Are Global Spillovers Complementary or Competitive? Need for International Policy Coordination

April 2020

Abstract

Advanced and emerging economies are becoming more interdependent with rapid pace of globalization of capital markets and technological innovations in recent years. We examine whether technology and monetary policy shocks get transmitted between advanced and emerging market economies and to what extent they generate complementary or competitive effects. Given the globally integrated nature of capital markets, we uncover a transmission mechanism by which technology and policy shocks in advanced and emerging countries spill over between them through the capital flow channel. We mainly investigate whether analysis from a SVAR model by econometricians provides empirically similar conclusions to those from a macroeconomic theory-based DSGE model in measuring the impact of demand-side policy and technology shocks. We fit our VAR models to the same time series data used to calibrate and estimate the DSGE model. We conclude that monetary and fiscal policy shocks are competitive between the US (advanced economy) and India (emerging market), while domestic and global technology shocks or the exchange rate shocks have complementary effects. Intuitively, technology enhances productivity in both countries, while policy shocks tend to drive capital to a country with higher rate of return. Thus policy shocks in advanced countries could have unintended effects in terms of capital inflows to emerging economies and hence greater coordination of policies can help limit adverse cross-border spillovers.

JEL classification: C61, E61, C32

Keywords: Structural VAR, DSGE Model, Spillovers, Economic Growth, Policy Coordination, India, US

1 Introduction

Growing bilateral and multilateral cooperation is making advanced and emerging economies more interdependent. Both demand and supply sides of emerging or developing countries are affected when advanced countries change their fiscal, monetary and trade policies. The major economies are also influenced by policies adopted in emerging or developing countries. While the financial variables in emerging economies are sensitive to the real interest rate, stock prices and real exchange rates in advanced economies, macroeconomic conditions in emerging countries have significant effects in major economies (Aizenman et al. [2016]). The financial meltdown of September 2008 and the prolonged recession that followed in the EU and US raised concerns on the adverse impacts of non-cooperation and the need for macroeconomic policy coordination on bilateral and multilateral basis (Bernanke [2020], Ascari et al. [2017] and Mishkin [2017]). Cooperative mechanisms require evaluation of likely scenarios in order to illustrate the degree of interactions and interdependence in the global economy (Haskel and Westlake [2018], Weale and Wieladek [2016]). Central bank cooperation is worth pursuing to mitigate global uncertainty even though the apparent welfare gains are not very large (Ostry and Ghosh [2016]).

Following the global financial crisis of 2008-09, bond markets have been highly volatile reflecting uncertainty about the conduct of monetary policy or the fragility of leveraged financial institutions. Such financial market implications of monetary policy were given limited attention in modern macroeconomics (Stiglitz [2018]). As the policy rate in advanced countries stays near zero, interest rate expectations and long-term interest rates remain low, thus making investment in emerging market dollar-denominated bonds more attractive. In particular, global capital flows turned towards the emerging markets and the volatility of these flows raised concerns about the need for macroeconomic policy coordination. Recent episodes of financial turmoil have highlighted the need to understand how external shocks are propagated in emerging economies since these economies face additional vulnerabilities in the form of imperfect access to capital markets and fragile financial sectors. Furthermore, technological innovations after the Internet and information revolution have been very fast and spreading very quickly from advanced to emerging economies.

While the share of advanced economies in the global nominal GDP fell from 76% in 1980 to 60% in 2018, the share of emerging and developing economies increased from 24% to 40% during the same period (see Figure 1 below). From Figure 9 in Appendix A, it is clear that the global share of advanced economies fell even more sharply (Panel (a)) but for emerging economies the share rose steeply (Panel (b)). These figures further illustrate the increasing interdependence and interactions between developed and emerging market economies in the context of the global financial crisis. Analysing the business cycle movements and interactions among them requires models with a global approach, that we intend to pursue in this study.

One main objective of this paper is to build on a small scale global economy model to measure the impacts of technological and policy shocks in the midst of international financial frictions, with the possibility of international risk sharing. We take the US as a representative country for

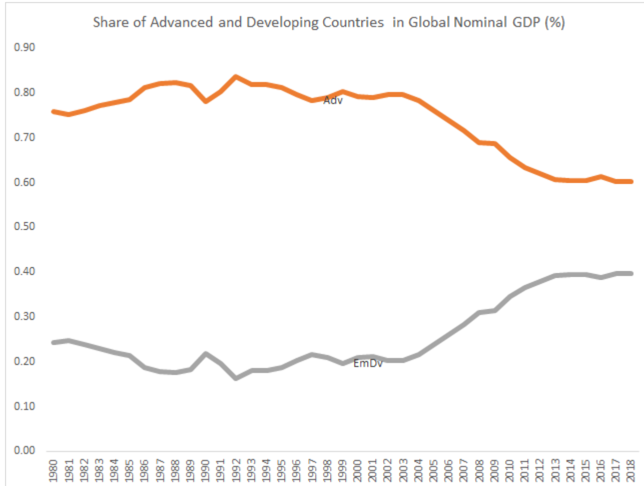


Figure 1: Shares of Advanced and Emerging Economies in the Global Nominal GDP (1980-2018)
Note: The y-axis shows percentage share. The x-axis shows years. Data source: the IMF.

the advanced economies and India to represent the emerging economies. India is now the 5th largest economy in the world, according to the IMF. There is evidence of up to 46% spillover to the growth of the US coming from other economies, and 33% of India's growth spillover occurs mainly from advanced countries, particularly the US (Table 5 in Appendix B). Given this significant spillover, potential gains can be expected from policy coordination between India and the US. From the early 1990s, high growth rates in India were accompanied by a significant wave of trade and financial liberalization, with export promotion involving skill-intensive sectors. Given the stage of development of India's financial and trade openness, this implies that the policymakers, in their quest for price and financial stability, face significant challenges to ensure stable monetary conditions in response to external shocks, and to realise India's current ambition for becoming a five trillion dollar economy by 2025. This, in turn, requires careful investigation of the spillover effects that contribute to the propagation of economic shocks hitting the economy.

In this paper we also aim to make methodological and empirical contributions to the existing literature by producing results with two popular macroeconomic models, (1) a prototypical structural model, i.e., a dynamic stochastic general equilibrium (DSGE) model, and (2) an empirical multivariate autoregressive vector autoregressive model (VAR). Methodological contribution comes from our integration of VAR analysis to the DSGE analysis by combining the flexibility of the VAR and the rich cross-equations restrictions of the DSGE model. Then empirically to assess interdependence, using the same quarterly time series dataset of the US and India, we estimate and compare the impulse responses as well as the uncertainty surrounding them from the VAR to the DSGE model for these two economies. We aim to illustrate acceptable empirical fit for the set of key macro-variables and generate their reliable moments for future policy analysis. Our finding is that a well-specified SVAR model and the estimated DSGE model lead to similar conclusions on assessment of spillover effects among these economies.

The evaluation of the two models is qualitative: it is intended to examine whether the dynamics of the model and the data are broadly consistent, or whether a particular structural DSGE model is able to mimic the dynamic properties captured by the VAR model. The difficulty in identifying structural disturbances using data-coherent VARs is always subject to numerous debates in the literature and the VAR models can typically perform poorly at predicting population moments because of over-parameterization. DSGE models, on the other hand, are tightly parameterized, and, despite their negative trade-off between theoretical consistency and data coherence in macroeconomic modeling, these models can provide a unique identification mapping between economic shocks and tight cross-equation restrictions.[1]

While there is a substantial body of literature devoted to understanding the business cycle dynamics and policy transmission between developed economies, research focusing on the interdependence between emerging and developed economies is relatively sparse.[2] In addition, our main modelling contributions lie in the use of a variant of uncovered interest rate parity (UIP) in the two-country framework of Lubik and Schorfheide [2005]. We extend the framework where the domestic economy faces a shock to the country's external risk premium, and undertake an empirical VAR imposing sign restrictions for shock identification that provide explicit ways to interpret spillover effects.[3] This paper is, to the best of our knowledge, the first to simultaneously estimate a two-country structural model and an empirical model comprising an emerging and a developed economy. Economists often use VAR and DSGE models separately to identify economic shocks and answer policy questions but our interest here is to assess to what extent results of these two models are comparable in assessing impacts of policy and technology shocks between these economies.

In this paper we examine each model uncovering a number of interesting results from the analysis. Our impulse response and variance decomposition estimation results are similar in the traditional VAR and estimated DSGE models. Based on the comparable results from the VAR and DSGE models, monetary and fiscal policy shocks are found to be competitive between the US (advanced economy) and India (emerging market), while domestic and global technology shocks or the ex-

[1] A growing number of criticisms has been leveled against DSGE models (and much more severely against VARs and their identifiability). The concerns of prevailing approaches to macroeconomic modeling are now driving research into more flexible Agent-Based (AB) models to connect the real and financial sides of the economy (Caiani et al. [2016]). However, VAR and DSGE models are still very popular in analysing macroeconomic interactions (Blanchard et al. [2017]).

[2] We acknowledge that estimation of global VAR (GVAR) models has been popular to construct a multi-country framework to assess the dynamic movement of key economic variables in response to simultaneous shocks. These models can account for interaction between a large number/groups of countries and capture many potential inter-country linkages.

[3] The UIP assumption is also motivated by the stylized facts reported in Banerjee and Basu [2016] which reveal statistically significant correlation between interest rate differential (between RBI Repo rate and Federal Fund's rate) and home currency depreciation for both raw data and data filtered for the business cycle component.

change rate shocks have complementary effects. We have quantified the extent of complementary and competitive spillover effects of technology (TFP) and monetary policy shocks respectively between these two countries. Intuitively, technology enhances productivity in both countries, while policy shocks tend to drive capital to a country with higher rate of return. Thus policy shocks in advanced countries could have unintended effects in terms of capital inflows to emerging economies. Proper quantification of such positive or complementary effects and negative or competitive effects can help determine appropriate actions for policy coordination. Such coordination can enhance economic growth and macroeconomic stability in both countries.[4]

The rest of the paper proceeds as follows. Section 2 provides a VAR model specification and discusses its various identification schemes. We then describe the specification of the two-country global economy DSGE model with a risk premium in the interest rate in Section 3 and Appendix C. Our estimation results of the DSGE model and the SVAR are analysed in greater detail in Section 4. Conclusions of the study are in Section 5.

2 A Two-country VAR Model to Assess Shock Spillovers

Growth spillovers occur in the global economy. For instance, about 46% of growth in the US are due to external factors compared with 33% for India. External factors are more important for all major countries ranging from 46% for Japan to 67% for France. The global spillover index measures the degree of spillover effect to a particular country from various economies in the world (Diebold and Yilmaz [2009], Stock and Watson [2011]). These spillover effects can vary from time to time (Taylor [1993], Nordhaus et al. [1994])(Table 5 in Appendix B provides a summary of these effects).

