^{1-\alpha} && \text{(C.104)}\\
\frac{P_H^W}{P_C} &= MC\frac{P_H}{P_C} && \text{(C.105)}\\
K &= \frac{(1-\alpha)MC\frac{P_H}{P_C}Y}{(R+\delta)Q} && \text{(C.106)}\\
1+R &= \frac{1+R_n}{\Pi} && \text{(C.107)}\\
I &= (g+\delta)K && \text{(C.108)}\\
X &= 1 && \text{(C.109)}\\
S(X) &= S'(X)=0 && \text{(C.110)}\\
Q &= \frac{P_I}{P_C} && \text{(C.111)}\\
I_H &= \mathrm{w}_I\left(\frac{P_H/P_C}{P_I/P_C}\right)^{-\mu_I} I && \text{(C.112)}\\
I_F &= (1-\mathrm{w}_I)\left(\frac{P_F/P_C}{P_I/P_C}\right)^{-\mu_I} I && \text{(C.113)}\\
I_H^* &= (1-\omega_I^*)\left(\frac{P_H}{PRER}\right)^{-\mu_I^*} I^* && \text{(C.114)}\\
\frac{P_I}{P_C} &= \left[\mathrm{w}_I\left(\frac{P_H}{P_C}\right)^{1-\mu_I}+(1-\mathrm{w}_I)\left(\frac{P_F}{P_C}\right)^{1-\mu_I}\right]^{\frac{1}{1-\mu_I}} && \text{(C.115)}\\
Y &= C_H+I_H+EX_C+EX_I+G_t && \text{(C.116)}\\
EX_C &= C_{H,t}^*=(1-\omega_{C,t}^*)\left(\frac{P_H}{P_C RER_C}\right)^{-\mu_C^*} C^* && \text{(C.117)}\\
EX_I &= I_{H,t}^*=(1-\omega_{I,t}^*)\left(\frac{P_H}{P_I RER_I}\right)^{-\mu_I^*} I^* && \text{(C.118)}\\
RER_C &= \frac{1}{\left[1-\mathrm{w}_C+\mathrm{w}_C\mathcal{T}^{\mu_C-1}\right]^{\frac{1}{1-\mu_C}}} && \text{(C.119)}\\
RER_I &= \frac{1}{\left[1-\mathrm{w}_I+\mathrm{w}_I\mathcal{T}^{\mu_I-1}\right]^{\frac{1}{1-\mu_I}}} && \text{(C.120)}\\
R_n^*:\quad 1 &= \beta(1+R_n^*) && \text{(C.121)}\\
1+R^* &= \frac{1+R_n^*}{\Pi^*} && \text{(C.122)}
\end{aligned}
$$

The model is complete if we pin down the steady state of the foreign assets or equivalently the trade balance (TB). In other words, there is a unique model associated with any choice of the long-run assets of our SOE.[17] The trade balance is

$$
TB = P_H Y - P_C C - P_I I - P_H G = \underbrace{P_H EX_C - (P_C C - P_H C_H)}_{\text{Net Exports of C-goods}} + \underbrace{P_H EX_I - (P_I I - P_H I_H)}_{\text{Net Exports of I-goods}} \qquad \text{(C.123)}
$$

[17] The same point applies to government debt when we introduce fiscal policy.

using (C.116), for some choice of TB, say zero.

The problem now is that we need to force the non-linear model to this steady state even when the latter may not be completely accurate. A way of doing this is to add a term $\theta_{tb}\log(TB_t/TB)$ to the Taylor rule with a very small $\theta_{tb} > 0$ so that when there is a trade surplus the rule makes the nominal exchange rate appreciate slightly.

Finally we calibrate ω_C and ω_I using trade data. From (C.123) we have

$$cs_{imp} \equiv \frac{\text{C-imports}}{\text{GDP}} = \frac{C_F}{Y} = c_y(1-\text{w}_C)\left(\frac{P_F}{P_C}\right)^{-\mu_C} \tag{C.124}$$

$$is_{imp} \equiv \frac{\text{I-imports}}{\text{GDP}} = \frac{I_F}{Y} = i_y(1-\text{w}_I)\left(\frac{P_F}{P_I}\right)^{-\mu_I} \tag{C.125}$$

$$cs_{exp} \equiv \frac{\text{C-exports}}{\text{GDP}} = (1-\omega_C^*)\left(\frac{P_H}{P_C RER_C}\right)^{-\mu_C^*} c_y^*\frac{Y^*}{Y} = \frac{C_H^*}{Y} \tag{C.126}$$

$$is_{exp} \equiv \frac{\text{I-exports}}{\text{GDP}} = (1-\omega_I^*)\left(\frac{P_H}{P_I RER_I}\right)^{-\mu_I^*} i_y^*\frac{Y^*}{Y} = \frac{I_H^*}{Y} \tag{C.127}$$