In this context considering a two-country VAR model for the US and India, we reinforce between them covering transfer of advanced technologies via FDI and trade. In general, a VAR(1) for endogenous variables Y_t can be represented as

$$Y_t = B^{-1}\Gamma_0 + B^{-1}\Gamma_1 Y_{t-1} + B^{-1}\varepsilon_t$$

The reduced form of this VAR system is then given by

$$Y_t = B_0 + B_1 Y_{t-1} + e_t$$

where $B_0 = B^{-1}\Gamma_0$, $B_1 = B^{-1}\Gamma_1$, $e_t = B^{-1}\varepsilon_t$. We use seven macroeconomic time series for this model as in the DSGE formulation in the next section. Namely, the observables are growth rates,

[4] There are several papers that have also evaluated the need for policy coordination between countries (see, among others, Adam et al. [2012]) and Bucci et al. [2019]). In the early literature, a case was made for coordinating monetary policy reactions across major economies (Adam et al. [2012], Barrell et al. [2003]). Among advanced economies, greater policy coordination with the US occurred in the aftermath of the recent global financial crisis (2008-12) which led to rise in the connectedness of interest rates in the advanced economies (Rohit and Dash [2019], Chang [1997], Borio and Disyatat [2010], Bullard and Singh [2008]). Such coordination however is yet to happen between emerging and advanced economies which can offset the competitive effect that we have observed in our model.

inflation and interest rates in India and the US and the change in the real exchange rate of Indian Rupee against the US dollar, from 1981:1 to 2014:4, so $Y_t = [g_{us,t}, \pi_{us,t}, r_{us,t}, g_{ind,t}, \pi_{ind,t}, r_{ind,t}, ex_{rsd,t}]'$.

We impose structural restrictions for identification of the model. Thus the reduced-form errors and structural errors can be written as an identification system where the reduced-form residuals are mapped to structural shocks. The shock process ε_t is then said to be fundamental for Y_t, with current and past values of the ε_t process. An impulse response function (IRF) associated with an infinite order VAR is by construction a Wold representation describing the VAR-based IRFs. In the VAR literature, there are many different identification strategies that impose enough restrictions to identify the shocks in the VAR. We start with the typical and simple way of achieving this which is to orthogonalize the covariance matrix of the VAR residuals using a Cholesky decomposition or a type of *recursive* identification system.[5] Obviously, because of the simplicity of this method, the identification restrictions imposed regarding the rotation matrix can be inconsistent with the complex structure of DSGE models. To make them comparable and as a robustness check to our main result, we also fit a VAR to the DSGE model generated data and apply the simple Cholesky scheme. We report all the IRF results together in Figures 2 to 6 in Sections 4.2-4.4.

More identification strategies use a *non-recursive* approach of Gordon and Leeper [1994] and Sims and Zha [2005], and a combination of contemporaneous and long-run restrictions on impulse responses as introduced by Blanchard and Quah [1993] and Gali [1992]. Canova and Nicolo [2002] and Uhlig [2005] implement sign restrictions to identify the structural shocks in VARs. A prerequisite for matching/comparing impulse responses is that the identification restrictions imposed on the VAR are consistent and compatible with the theoretical model (e.g., DSGE models).[6] We acknowledge that how identifying our VARs in a way that is consistent with the DSGE model is, in theory, far from straightforward because identification of structural shocks can be subject to nonfundatmentalness.[7] More recent literature stresses this, as econometricians are often only interested in recovering the IRFs for one or a subset of particular shocks from a structural model. In this paper, we address our research question by focusing on the effects from the technology and monetary policy shocks, identifying our SVAR using the sign restriction approach, comparing the results with an estimated DSGE model and another fitted VAR with the Cholesky scheme to a

[5]We first adopt a simple identification strategy, which is based on a timing convention for policy implementation and is satisfied by a Cholesky decomposition with the interest rate ordered first (Christiano et al. [2005]). For instance, for the policy rate shock: if the policymaker observes the variables that enter its Taylor rule (inflation and the output growth) after a lag, the contemporaneous shocks to the other variables in the VAR would not affect the current policy rate, and therefore the non-interest rate elements in one row of B_1 must be set equal to zero.

[6]In addition, a section of our WP paper (not reported here) compares two different versions of Bayesian VAR (BVAR) developed by Doan et al. [1984]. The VAR model is compared to the DSGE model with BVARs estimated under Minnesota-type prior distributions where the prior over the parameters of a VAR(p) is implemented based on observations that take into account the degree of persistence and cointegration of the variables. We find that the forecasting performance measured by RMSEs from our estimated VAR is comparable with that of the BVAR, whereas the latter model uses prior information that may improve the in-sample fit of the VAR.

[7]The issue of invertibility or fundamentalness (i.e., how informationally sufficient SVARs can validate DSGE models) has been extensively reviewed and studied in Forni et al. [2016]) and Beaudry et al. [2016].

DSGE-generated sample.

Unlike the traditional VAR approach, in order to completely identify the system with the international linkages in a VAR, we follow Uhlig [2005] which proposes imposing sign restrictions on the IRFs. We use the reduced-form of the above VAR model of order p with the following standard representation

$$Y_t = B(L)\, Y_{t-1} + u_t$$

where $B(L)$ is now a lag polynomial of order p and the covariance matrix of the vector of reduced-form residuals u_t is denoted as Σ.

Uhlig [2005]'s identification method searches over the space of possible impulse vectors, $A_i \varepsilon^i$, to find those impulse responses that agree with standard theory. We undertake the sign-VAR approach with sign restrictions in order to identify the two shocks. The aim is to identify an impulse vector, a, where $a \in \Re^n$, if there is some matrix A, such that $AA' = \Sigma$ of n by n dimension, where $A = [a_1, ..., a_n]$, so that a is a column vector of A. As a result, a is an impulse vector if and only if there is an n-dimensional vector α of unit length so that $a = A'\alpha$ and, hence,

$$\Sigma = AA' = \sum_{i=1}^{n} a_i a_i'$$

Once the impulse vector a has been appropriated, the impulse response is calculated as

$$\varepsilon_a(k) = \sum_{i=1}^{n} \alpha_i \varepsilon_i(k)$$

where $\varepsilon_i(k) \in \Re^n$ is the vector response at horizon k to the i^{th} shock in a Cholesky decomposition of Σ (Uhlig [2005]). This way, we obtain a range of impulse responses that are compatible with the sign restrictions.

The following sign restrictions can help us establish the linkage between the two countries and identify the shocks (see Table 1 below). Four restrictions are imposed to identify a technology shock – an increase in the US growth rate, a reduction in inflation and interest rates, and an increase in India's growth rate through the trade and investment channels. We also jointly identify a monetary policy shock, by imposing another four restrictions that an increase in US interest rate could lower growth rate and inflation, but it could give rise to a similar increase in Indian interest rate. The contradictory signs between the two shocks on the GDP growth rate and the interest rate will correctly identify both of these shocks. In terms of linkage between two countries, we rely on the assumption that an increase in the US growth rate and the US interest rate will have similar increase in the foreign country, given the integrated nature of trade and capital flows.

These restrictions seem reasonable in the light of the observed pattern in the data (Mallick et al. [2017]). As growth rate increases due to a technology shock, inflation could decline leading to lower interest rate in the home country, while a technology shock in the home country could increase demand for foreign goods and thus higher output growth in the foreign country. But

Shocks	g_{us}	π_{us}	r_{us}	g_{ind}	π_{ind}	r_{ind}	ex_{rsd}
$\text{US}_{\text{Technology}}$	+	-	-	+			
$\text{US}_{\text{Policy}}$	-	-	+			+	
$\text{India}_{\text{Technology}}$	+			+	-	-	
$\text{India}_{\text{Policy}}$			+	-	-	+	

Table 1: Identifying Sign Restrictions

we do not pre-judge the inflation and interest rate outcomes in the foreign country, as we would like this to be revealed from the impulse response functions. Also exchange rate changes can either exhibit depreciation or appreciation. The restrictions imposed can help derive the respective impulse vectors, which are defined as innovations to the VAR system in response to a unit shock in each disturbance. We keep those impulse vectors whose impulse response functions satisfy the sign restrictions and discard the others.

Higher interest rate in India raises the cost of capital and lowers growth rate there but does not have significant impact on inflation. This problem is further deteriorated because of appreciation of Rupee which leads to greater competitiveness of the US economy. Expansion in the US production raises interest rates but has no significant impact on inflation. These estimations imply that capital markets are more integrated than the goods markets. Higher interest rate in India raises the interest rate in the US.

How do these impulse responses to technology and monetary shocks from the empirical VAR model compare to the structural shocks in the DSGE model? We complement our econometric model based analysis to a two-country structural DSGE model for the US and India in the next section. In what follows, we first provide some references within the macroeconomic literature that have focused on studying policy coordination, before we also briefly review the literature on open economy DSGE models.

3 A Two-country DSGE Model for the Global Economy

The literature on open economy models dates back to the late 1960's and 70's (Kumar [1969], Cooper [1969] and Hamada [1976]), examining policy formulation with the inclusion of international capital movements in a two-country framework, which can increase interdependence between countries through policy coordination. More recent studies of policy coordination include Barrell et al. [2003], Adam et al. [2012], Bucci et al. [2019], Rohit and Dash [2019], Davoine and Molnar [2020] and Devereux et al. [2020], and mainly focus on advanced economies. Adam et al. [2012] and Barrell et al. [2003] both discuss cases for coordinating monetary policy across major economies, while the former conduct a comparative analysis on the evolution of international coordination across different policy phases since the beginning of the Bretton Woods system, the latter results are based on stochastic simulations of different regimes using an econometric model. The policy discussions focusing on regional coordination in Bucci et al. [2019] are based on the causal relationship between the degree of financial crisis contagion and macroeconomic activities examined in a spatial framework. Davoine and Molnar [2020] show how capital-skill complementarity can lead to large spillovers, and that particularly the fiscal policy spillover can be large when monetary policy is close to hitting the zero lower bound constraint. By treating a calibrated DSGE model as the data generating process, Devereux et al. [2020] conduct optimal policy analysis for financially integrated economies using an identified SVAR and show how the financial integration can raise welfare under coordination.

3.1 The Baseline and Open Economy Models

Let us consider a global economy consisting of home and foreign countries, indexed by $k = H, F$. In each country there is a representative household that works, earns income, consumes and accumulates assets. There are firms that produce differentiated goods and supply to home and foreign markets. Each country has a government that provides public services collecting revenue from taxes and a central bank that decides on the interest rate following a Taylor rule. Households purchase home and foreign bonds and pay a risk premium to protect themselves to the volatility of exchange rates between these two economies. The household and firm sectors are standard in the literature and are therefore set out in Appendix C. In what follows, we modify the standard Lubik and Schorfheide [2005] two-country DSGE economy model with a risk premium adjustment in the foreign exchange market in order to assess how the policy spillover effects transmit from an advanced to an emerging economy or the other way round. The analysis focuses on business cycle impacts of shocks to the technology as well as demand management using monetary policy as in the VAR model in the last section.

The model developed in this section is based on an extension of a category of standard small scale models which have been theoretically stylized at its early stage and subsequently estimated by a number of authors.[8] Our model thus shares a number of common features with these models. Other developments have focused on larger and more realistic open economy and two- or multi-country features, differences in the transmission mechanism of monetary policy, and features that are important to model the exchange rate pass-through to domestic currency prices (Adolfson et al. [2007], Corsetti and Dedola [2005]). More recent papers have studied the role of financial and credit market frictions, allowing a structural interpretation of movements observed in exchange rates and trade balances (e.g. Jacob and Peersman [2013]).

The main objective in this section is to build on the open economy model and construct an international financial friction, with the possibility of international risk sharing, for the US and India. We take inspiration from Benigno [2002] and provide the model with a variant in which UIP no longer holds. This highlights the deviation from risk sharing under complete international

[8]See, for example, Bergin [2006], Lubik and Schorfheide [2005], Lubik and Schorfheide [2007] and Rabanal and Tuesta [2010].

financial markets between the two economies. We bring together the features in the context of an open economy, including incomplete exchange rate pass-through. The pass-through from exchange rate movements to domestic prices is reduced in this model due to the existence of monopolistically competitive domestic importers whose optimal pricing behaviour produces endogenous deviations from PPP in the short run (following Lubik and Schorfheide [2005]).[9]

The two countries have different sizes and different technologies. Indeed part of the model is calibrated mainly on the basis of this, but we assume that they share the similar structure and nominal rigidities for the purpose of the analysis in this paper. This assumption is consistent with our VAR specification. However, any model is not without caveats. One potentially important feature that has become popular especially in the small open economy (SOE) modelling and is widely accepted in the literature on emerging economies as an important transmission channel of shocks is in the form of liquidity constrained 'rule of thumb' consumers. In India, 'rule of thumb' consumers constitute a significant proportion of households and this category of consumers comprises those who are unable to smooth consumption overtime due to the lack of access to financial services. The presence of a significant fraction of households being non-Ricardian, coupled with their inaccessibility to formal financial services should amplify the propagation of shocks in a relatively more volatile output environment of India (see Gabriel et al. [2012] and Gabriel et al. [2016]). The main objective of this paper, along with these features, is to uncover and evaluate the interconnections and spillover effects in the two-country setting.

3.2 Risk Premium and UIP

The model in Appendices C and D is set out without financial frictions where UIP holds; this means perfect international risk-sharing. More realistic set up here would be to consider a modified UIP condition assuming that households face a risk premium on international asset markets. Departing from the representative household behaviour we incorporate a world financial friction facing households as in Benigno [2002]. In particular, there are two risk-free one-period bonds denominated in home and foreign currencies with payments in period t, $B_{k,H,t}$ and $B^*_{k,F,t}$, respectively, in per capita or aggregate terms. The prices of these bonds are given by

$$P_{k,B,t} = R_{k,t}^{-1} \tag{1}$$

$$P^*_{k,B,t} = R_{k,t}^{*-1}\phi\left(\frac{e_t B^*_{k,F,t}}{P_{k,H,t}Y_{k,t}}\right)^{-1} \tag{2}$$

where $\phi(\cdot)$ captures the cost in the form of a risk premium for home households to hold foreign (F) bonds. $e_t B^*_{k,F,t}$ is the aggregate foreign asset position of the economy denominated in home

[9] An alternative mechanism that may be important to slow down the pass-through of changes in exchange rates or foreign prices can be constructed by attributing a role of tradable and non-tradable goods or of a distribution sector in the model, as in Corsetti and Dedola [2005] or Corsetti et al. [2008]. Both features are likely to affect the pass-through towards import and consumption prices in the short run.

currency, where e_t is the nominal exchange rate and $P_{k,H,t}Y_{k,t}$ is nominal GDP. We assume that $\phi(0) = 1$ and $\phi' < 0$. This means the risk premium term is strictly decreasing in aggregate foreign asset position of the home economy. $R_{k,t}$ and $R^*_{k,t}$ denote the nominal interest rates over the interval $[t, t+1]$. The price of the nominal bond depends inversely on its gross nominal interest rate. For analytical convenience, the home households can hold foreign bonds, but foreign households cannot hold home bonds. Then the net and gross foreign assets in the home bloc are equal.

The standard inter-temporal optimality conditions for consumption decisions of households are

$$P_{k,B,t} = \beta_k E_t \left[\frac{\lambda_{k,t+1}}{\lambda_{k,t}\Pi_{k,t+1}} \right] \tag{3}$$

$$P^*_{B,t} = \beta_k E_t \left[\frac{\lambda_{k,t+1}e_{t+1}}{\lambda_{k,t}\Pi_{k,t+1}e_t} \right] \tag{4}$$

where β_k is the discount factor as defined in Appendix C, $\Pi_{k,t} \equiv \frac{P_{k,t}}{P_{k,t-1}}$ is consumer price inflation (CPI) and $\lambda_{k,t}$ is the marginal utility of income. The producers' decisions are as before, except, $\Pi_{k,t}$ is replaced with domestic price inflation $\Pi_{k,H,t} \equiv \frac{P_{k,H,t}}{P_{k,H,t-1}}$ which differs from consumer price inflation. Same for the importers; so import price inflation is $\Pi_{k,F,t} \equiv \frac{P_{k,F,t}}{P_{k,F,t-1}}$.

Combining the home and foreign Euler equations, we arrive at the *modified UIP condition*

$$\frac{P_{k,B,t}}{P^*_{k,B,t}} = \frac{E_t\left[\lambda_{k,t+1}\frac{P_{k,t}}{P_{k,t+1}}\right]}{E_t\left[\lambda_{k,t+1}\frac{e_{t+1}P_{k,t}}{e_t P_{k,t+1}}\right]}$$

then adding a risk premium shock in period $t-1$, $\exp(\epsilon_{UIP,t})$, that captures stochastic deviations from the UIP condition, and using (1), (2), (3), (4) and

$$R^{*-1}_{k,t} = \beta_k E_t \left[\frac{\lambda^*_{k,t+1}}{\lambda^*_{k,t}\Pi^*_{k,t+1}} \right]$$

we obtain

$$\phi\left(\frac{e_t B^*_{k,F,t}}{P_{k,H,t}Y_{k,t}}\right)\exp(\epsilon_{UIP,t}) E_t \left[\frac{\lambda^*_{k,t+1}}{\lambda^*_{k,t}\Pi^*_{k,t+1}} \right] = E_t \left[\frac{\lambda_{k,t+1}e_{t+1}}{\lambda_{k,t}\Pi_{k,t+1}e_t} \right]$$

Now defining the risk sharing condition $s^r_{k,t} = \frac{\lambda^*_{k,t}}{\lambda_{k,t}}$, and noting that $\frac{e_{t+1}}{\Pi_{t+1}e_t} = \frac{e_{t+1}P_t}{P_{t+1}S_t} = \frac{s_{t+1}}{s_t\Pi^*_{t+1}}$, we then obtain the real exchange rate s_t as $s_{k,t} = s^d_{k,t}s^r_{k,t}$, where the deviation of the real exchange rate from its risk-sharing value, s^d_t, is given by

$$E_t \left[\frac{\lambda_{k,t+1}}{\lambda_{k,t}} \frac{s^r_{k,t+1}}{s^r_{k,t}} \frac{1}{\Pi^*_{k,t+1}} \left(\frac{1}{\phi(\frac{e_t B^*_{k,F,t}}{P_{k,H,t}Y_t})\exp(\epsilon_{UIP,t})} - \frac{s^d_{k,t+1}}{s^d_{k,t}} \right) \right] = 0$$

The real exchange rate is same as before, $s_{k,t} = \frac{e_t P^*_{k,t}}{P_{k,t}}$. Finally current account dynamics are given by

$$
\begin{aligned}
R_{k,t}^{*-1}\phi(\frac{e_t B_{k,F,t}^*}{P_{k,H,t}Y_{k,t}})e_t B_{k,F,t}^* &= S_{k,t}B_{k,F,t-1}^* + TB_{k,t} \\
\phi(\frac{e_t B_{k,F,t}^*}{P_{k,H,t}Y_{k,t}}) &= \exp\left(\frac{\chi_B e_t B_{k,F,t}^*}{P_{k,H,t}Y_{k,t}}\right) \ ; \ \chi_B < 0 \\
TB_{k,t} &= P_{k,H,t}Y_{k,t} - P_{k,t}C_{k,t} - P_{k,H,t}G_{k,t}
\end{aligned}
$$

This part of the model is complete by identifying the foreign assets or equivalently the trade balance at home as, $TB_{k,t} = P_{k,B,t}^* e_t B_{k,F,t} - e_t B_{k,F,t-1}$. Linearizing around $B_{k,F} = TB_k = 0$ and defining $\widetilde{b}_{k,F,t} \equiv \frac{S_{k,t}B_{k,F,t}}{P_{k,H,t}Y_{k,t}}$ and $\widetilde{tb}_{k,t} \equiv \frac{TB_{k,t}}{P_{k,H,t}Y_{k,t}}$, the balance of payments in the linearized form becomes

$$\beta_k \widetilde{b}_{k,F,t} = \widetilde{b}_{k,F,t-1} + \widetilde{tb}_{k,t}$$

The linearized trade balance equation is given by

$$\widetilde{tb}_{k,t} = \widetilde{y}_{k,H,t} - \widetilde{c}_{k,t} - \widetilde{g}_{k,t} + \frac{\alpha_k}{\tau}\widetilde{s}_{k,t} + \alpha_k(1-\alpha_k)\eta_k(\widetilde{q}_{k,t} - \widetilde{q}_{k,t}^*)$$

The real exchange rate is the risk-sharing value plus a risk premium deviation given by the system

$$
\begin{aligned}
\widetilde{s}_{k,t} &= \widetilde{s^r}_{k,t} + \widetilde{s^d}_{k,t} \\
\widetilde{s^r}_{k,t} &= \widetilde{\lambda}_{k,t}^* - \widetilde{\lambda}_{k,t} \\
E_t[\widetilde{s^d}_{k,t+1}] &= \widetilde{s^d}_{k,t} + \delta_r \widetilde{b}_{k,F,t} + \widetilde{\epsilon}_{UIP,t}
\end{aligned}
$$

Finally the additional shock in the system for the Indian bloc is the country-specific risk premium shock (UIP) that follows an AR(1) process

$$\widetilde{\epsilon}_{UIP,t} = \rho_{UIP}\widetilde{\epsilon}_{UIP,t-1} + \varepsilon_{UIP,t}$$

The interest rate rule for this global economy includes adjustments to inflation, the output gap, the exchange rates and shocks to the monetary policy in the form of a Taylor rule given by

$$\widetilde{R}_{k,t} = \rho_{R_k}\widetilde{R}_{k,t-1} + (1-\rho_{R_k})\left[\psi_{1_k}\widetilde{\pi}_{k,t} + \psi_{2_k}\left(\Delta\widetilde{y}_{k,t} + \widetilde{z}_{k,t}\right) + \psi_{3_k}\Delta\widetilde{e}_{t+1}\right] + \epsilon_{k,R,t}$$

where $\epsilon_{k,R,t}$ represents the country-specific monetary policy shock.

4 Model Solutions and Analysis of Results

This model consists of five types of variables and eight shocks: (1) Prices: $\widetilde{P}_{k,t}$, $\widetilde{P}_{k,t}^*$, $\widetilde{P}_{k,H,t}$, $\widetilde{P}_{k,H,t}^*$, $\widetilde{P}_{k,F,t}$, $\widetilde{P}_{k,F,t}^*$, $\widetilde{\lambda}_{k,t}$, $\widetilde{\lambda}_{k,t}^*$, $\widetilde{Q}_{k,t}$, $\widetilde{Q}_{k,t}^*$; (2) Growth and inflation: $\widetilde{y}_{k,H,t}$, $\widetilde{y}_{k,H,t}^*$, $\widetilde{\pi}_{k,H,t}$, $\widetilde{\pi}_{k,H,t}^*$, $\widetilde{\pi}_{k,F,t}$, $\widetilde{\pi}_{k,F,t}^*$; (3) Quantities: $\widetilde{C}_{k,t}$, $\widetilde{C}_{k,t}^*$, $\widetilde{Y}_{k,t}$, $\widetilde{Y}_{k,t}^*$; (4) Interest rates and exchange rates: $R_{k,t}$, $R_{k,t}^*$, $S_{k,t}$,

$R_{k,t}$, $\Delta_{e,t}$; (5) Exchange rate pass-through: $\widetilde{\psi}_{k,F,t}$ and $\widetilde{\psi}^*_{k,F,t}$ and (6) Shocks: A_t, A^*_t, G_t, G^*_t, $\epsilon_{k,R,t}$, $\widetilde{z}_t$, $\widetilde{\epsilon}_{UIP,t}$. Appendix D presents the log-linearization of the baseline non-linear model.