Hence using data for shares cs_{imp}, is_{imp}, cs_{exp} and is_{exp}, we can calibrate ω_C and ω_I. Use data for India: $cs_{imp} = 0.10$, $is_{imp} = 0.15$, $cs_{exp} = 0.23$ and $is_{exp} = 0.02$ for $TB = 0$. With balanced steady-state growth, the balanced growth steady state path of the model economy with or without investment costs is given by $Q = 1$ and

$$\frac{\bar{\Lambda}_{C,t+1}}{\bar{\Lambda}_{C,t}} \equiv 1 + g_{\Lambda_C} = \left[\frac{\bar{C}_{t+1}}{\bar{C}_t}\right]^{(1-\varrho)(1-\sigma)-1} = (1+g)^{((1-\varrho)(1-\sigma)-1)} \tag{C.128}$$

Thus from (C.39)

$$1 + R = \frac{(1+g)^{1+(\sigma-1)(1-\varrho)}}{\beta} \tag{C.129}$$

Similarly for the foreign bloc

$$1 + R^* = \frac{(1+g^*)^{1+(\sigma^*-1)(1-\varrho^*)}}{\beta^*} \tag{C.130}$$

It is then possible to have different preferences, inflation and growth rates provided

$$\frac{1+R_n}{1+R_n^*} = \phi\left(\frac{SB}{P}\right) = \frac{\Pi(1+R)}{\Pi^*(1+R^*)} = \frac{\Pi\beta^*}{\Pi^*\beta}\frac{(1+g)^{1+(\sigma-1)(1-\varrho)}}{(1+g^*)^{1+(\sigma^*-1)(1-\varrho^*)}} \tag{C.131}$$

which pins down the assets in the steady state.

D Summary of Open Economy Model with Financial Frictions: Complete Exchange Rate Pass-Through

Note that there are already two financial frictions in the previous model: Ricardian households pay a risk premium for their international borrowing there are liquidity constrained households. To complete the model we add a financial accelerator consisting of

$$E_t[1+R_{k,t+1}] = E_t\left[\Theta_{t+1}\left(\varphi E_t\left[(1+R_{t+1})\right]+(1-\varphi)E_t\left((1+R^*_{t+1})\frac{RER_{C,t+1}}{RER_{C,t}}\right)\right)\right] \tag{D.132}$$

$$\Theta_t = k\left(\frac{N_t}{Q_{t-1}K_t}\right)^{-\chi} \tag{D.133}$$

$$N_{t+1} = \xi_e V_t + (1-\xi_e)D^e_t \tag{D.134}$$

$$V_t = (1+R_{k,t})Q_{t-1}K_t - \Theta_t\left[\varphi(1+R_t)+(1-\varphi)(1+R^*_t)\frac{RER_{C,t}}{RER_{C,t-1}}\right](Q_{t-1}K_t - N_t) \tag{D.135}$$