Lubik and Schorfheide [2005] applied their model to study interactions between the US and the Euro area and the business cycle policy spillover effects across the two economies (Goyal [2011], Kose et al. [2008]). We modify the model by augmenting a risk premium mechanism and apply it to study interactions between the US and the Indian economy, particularly to see if this model generates the patterns we observe in macroeconomic time series as demonstrated in the SVAR model earlier.

We use the same time series quarterly observations from 1981:1 to 2014:4 as used in the VAR analysis to estimate this two-country DSGE model with Bayesian methods. The posterior estimates are used to compute impulse responses to technology and policy shocks and for variance decomposition of the key model variables. Using the beta, normal, gamma and inverse gamma priors, we apply the standard Bayesian filtering approach to obtain the posterior means and confidence intervals for the model parameters and shocks.

4.1 Prior and Posterior Estimation

As is standard in the literature, the Bayesian estimation process involves search through the parameter space of θ using appropriate size of steps. The Bayes' theorem is used in order to obtain the posterior distribution on parameters θ, $p\left(\theta|Y^T\right)$, which can be derived by multiplying the prior $(p(\theta))$ by the likelihood function $(p\left(Y^T|\theta\right))$ as: $p\left(\theta|Y^T\right) \propto p\left(Y^T|\theta\right)p(\theta) \equiv \Bbbk\left(\theta|Y^T\right)$, where $\Bbbk\left(\theta|Y^T\right)$ stands for the posterior kernel. The joint posterior distribution of the estimated parameters is obtained in two steps. First, the Kalman filter is used to evaluate the likelihood function from which the posterior mode and the Hessian matrix are obtained via standard numerical optimization routines. Second, the Hessian matrix is then used in the Metropolis-Hastings (MH) algorithm to generate a sample from the posterior distribution. Two parallel chains of 100,000 random draws are used in the Monte Carlo Markov Chain Metropolis-Hastings (MCMC-MH) algorithm, with the variance-covariance matrix of the perturbation term in the algorithm being adjusted in order to obtain reasonable acceptance rates (between 20%-30%).[10] The priors and posterior means along with the confidence intervals of these model parameters are reported in Tables 2 and 3.

The choice of priors for the estimated parameters is usually determined by the theoretical implications of the model and evidence from previous studies. We also 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 previous studies for the US economy (Smets and Wouters [2007] and Lubik and Schorfheide [2005]). For the Indian parameters, we follow Gabriel et al. [2012]. In particular, a few structural parameters are chosen based on the calibrated parameters reflecting steady state values of the observed variables. This applies to the preference and technology parameters (for which we

[10] Convergence of the MCMC chains are checked using the convergence indicators recommended by Brooks and Gelman [1998] to ensure robustness of the parameter estimates.

Parameters		prior mean	post. mean	90% HPD interval		prior	prior sd
Price adjustment by firms in H	θ_H	0.50	0.7394	0.6714	0.8089	beta	0.10
Price adjustment by firms in F	θ_F	0.50	0.7834	0.6989	0.8689	beta	0.10
Asset price adjustment in H	θ_H^*	0.50	0.6255	0.4236	0.8358	beta	0.15
Asset price adjustment in F	θ_F^*	0.50	0.9173	0.8896	0.9434	beta	0.15
Intertemporal subst. elasticity in H	τ	2.00	3.0291	1.9403	4.3571	gamma	0.50
Habit formation in H	h	0.70	0.6786	0.5589	0.8008	beta	0.10
CES elasticity for consumption in H	η	1.00	0.9044	0.5248	1.2707	gamma	0.50
Intertemporal subst. elasticity in F	τ^*	2.00	2.8560	2.1594	3.5596	gamma	0.50
Habit formation in F	h^*	0.50	0.8470	0.7755	0.9031	beta	0.20
CES elasticity in consumption in F	η^*	1.50	0.6133	0.2504	0.9370	gamma	0.50
Import share for H	α	0.38	0.3092	0.2498	0.3704	beta	0.05
Risk premium in exchange rate	δ	0.01	0.0049	0.0021	0.0077	invg	4.00

Table 2: Prior and Posterior Distributions for Home (H) and Foreign Countries (F)

do not impose a symmetry condition between the US and India). Using trade data for shares, the domestic import share parameter, α, is calibrated to be 0.38 as set out as in Gabriel et al. [2016]: $\alpha = 1 - (\frac{C}{Y} - cs_{imp})/\frac{C}{Y} = 1 - (0.6 - 0.23)/0.6 = 0.38$, where cs_{imp} is the imported consumption share in India and $\frac{C}{Y}$ reflects the steady state values of the observed consumption and GDP. The calibrated α then forms the prior mean. The elasticity of substitution between consumption goods has different prior means, centred at 1 and 1.5, for η and η^*, respectively.[11] The risk aversion parameter τ allows significant room for manoeuvre, with a normal prior defined with a mean of 2 and standard deviation of 0.5, same for both countries, whereas the habit parameter h for India is centred in the midpoint of the unit interval with a large standard deviation of 0.2, reflecting the uncertainty of the parameter value. For the price-setting parameters θ and θ^*, again we assume asymmetry in prior beliefs. The Calvo-pricing parameters for domestic/foreign firms and importers are beta distributed at 0.5 and 0.75 means, implying a contract length of 2 and 4 quarters. Both are assuming loose priors with standard deviation of 0.15, for example, for the latter this means the prior interval of $[0.458, 0.950]$ at 95%.

For the long-run steady state parameters, the prior means are set in accordance with the observed quarter-to-quarter growth rate of technology in the US, annualized steady state interest rate and annualized steady state inflation rate which are matching their sample means. For the Indian parameters, this is also done so that the calibrated parameter means reflect steady state values of the observed variables. For instance, the annualized steady state interest rate parameter is set at 1.5%, corresponding to $\beta = 1/(1 + \tilde{R}_t^*/100) = 0.9852$. The annualized inflation 6.5% with

[11] See Bhattarai et al. [2017] for the dynamic CGE model of the US and Banerjee and Basu [2016]) for a DSGE model of India.

Parameters		prior mean	post. mean	90% HPD interval		prior	prior sd
Weight on inflation in Taylor rule for H	ψ_1	1.50	2.4007	2.0621	2.7374	gamma	0.25
Weight on output in Taylor rule for H	ψ_2	0.50	0.5500	0.3759	0.7180	gamma	0.25
Weight on exchange rare in Taylor rule for H	ψ_3	0.10	0.0403	0.0169	0.0627	gamma	0.05
Weight on inflation in Taylor rule for F	ψ_1^*	2.00	1.8376	1.4299	2.2204	gamma	1.00
Weight on output in Taylor rule for F	ψ_2^*	0.50	2.0425	1.3963	2.6493	gamma	0.25
Weight on exchange rare in Taylor rule for F	ψ_3^*	0.50	0.2020	0.0972	0.3086	gamma	0.25
Nominal interest rate for US in %	$\widetilde{R}$	0.50	0.6259	0.4602	0.7867	gamma	0.10
Growth rate of global Productivity in US	$\widetilde{\gamma}$	0.40	0.3027	0.1738	0.4297	norm	0.10
Composite inflation in US	$\widetilde{\pi}_H$	0.63	0.4772	0.3995	0.5518	gamma	0.10
Nominal interest rate in India in %	$\widetilde{R}_t^*$	1.50	2.6104	2.3057	2.9103	gamma	0.50
Growth rate of global technology	$\widetilde{\gamma}^*$	1.55	1.2897	1.1472	1.4339	norm	0.50
Composite inflation in India	$\widetilde{\pi}_H^*$	1.62	2.3466	2.0147	2.6848	gamma	0.50
AR(1) coefficient, productivity in US	ρ_A	0.80	0.8937	0.8417	0.9431	beta	0.10
Interest rate smoothing in US	ρ_R	0.50	0.8293	0.8006	0.8583	beta	0.20
AR(1) coefficient, government spending in US	ρ_G	0.80	0.8802	0.7855	0.9744	beta	0.10
AR(1) coefficient, productivity in India	ρ_A^*	0.50	0.9504	0.9162	0.9867	beta	0.20
Interest rate smoothing in India	ρ_R^*	0.50	0.9053	0.8848	0.9266	beta	0.20
AR(1) coefficient, government spending in India	ρ_G^*	0.50	0.9504	0.8922	0.9987	beta	0.20
AR(1) coefficient, global productivity	ρ_z	0.66	0.8138	0.6965	0.9706	beta	0.15
AR(1) coefficient, risk premium shock	ρ_{UIP}	0.50	0.8821	0.7966	0.9662	beta	0.20

Table 3: Prior and Posterior Distributions for Home (H) and Foreign Countries (F)

$\beta = 0.9852$ implies nominal rate of around 8%. Again, we use loose priors for India, imposing less informative priors and allowing for the data to determine the parameters' location. So the interest rate prior implies a prior interval of $[0.216, 3.430]$. Normal distributions are used when more informative priors seem to be necessary and gamma distributions for non-negativity. For the policy parameters in India, priors were chosen so that a large domain is covered, reflecting lack of information on monetary policy reaction function of the Reserve Bank of India (RBI). The inflation feedback parameter has gamma prior with a mean of 2 and a standard deviation of 1, thus covering a relatively large parameter space, considering that the RBI has implemented a flexible monetary regime from which an inflation targeting policy has been pursued. The output and exchange rate feedback also has a relatively diffuse prior. For the US counterpart, we simply follow the priors in the literature that are consistent with the Taylor rule.

The estimation results are plausible and are generally similar to those of Lubik and Schorfheide [2005] for the US and of Gabriel et al. [2016] for the Indian SOE. The estimated parameters capturing the policy response to both inflation and output, ψ_1^* and ψ_2^*, suggest that the RBI appears to be quite aggressive in preempting inflationary pressures and responding to output stabilisation. However, the response for fluctuations in the exchange rate is estimated to be quite feeble. One interesting aspect is that prices are estimated to be a lot stickier in the US, while it remains low for India which suggests that prices are more flexible, adjusting quite frequently, between 1 and 3 quarters. The degree of consumption habit, h, is found high and statistically significant in India, implying that these frictions play a role in explaining overall persistence in the data. The estimation of the shock processes, as in Gabriel et al. [2016], shows some persistence, more so in India than in the US. Interestingly, the external shock (the global shock z_t in particular) is also less persistent, but the shock corresponding to the UIP premium exhibits a high degree of persistence. The domestic and foreign productivity shocks, $\widetilde{\gamma}^*$, are the most persistent shocks. The prior and posterior means with the highest posterior density (HPD) are given in Table 3.

The prior of each shock's standard deviation is assumed to have an inverse gamma distribution. Shock processes are the most likely elements to differ from previous studies based on developing economies. In the case of India, it is natural to expect significantly larger swings in macro observables. Thus the prior means for the standard deviations are set at 2, which is higher than that of the US, using the inverse gamma distribution.

The estimated standard deviations of parameters for India are larger than the values commonly found for developed economies (except the monetary policy shock), in accordance with the macroeconomic volatility stylized facts typically associated with emerging economies. Most strikingly, the standard errors associated with foreign (Indian) technology and exchange rate shocks stand out as being the most volatile shocks in the economy, picking up the largest standard deviation coming from foreign technology. This suggests that more volatility is being transmitted by the supply side of the economy.

4.2 Estimated Impulse Response Functions

We now focus on the (estimated posterior) impulse responses for two selected shocks: a technology-led productivity shock and a shock to domestic monetary policy, for the US and Indian economies, respectively. We investigate the importance of shocks to the endogenous variables of interest in order to gain a better understanding of the model uncertainties (projected trajectories) faced by the policymakers. The endogenous variables of interest are the observable variables in the estimation, and each mean response is for 20 period (5 years) horizon. Overall, the impulse responses of macroeconomic variables vary between the US and India. As expected, a positive one standard deviation productivity shock has a positive impact on the growth rate of domestic output which implies an immediate fall in inflation and interest rate (Figure 2). The effect on exchange rate dies out rapidly (less than half a year) which appears to be fairly persistent while affecting other domestic variables, as confirmed by the estimated AR(1) coefficient. Interestingly, these DSGE results are consistent with the responses in the SVAR model. Many of the VAR responses fall into the 90% confidence bands of the DSGE model. To make them comparable, the VAR responses with the simple Cholesky scheme using the DSGE simulated data also produce similar results, at least for the domestic economies.

The responses do satisfy the identifying sign restrictions even in the long run (see Figures 2-5), although they are required to satisfy the sign restrictions for 2 quarters. With GDP growth rate in the US being restricted not to decline (increase), which is likely to occur as a result of a technology shock, we would expect inflation to decline, whereas in case of positive monetary policy shock, GDP growth rate and inflation can be expected to decline. When interest rate is likely to decline due to a technology shock on the back of lower inflation, a monetary policy shock calls for an increase in interest rate, helping us identify both the shocks correctly.

We undertake the SVAR exercise for the two shocks jointly. In Figures 2-5, in response to a contractionary monetary shock, we find that output growth contracts, while a technology shock has a positive impact on output growth in both countries (i.e., the dotted lines). A monetary policy shock in the US, on the other hand, has no contractionary impact on Indian GDP growth, suggesting a competitive real effect, although the technology shock in the US has complementary real effect on India (see Figure 4). This clearly suggests that the global technology shocks are complementary in nature, while policy shocks have competitive real effects.

Now let us focus on the effects of individual shocks from each structure. In Figures 2 and 3, as expected, a positive technology shock to the growth rate of the US leads to a decrease in the interest rate in the US, which triggers capital outflows, lowering the interest rate in India with moderate growth effect in India, suggesting a complementary real effect of US technology shock. Considering a similar technology shock in India, the consequent lower interest rate in India will lead to capital inflows to the US, which can be possible only with higher interest rates in the US (Figure 3). This follows from the capital account channel that an increase in growth in India drives FDI to India from the US, suggesting that any outflow of capital would raise the interest rate in the short run in the US (less than 2-3 quarters). Indian technology shock however has relatively modest impact on growth in the US.

With regard to the monetary shocks, a rise in the interest rate induces more savings and tightens access to credit for the domestic firms. The higher cost of capital causes reduction in the investment demand, pushing down capital accumulation. This could be translated into a fall in output and inflation (as correctly predicted by the estimated SVAR and DSGE models). In Figures 4 and 5, output and inflation in the US and India are subsequently rising. This could be explained by the so-called 'price puzzle' as firms supply more when prices rise. It should also lower the interest rate in India because of increased potentials for capital inflows; so a lower interest rate in India explains the higher rate of output growth and subsequent inflationary pressure in India. The period of positive outlook due to optimism caused by the inflows in India should be brief, as the RBI could subsequently raise the interest rate to combat the rising inflation as shown in Figure 4. The higher output growth in the US also contributes to a temporary increase in output and inflation in India (Figure 4). The US monetary policy does not seem to have significant impact on the exchange rate of the Indian Rupee.

In Figure 5, the lower prices in India can then get transmitted through the trade channel, giving rise to subsequent demand effects on the US inflation, raising the interest rate in the US. Also, the

Rupee appreciation can lead to greater competitiveness of the US economy, relatively expanding the US demand and production, which induces higher inflation after a few quarters (although there is no initial effect from the Indian monetary policy contraction) and the US monetary policy responds to combat the rising price level in the US. Another interesting finding emerges from our comparison analysis. In response to an exogenous policy tightening, our DSGE model predicts a decline in output following a 'hump shaped' response for the US. This can be viewed as evidence of sizeable and persistent real effects of monetary policy shock captured by our structural model.

4.3 Differences between DSGE and SVAR Models

The IRF results are in line with the findings in Gabriel et al. [2016] which estimates a SOE model for India with external shocks and financial frictions, and a US counterpart for the foreign economy. However, it is expected that there are difficulties in applying both the VAR and DSGE models to obtain comparable results. We do not find that our DSGE responses following a positive productivity shock match well with the results of our SVAR in terms of their sign and persistence (i.e., the US and India output responses in Figures 2 and 3). This is not surprising because of the large values estimated for the elasticity of substitution between the home and foreign goods ($\frac{1}{\eta_k} = 1.63, 1.11$ for India and the US, respectively) which implies a small output co-movement between these two countries (this implies an increase in competitiveness between the tradable goods). Most existing models of the open economy framework have been shown to face the problem of not being able to generate significant endogenous transmission, generating even negative correlation of key aggregate variables.[12]

Given that this type of model typically does a poor job of explaining the co-movements in the data and the success of the SVAR in predicting the stylized fact, the state of the literature suggests looking at the key features characterising the transmission of technology shocks across countries including, for example, the features determining the responsiveness of labour decisions to international relative prices.[13] Other proposed mechanisms to overcome this negative results in the literature include Corsetti et al. [2008] with incomplete asset markets and Burstein et al. [2008] that calibrates the elasticity of substitution in production sharing to capture complementarity. Nevertheless, from the VAR analysis, including the empirical VAR fitted with the DSGE-simulated data, we find that the foreign country benefits from technological innovations as it can import cheap products via an improvement in its terms of trade.

Examining again both Figures 4 and 5, where we investigate IRFs from the monetary policy shocks, there are more notable differences between the DSGE and VAR results. First, a rise in the US interest rate reduces the US output, but with a lag of around 1 quarter, and pushes down

[12]A few examples date back to the international RBC literature such as Backus et al. [1992], and include more recent attempts such as Justiniano and Preston [2010], Adolfson et al. [2007] and Schmitt-Grohe and Uribe [2003] in which the structural analysis fails to explain the documented importance and transmission of foreign shocks.

[13]For example, Miyamoto and Nguyen [2017] model weak wealth effects from labour supply with Jaimovich-Rebelo preferences (Jaimovich and Rebelo [2009]) and variable capacity utilization for the demand side.

inflation in the US, as expected. Second, in the DSGE model with nominal rigidities and a working mechanism of a borrowing premium, a higher US interest rate sets pessimism immediately initiating a period of contraction, leading to an increase in external risk premium in India, tightening credit in India. That restricts the capital accumulation and investment. As a result, there is a sharp fall in the Indian output growth, after an initial rise that is reverted subsequently. Clearly our VAR models do not pick up this effect, producing the opposite response. Inflation falls after some initial rise, which is potentially caused by the initial inflows of capital from the US. In response to the expected higher inflation, as in the VAR analysis earlier, the RBI goes through a phrase of contractionary monetary policy to handle spillovers and volatilities from monetary policy in the US on interest and exchange rates. Interestingly, the DSGE results show a better mechanism for the transmission of the risk premium in India than in the structural VAR models. These responses provide strong implications for policy coordination and intervention from a background of increased financial integration of the Indian economy since early 1990's.

Finally, the differences in results also indicate that India may have experienced negative spillovers through the exchange rate channel in response to the US monetary policy shock. The DSGE model responds with a currency appreciation on impact while the VARs show the same implications for their responses to the shock, but only after several quarters have elapsed. India tends to have more lagged variations in their exchange rate responses, as the exchange rates serve as buffers to external shocks. In particular, the SVAR IRFs suggest that the policy rate and inflation responses in India are much more persistent following a shock to the US interest rate. Our results are very similar to the simulations in Banerjee and Basu [2016]. Their paper models a SOE with a UIP channel for India to study the QE effects and shows that, given the domestic interest rate, a rise in the foreign interest rate appreciates the currency via the UIP condition and the impact on GDP is positive, because of the improved terms of trade, but is quickly reversed. In contrast, our empirical VAR response on the exchange rate does not pick up the UIP condition and predicts the opposite effect.

4.4 External Risk Premium

Now in Figure 6 we evaluate the responses from the external risk premium shock (the UIP shock) identified only by the theoretical restrictions, as this seems to be one of the key factors that explain the IRF differences, especially in terms of monetary transmissions. The model predicts that a positive risk premium shock immediately depreciates the exchange rate and causes output growth in both countries. The nominal interest rates in both countries jump 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. The immediate currency depreciation prompts an increase in exports and a sharp rise in inflation. The monetary policy is tightened to fight inflation, according to the estimated feedback rule. Output rises slightly due to increasing exports, offsetting the effects of a reduction in investment. Inflation in the US falls on

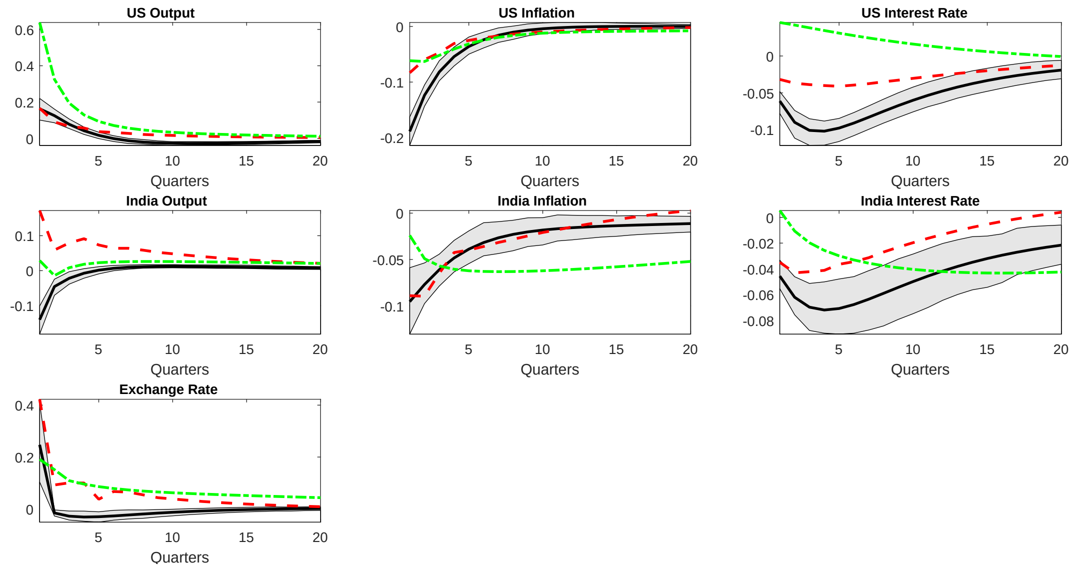


Figure 2: Estimated Impulse Responses – Technology Shock in US

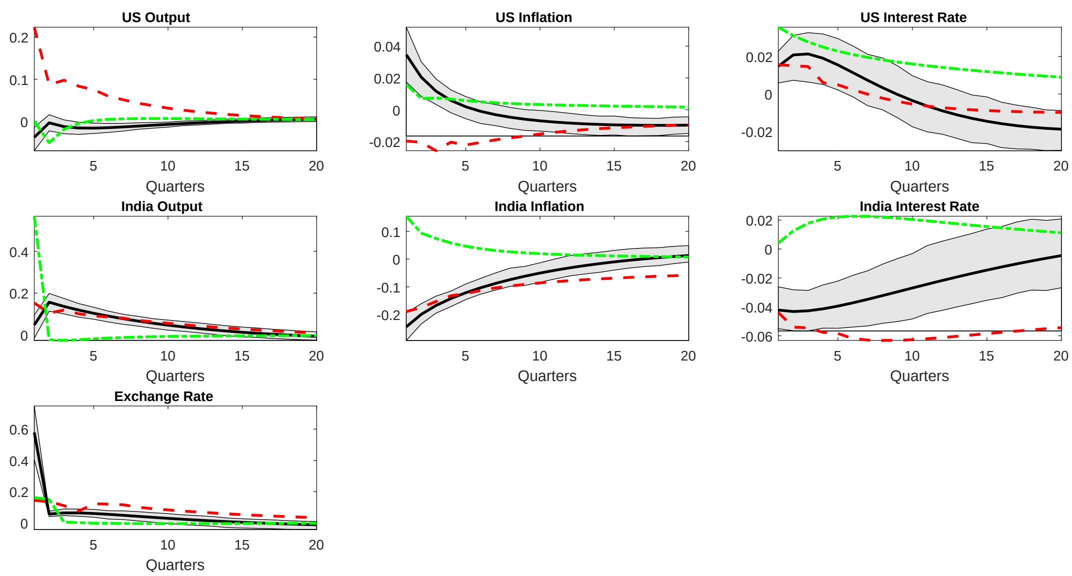


Figure 3: Estimated Impulse Responses – Technology Shock in India

Note: Solid black lines for DSGE model, dotted red (green) lines mean responses from SVAR (VAR using simulated data) and shaded areas 90% High Probability Density sets.