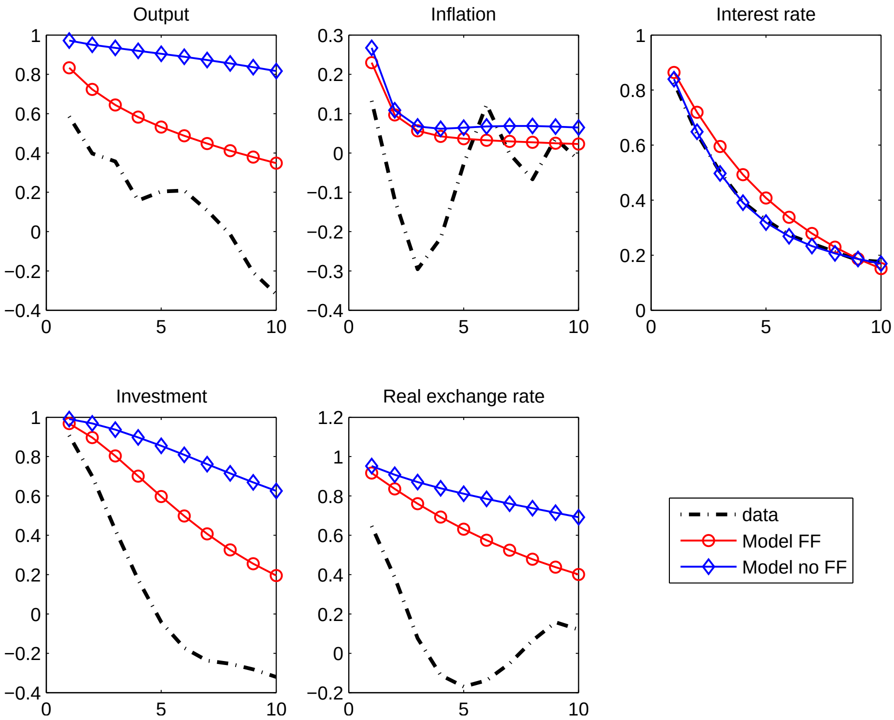

FIGURE 1: AUTOCORRELATIONS OF OBSERVABLES IN THE ACTUAL DATA AND IN THE ESTIMATED MODELS

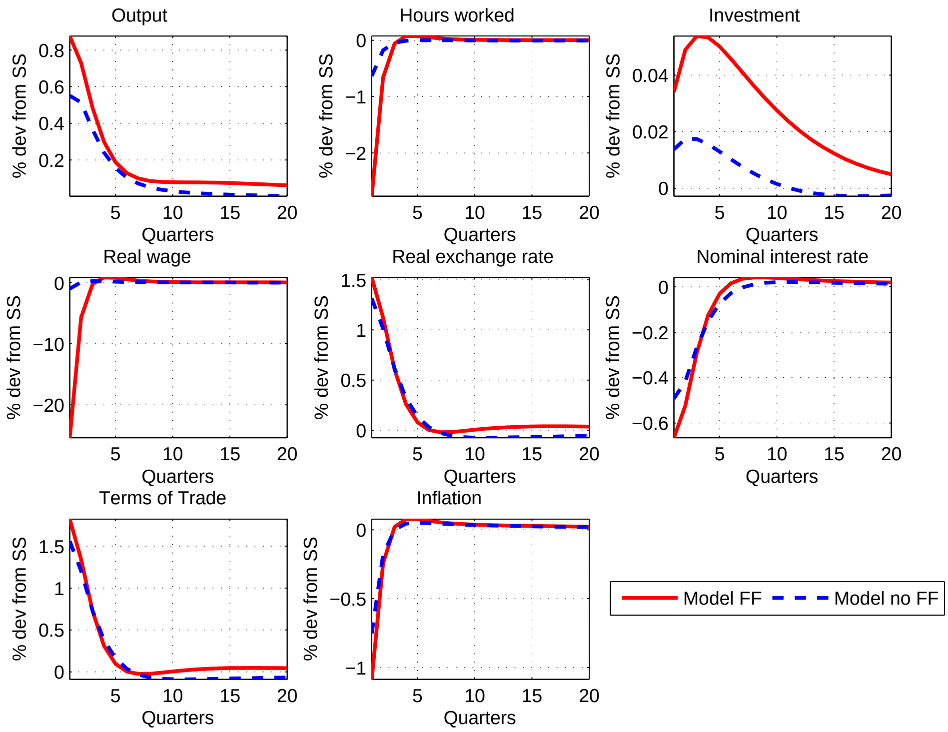

Figure 2: Estimated Impulse Responses to a Positive Productivity Shock$^{\diamond}$

$^{\diamond}$ Each panel plots the mean response corresponding a positive one standard deviation shock. Each response is for a 20 quarters (5 years) horizon. All DSGE impulse responses are computed simulating the vector of model parameters at the posterior mean values reported in Table 3.

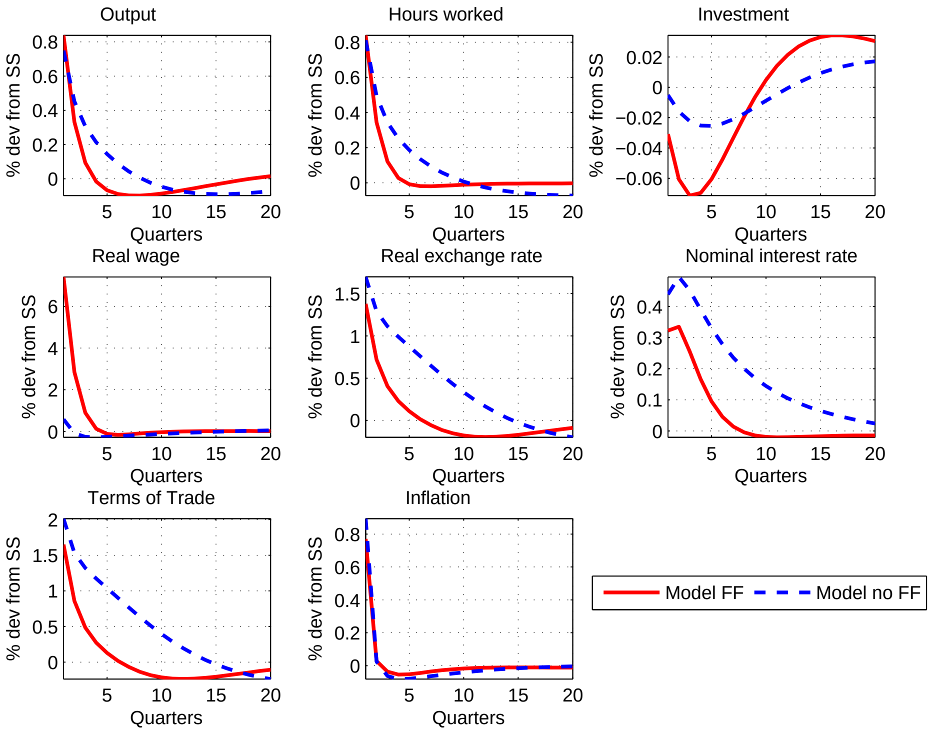

Figure 3: Estimated Impulse Responses to a Positive UIP Shock