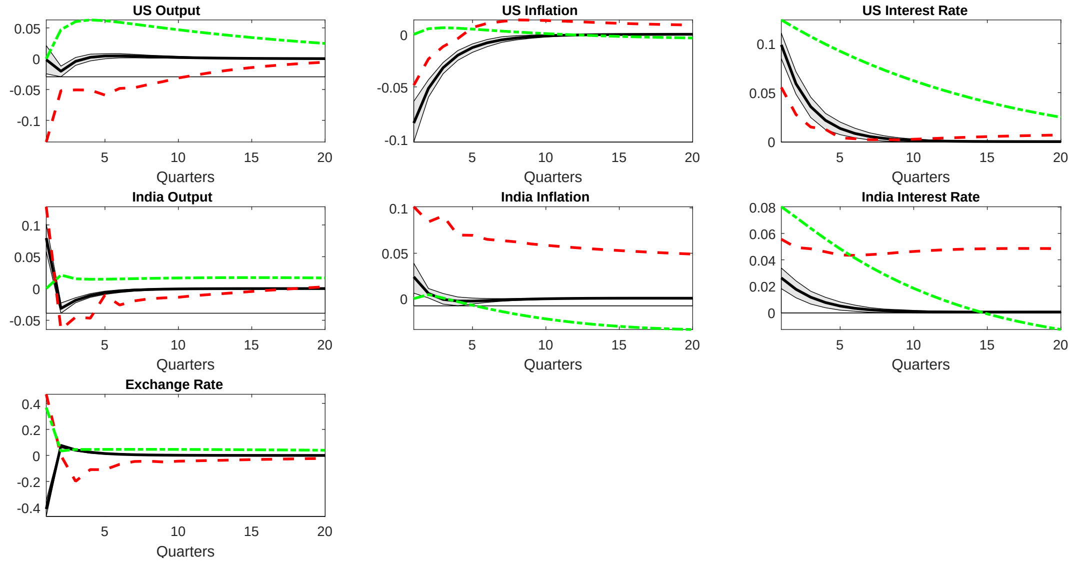


Figure 4: Estimated Impulse Responses – Monetary Policy Shock in US

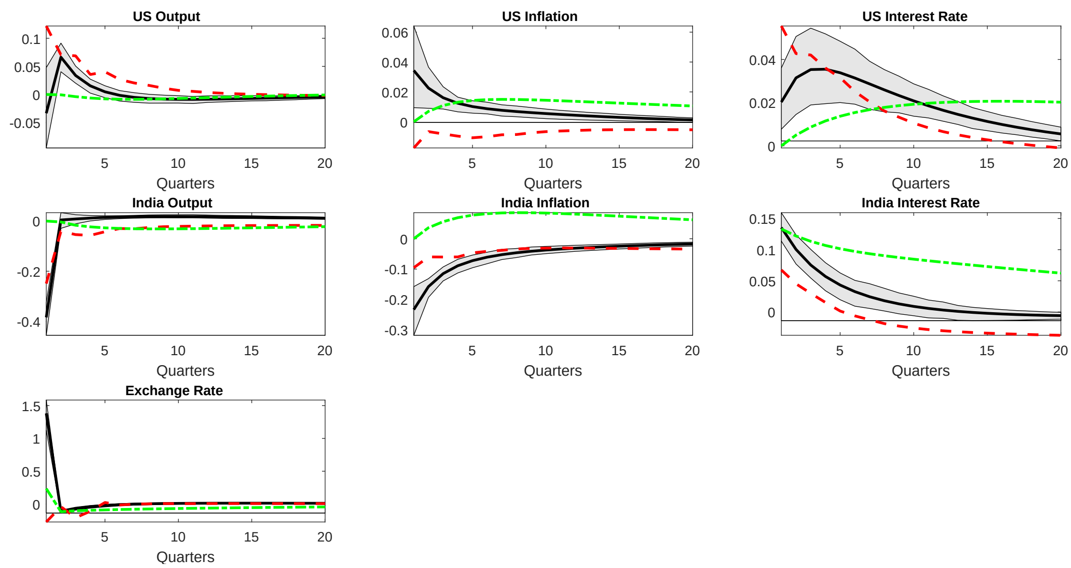


Figure 5: Estimated Impulse Responses – Monetary Policy Shock in India

Note: Solid black lines for DSGE model, dotted red (green) lines mean responses from SVAR (VAR using simulated data) and shaded areas 90% High Probability Density sets.

impact but the effect is also short-lived. Most responses are consistent with the findings of Bernanke et al. [1999]), using a calibrated costly verification model, and from Gertler et al. [2003]'s model simulation.

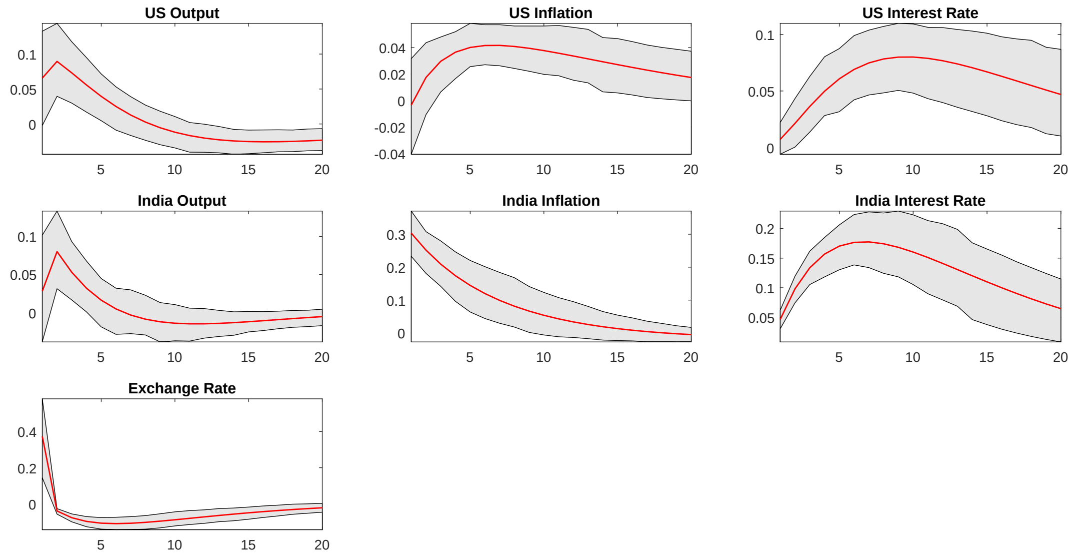


Figure 6: Estimated DSGE Impulse Responses – UIP Shock

In general, we find that, with the VAR precisions, technology shocks have complementary effects, while policy shocks have competitive effects in the sense that higher interest rates in the US give rise to an increase in the interest rate in India, indicating the case of a more competitive capital market (and indicating evidence of some risk premium effects when external borrowing is necessary). At the same time, positive monetary policy shocks in both countries do have contractionary output effects while stabilising inflation, unlike in the empirical VAR model as described earlier. The features reported by our analysis are broadly consistent with the stylized facts and empirical findings reported in the emerging open-economy literature.[14] Technology shocks have limited complementary effects possibly because of lack of integration of goods markets, although imports and capital flow channels appear to explain the technology spillovers.

4.5 Variance Decomposition of Business Cycles

The variance decomposition analysis provides measures of the proportions of variances explained by shocks to the variable itself versus from the shocks to the other variables. The forecast-error

[14]See, for example, Banerjee and Basu [2016],Belke and Gros [2017], Bhattarai et al. [2015] on the effects of a US QE shock; Galesi and Lombardi [2009], Dumrongrittikul et al. [2014] using a GVAR approach for emerging economies including India.

variance decomposition for the DSGE model is presented in Figures 7 and 8. The DSGE results are based on an explicit channel of transmission and on the model's posterior distribution reported in Tables 2 and 3. As before, we focus only on the two shocks for the two economies, and show the 12-period forecast horizon shock decomposition for the output growth paths. Table 4 provides a summary of variance decomposition of all the shocks in the DSGE model for all the observed variables in the long run.

It is clear that nearly 35% of the variation in the US growth rate is explained by the shock to the global technology and 43% by its public spending shock. Then 12% and 0.89% variances are explained by domestic and foreign technology shocks. Shocks to domestic technology, fiscal spending and monetary policy play prominent role in the growth rate of India. It explains nearly 70% of variations on it. The global technology changes are also important in explaining these growth rates, in the US and India. The variance decomposition table also shows that the variances in the domestic and foreign interest rates are more due to these technology shocks as is the inflation. About 82% of the variation in the change in the exchange rate is due to its own shock. The decomposition results from the estimated DSGE model in Figures 7 and 8 are comparable to magnitude in SVAR. An interesting result in Figure 7 is that an emerging economy such as India gaining systematic importance in recent decades begins to have large spillover effects on the US (and the rest of the world) as a one-standard deviation monetary shock in India produces some sizeable effect on the US growth from the second quarter onwards. A growing number of studies focusing on the effect of BRICS and Chinese spillovers have found similar results with significant and persistent growth spillovers via bilateral trade (Arora and Vamvakidis [2010], Samake and Yang [2011]).

In Figure 8, in the short run, within a year ($t = 1, 2, 3$), unexpected movements in Indian output are primarily driven by the exogenous monetary policy shock (by far the dominant influence more than 50%), further suggesting the strong implications for policy intervention from a background of increased financial integration, as found from our IRF results. Over time, in Table 4, the policy shock still dominates, accounting for the biggest part of the output forecast error variance under this model. Not surprisingly, in the medium (to long)-run the supply-side shock begins to become the other driving force of output. In contrast, the US productivity shock explains a moderate part of US output variation over time (15%) and a moderate but significant factor behind both short-run and longer-run movements in Indian output. Existing studies on business cycle transmission including several IMF working papers have focused on spillovers based on VARs of growth from the US and EU to other countries or regions such as emerging Asia and Latin America. A major result of these case studies show that the external shocks can explain a significant portion of the variation in domestic GDP growth (Bayoumi and Swiston [2009], Osterholm and Zettelmeyer [2008]).

4.6 Some Policy Implications of Our Results

Policies of one country can have impact on growth in other countries. We include an empirical policy reaction function as in Smets and Wouters [2007], where the policy instrument reacts to inflation and

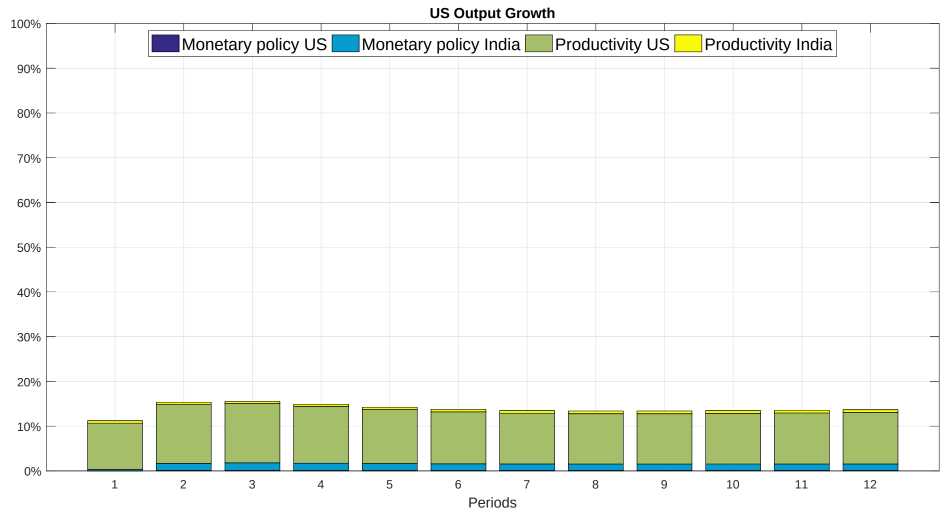


Figure 7: Variance Decomposition – Output Growth in the US

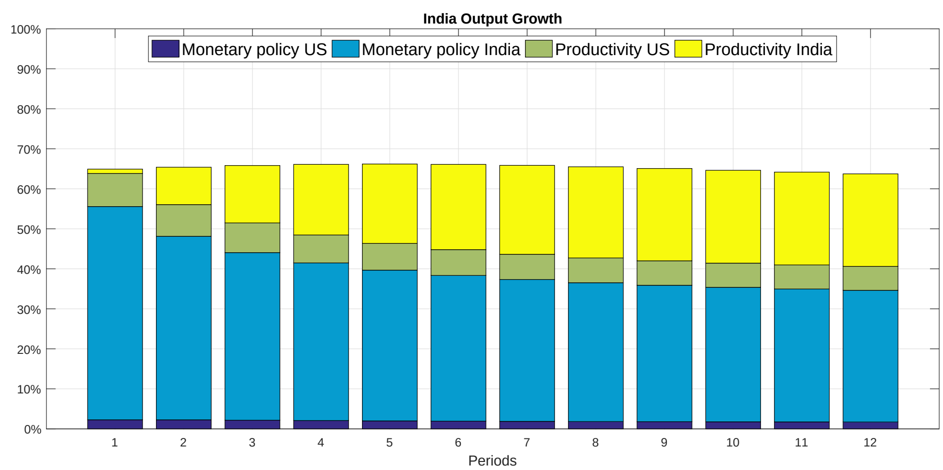


Figure 8: Variance Decomposition – Output Growth in India

	Shocks of the Estimated DSGE Model								
Observable variables	Monetary US	Monetary India	Productivity US	Productivity India	Government US	Government India	Global shock	Exchange rate	UIP shock
Output US	0.10	1.47	12.09	0.89	43.13	0.04	34.32	0.17	7.79
Inflation US	9.42	1.95	58.72	3.91	0.30	0.08	3.07	1.07	21.48
Interest rate US	5.68	3.66	36.03	4.81	1.17	0.11	7.39	0.26	40.88
Output India	1.54	30.06	5.64	24.92	0.11	15.70	14.71	3.47	3.87
Inflation India	0.06	14.01	3.63	28.97	0.01	0.21	15.28	1.31	36.52
Interest rate India	0.20	6.96	10.28	5.58	0.01	1.42	3.77	0.48	71.28
Exchange rate	1.03	10.94	0.41	2.39	0.06	0.29	1.08	82.06	1.74

Table 4: Variance Decomposition – DSGE Model (in Percent)

Note: All the variance decomposition is computed from the model solutions (order of approximation = 1). The results are based on the model's posterior means.

the output gap. Exchange rates also play a role as to how monetary policy is conducted in emerging economies. In normal times, central banks may not wish to focus on the exchange rate, as it can lead to a weakening of the inflation target as a nominal anchor (see Mishkin and Sevastano [2001]), but in a sudden-stops world, when capital abruptly stops to flow into a country (a less developed one in particular), interest rate interventions may not work and monetary authorities may occasionally resort to foreign exchange interventions instead (Ganelli and Rankin [2020], Rogoff [1999]). Thus in our theoretical framework and data VAR, we also include the exchange rate as part of the policy variables.[15] Through explicitly assuming the cross-border transmission effects via the channels of capital flows, trade and exchange rate interactions in our models, we are able to identify empirically the types and directions of spillovers that arise when there is lack of international cooperation on policies. From counterfactual analysis comparing the VAR and DSGE simulations, capital flows seem to be one of the main factors that generates positive and negative spillovers.

Naturally, while our results appear to be robust, they are driven by our methodological choices. On the estimation front, we believe that in the case of emerging economies, the role of trends in the data requires careful treatment. Andrle [2008], for example, argues that assumptions on trending behaviour should be explicitly modelled, rather than sidestepped by means of an ad-hoc filtering procedure. Recent developments, namely by Canova and Ferroni [2011] and Ferroni [2011], might

[15]One caveat of our model is that we assume a conventional monetary policy for the entire sample period so that we do not consider the fact that the behaviour of capital flows has differed through time (Barro and Gordon [1983], Fielding and Mizen [1997]). In other words, we cannot examine the impact of different episodes of unconventional monetary policy on capital flows to/from emerging economics, such as the effects of tapering for instance. One reason is because the post-crisis sample is still relatively short especially for India for constructing a satisfactory structural estimation. On the other hand, for the US, the ZLB may invalidate the conventional policy analysis when the key interest rates are near zero. However, this latter challenge has only recently been addressed by the Wu-Xia Shadow Federal Funds Rate (Wu and Xia [2016]) as a measure of the macroeconomic effects of qualitative easing therefore we wish to consider this for future work.

provide an alternative that allows for formal statistical comparisons among different de-trending procedures. On the VAR identification, there are various alternative identification schemes we already mentioned in the previous section. For a robustness check on our results, we implement an estimated BVAR model imposing the Minnesota priors to cross-validate our estimated DSGE and VAR models.

Based on the comparisons between the VAR and DSGE implied dynamics we test whether the DSGE model is as plausible a candidate as the empirical VAR in terms of the ability of capturing some of these dynamics seen in the data. This model can be applied to assess the impacts of fiscal and monetary policies adopted by emerging and advanced economies on output, employment and welfare of households in these economies. These can also be used to assess the rising or falling degree of integration in the global economy when single country or multi-country focused policy initiatives require coordination that can promote stability and growth across all economies.

Many inflation targeting central banks generate model-based forecasts conditional on the expected interest rate paths for the near future. One popular scenario in policy discussion is constant interest rate scenario, based on a policy announcement, such as forward guidance. The announced future policy guidance, if communicated effectively by the central bank, can have a positive effect on inflation expectations and the expected future behaviour of monetary policy. Our results suggest, from an empirical perspective, that such policy transmission may have its macroeconomic effects across two economies through the expected impact on the nominal long rates and the role of capital flows. We leave this to future research which will aim to consider the impact of forward guidance on the long term interest rate and its relation to the zero lower bound in the context of open-economy DSGE models along the line of the work by De Graeve et al. [2014]. Finally, we suggest that more policy coordination is required to avoid situations of the Bernanke taper tantrum. This is possible by the alignment of expectations about the gradual monetary expansion in order to avoid the unnecessary surge in bond yields. By manipulating risk adjusted return on investment in bonds across countries or setting the more realistic cost of capital through the optimality conditions, this model can help solve the type of dilemma such as the taper tantrum. Modelling of the term structure within the DSGE-expected utility framework and impulse response simulations can further reveal how the macroeconomic variables and bond yields respond to exogenous shocks across the different policy scenarios.

5 Conclusions

Does policy coordination between a major advanced economy and a major emerging market economy matter in the global economy? The estimated VAR and DSGE models in this paper illustrated how the business cycle effects of interdependence between India and the US could be explained through the capital flow and trade channels. We developed and estimated a two-country DSGE model, where India, as an emerging economy, had strong competitive policy effects as well as complementary technology effects with the US. The same observations of seven variables were used both in the VAR and DSGE estimation to study the impulse responses to technology and monetary policy shocks in order to establish empirical equivalence between these two types of macroeconomic models.

As expected, while the DSGE model provides the theoretical and structural reasons behind the estimated parameters, the VAR provides the empirical regularities econometrically. Disentangling such positive or complementary impacts from negative or competitive effects could be helpful for developing the policy coordination scenarios in the context of competitive spillover effects of monetary or fiscal policies on the one hand and complementary effects of technology shocks on the other.

Given the global imbalances and the emergence of bilateral negotiations for better cooperation between countries, policy shocks in an advanced economy can get transmitted to a rapidly growing emerging market economy, signaling either complementarity or competitive effects. We showed that the impulse responses and variance decomposition estimations produce similar results from both the SVAR and DSGE models, but the latter provides the structural explanations for the linkages, although traditional VAR or BVAR models are often more efficient on RMSE considerations.

A substantial body of research in the literature focuses on improving the DSGE and VAR specifications separately. Our comparable results from the econometric VAR and theory-rich DSGE models suggest that both of these should be taken as complementary techniques for empirical assessment of macroeconomic spillovers in advanced and emerging economies. Using the same data for estimating VAR, and calibrating and simulating DSGE models can help us to measure impacts of shocks from the demand management policies and changes in technologies. For each model we characterise the structural and cross-equation restrictions from the macroeconomy and the data. We keep our models relatively parsimonious in micro-structure and frictions but are still able to generate important dynamics in the data. Our methodology focuses on the big picture and the role of policies in driving aggregate results without resorting to extra detail in both models that may be misspecified and cause them to be rejected by the data.

Comparing the two key shocks identified in this paper, we find that, while the domestic and global technological shocks are complementary, the monetary policy shocks are competitive between a major economy and an emerging economy. The spillovers following a risk premium shock are also similar to the technology shocks. The negative spillovers are reduced when households and firms in India pay a currency risk premium in the interest rate to mitigate the effects of external shocks coming from the US. Policy measures to minimise competitive demand shocks thus require better policy coordination to avoid the international risk spilling-over into the home country. Intuitively, technology enhances productivity in both countries, while policy shocks tend to drive capital to a country with higher rate of return. Thus policy shocks in advanced countries actually lead to unintended effects in terms of capital inflows to emerging economies. These results are close to the results in the second and third generation studies on policy coordination. For future work, we wish to compare the quantitative results to models equipped with more credit market frictions.

References

C. Adam, P. Subacchi, and D. Vines. International macroeconomic policy coordination: an overview. *Oxford Review of Economic Policy*, 28(3):395–410, 2012.

M. Adolfson, S. Laseen, J. Linde, and M. Villani. Bayesian estimation of an open economy dsge model with incomplete pass-through. *Journal of International Economics*, 72(2):481–511, 2007.

J. Aizenman, M. D. Chinn, and H. Ito. Monetary policy spillovers and the trilemma in the new normal: Periphery country sensitivity to core country conditions. *Journal of International Money and Finance*, 46:298–330, 2016.

M. Andrle. The Role of Trends and Detrending in DGSE Models. manuscript, 2008.

V. Arora and A. Vamvakidis. Chinas economic growth: International spillovers? IMF Working Paper WP/10/165, 123., 2010.

G. Ascari, A. Colciago, and L. Rossi. Limited asset market participation, sticky wages, and monetary policy. *Economic Inquiry*, 55(2):878–897, 2017.

D. Backus, P. J. Kehoe, and F. E. Kydland. International real business cycles. *Journal of Political Economy*, 100(4):745775, 1992.

S. Banerjee and P. Basu. *Indian Economy During the Era of Quantitative Easing: A Dynamic Stochastic General Equilibrium Perspective*. Springer Verlag, 2016. Chapter in Monetary Policy in India: A Modern Macroeconomic Perspective.

R. Barrell, K. Dury, and I. Hurstd. International monetary policy coordination: an evaluation using a large econometric model. *Economic Modelling*, 20(3):507–527, 2003.

Robert J Barro and David B Gordon. Rules, discretion and reputation in a model of monetary policy. *Journal of monetary economics*, 12(1):101–121, 1983.

T. Bayoumi and A. Swiston. Foreign entanglements: Estimating the source and size of spillovers across industrial countries. IMF Staff Papers 56(2), 353383., 2009.

P. Beaudry, P. Fève, A. Guay, and F. Portier. When is Nonfundamentalness in SVARs A Real Problem? TSE Working Papers 16-738, Toulouse School of Economics (TSE), 2016.

A. Belke and D. Gros. The economic impact of brexit: Evidence from modelling free trade agreements. *Atlantic Economic Journal*, 45(3):317–331, 2017.

P. Benigno. A simple approach to international monetary policy coordination. *Journal of International Economics*, 57(1):177–196, 2002.

P. R. Bergin. How well can the new open economy macroeconomics explain the exchange rate and current account? *Journal of International Money and Finance*, 25(5):675–701, 2006.

B. Bernanke, M. Gertler, and S. Gilchrist. The Financial Accelerator in Quantitative Business Cycles. In M. Woodford and J. B. Taylor, editors, *Handbook of Macroeconomics, vol. 1C*. Amsterdam: Elsevier Science, 1999.

Ben S Bernanke. The new tools of monetary policy. *American Economic Review*, 110(4):943–83, 2020.

K. Bhattarai, J. Haughton, H. Michael, and D. Tuerck. Simulating corporate income tax reform proposals with a dynamic cge model. *International Journal of Economics and Finance*, 9(5): 20–35, 2017.

S. Bhattarai, A. Chatterjee, and W. Y. Park. Effects of US Quantitative Easing on Emerging Market Economies. Discussion Papers 2015-26, School of Economics, The University of New South Wales, 2015.

O. Blanchard, C. J. Erceg, and J. Linde. Jump-starting the euro-area recovery: would a rise in core fiscal spending help the periphery? *NBER Macroeconomics Annual*, 31(1):103–182, 2017.

O. J. Blanchard and D. Quah. The dynamic effects of aggregate demand and supply disturbances. *American Economic Review*, 83(3):655673, 1993.

Claudio Borio and Piti Disyatat. Unconventional monetary policies: an appraisal. *The Manchester School*, 78:53–89, 2010.

S. Brooks and A. Gelman. General Methods for Monitoring Convergence of Iterative Simulations. *Journal of Computational and Graphical Statistics*, 7(4):434–455, 1998.

A. Bucci, D. La Torre, D. Liuzzi, and S. Marsiglio. Financial contagion and economic development: An epidemiological approach. *Journal of Economic Behavior & Organization*, 162:211–228, 2019.

James Bullard and Aarti Singh. Worldwide macroeconomic stability and monetary policy rules. *Journal of Monetary Economics*, 55:S34–S47, 2008.

A. Burstein, C. Kurz, and L. Tesar. Trade, production sharing, and the international transmission of business cycles. *Journal of Monetary Economics*, 55(4):775795, 2008.

A. Caiani, A. Godin, E. Caverzasi, M. Gallegati, S. Kinsella, and J.E. Stiglitz. Agent based-stock flow consistent macroeconomics: Towards a benchmark model. *Journal of Economic Dynamics and Control*, 69:375–408, 2016.

F. Canova and F. Ferroni. Multiple filtering devices for the estimation of cyclical dsge models. *Quantitative Economics*, 2(1):73–98, 2011.

F. Canova and G. Nicolo. Monetary disturbances matter for business fluctuations in the g-7. *Journal of Monetary Economics*, 49(6):1131–1159, 2002.

Roberto Chang. Financial integration with and without international policy coordination. *International Economic Review*, pages 547–564, 1997.

L. Christiano, M. Eichenbaum, and C. Evans. Nominal Rigidities and the Dynamic Effects of a Shock to Monetary Policy. *Journal of Political Economy*, 113(1):1–45, 2005.

R. N. Cooper. Macroeconomic policy adjustment in interdependent economies. *Quarterly Journal of Economics*, 83(1):1–24, 1969.

G. Corsetti and L. Dedola. A macroeconomic model of international price discrimination. *Journal of International Economics*, 67(1):129–155, 2005.

G. Corsetti, L. Dedola, and S. Leduc. International risk sharing and the transmission of productivity shocks. *Review of Economic Studies*, 75(2):443–447, 2008.

T. Davoine and M. Molnar. Cross-country fiscal policy spillovers and capital-skill complementarity in integrated capital markets. *Economic Modelling*, 88:132–150, 2020.

F. De Graeve, P. Ilbas, and R. Wouters. Forward guidance and long term interest rates: Inspecting the mechanism. Sveriges Riksbank Working Paper Series, No. 292, 2014.

M. B. Devereux, C. Engel, and G. Lombardo. Implementable rules for international monetary policy coordination. *IMF Economic Review*, 68(1):108–162, 2020.

F. X. Diebold and K. Yilmaz. Measuring financial asset return and volatility spillovers, with application to global equity markets. *Economic Journal*, 119(1):158–171, 2009.

T. Doan, R. Litterman, and C. Sims. Forecasting and Conditional Projection Using Realistic Prior Distributions. *Econometric Review*, 3:1–100, 1984.

T. Dumrongrittikul, H. Anderson, and F. Vahid. The Effects of Productivity Gains in Asian Emerging Economies: A Global Perspective. Working Paper 23/14, Monash University., 2014.

F. Ferroni. Trend Agnostic One-Step Estimation of DSGE Models. *The B.E. Journal of Macroeconomics*, 11(1):1–36, July 2011.

David Fielding and Paul Mizen. Investment, output and interest rate policy when capital is mobile. *The Economic Journal*, 107(441):431–440, 1997.

M. Forni, L. Gambetti, and L. Sala. VAR Information and the Empirical Validation of DSGE Models. Center for Economic Research (RECent), Working Paper 119, University of Modena and Reggio E., Dept. of Economics, 2016.

V. Gabriel, P. Levine, J. Pearlman, and B. Yang. An Estimated Model of the Indian Economy. Chapter in the "Handbook of the Indian Economy", edited by Chetan Ghate, Oxford University Press , 2012.

V. Gabriel, P. Levine, and B. Yang. An Estimated Open-Economy DSGE Model of the Indian Economy with Financial Frictions. Chapter in Monetary Policy in India: A Modern Macroeconomic Perspective, 2016, Springer Verlag , 2016.

A. Galesi and M. J. Lombardi. External Shocks and International Inflation Linkages: A Global VAR Analysis. ECB Working Paper No. 1062, 2009.

J. Gali. How well does the is-lm model fit postwar us data? *The Quarterly Journal of Economics*, 107(2):709–738, 1992.

Giovanni Ganelli and Neil Rankin. Fiscal deficits as a source of boom and bust under a common currency. *Journal of International Money and Finance*, page 102149, 2020.

M. Gertler, S. Gilchrist, and F. M. Natalucci. External Constraints on Monetary Policy and the Financial Accelerator. NBER Working Paper No. 10128, 2003.

D.B. Gordon and E.M. Leeper. The dynamic impacts of monetary policy: an exercise in tentative identification. *Journal of Political Economy*, 102(6):1228–1247, 1994.

Ashima Goyal. A general equilibrium open economy model for emerging markets: Monetary policy with a dualistic labor market. *Economic Modelling*, 28(3):1392–1404, 2011.

K. Hamada. Strategic analysis of monetary interdependence. *Journal of Political Economy*, 84(4): 677–700, 1976.

Jonathan Haskel and Stian Westlake. *Capitalism without capital: The rise of the intangible economy*. Princeton University Press, 2018.

P. Jacob and G. Peersman. Dissecting the dynamics of the us trade balance in an estimated equilibrium model. *Journal of International Economics*, 90(2):302–315, 2013.

N. Jaimovich and S. Rebelo. Can news about the future drive the business cycle? *American Economic Review*, 4:10971118, 2009.

A. Justiniano and B Preston. Can structural small open-economy models account for the influence of foreign disturbances? *Journal of International Economics*, 81(1):6174, 2010.

M Ayhan Kose, Christopher Otrok, and Charles H Whiteman. Understanding the evolution of world business cycles. *Journal of international Economics*, 75(1):110–130, 2008.

T. K. Kumar. The existence of an optimal economic policy. *Econometrica*, 34(4):600–610, 1969.

T. Lubik and F. Schorfheide. A bayesian look at the new open economy macroeconomics. *NBER Macroeconomics Annual*, 20:313–382, 2005.

T. Lubik and F. Schorfheide. Do central banks respond to exchange rate movements? a structural investigation. *Journal of Monetary Economics*, 54(4):1069–1087, 2007.

S. Mallick, M. S Mohanty, and F. Zampolli. Market volatility, monetary policy and the term premium. *BIS Working Paper*, (606):1–42, 2017.

F. S. Mishkin. Rethinking monetary policy after the crisis. *Journal of International Money and Finance*, 73:252–274, 2017.

F. S. Mishkin and M. Sevastano. Monetary policy strategies for latin america. *Journal of Development Economics*, 66(2):415–444, 2001.

W. Miyamoto and T. L. Nguyen. Understanding the cross-country effects of u.s. technology shocks. *Journal of International Economics*, 106:143–164, 2017.

William D Nordhaus, Charles L Schultze, and Stanley Fischer. Policy games: coordination and independence in monetary and fiscal policies. *Brookings Papers on Economic Activity*, 1994(2): 139–216, 1994.

P. Osterholm and J. Zettelmeyer. The effect of external conditions on growth in Latin America. IMF Staff Papers 55(4), 595623., 2008.

J. D. Ostry and A. R. Ghosh. On the obstacles to international policy coordination. *Journal of International Money and Finance*, 67:25–40, 2016.

P. Rabanal and V. Tuesta. Euro-dollar real exchange rate dynamics in an estimated two-country model: An assessment. *Journal of Economic Dynamics and Control*, 34(4):780–797, 2010.

Kenneth Rogoff. Monetary models of dollar/yen/euro nominal exchange rates: dead or undead? *The Economic Journal*, 109(459):F655–F659, 1999.

A. K. Rohit and P. Dash. Dynamics of monetary policy spillover: The role of exchange rate regimes. *Economic Modelling*, 77:276–288, 2019.

I. Samake and Y. Yang. Low-income countries BRIC linkage: Are there growth spillovers? . IMF Working Paper WP/11/267, 136., 2011.

S. Schmitt-Grohe and M. Uribe. Closing small open economy models. *Journal of International Economics*, 61:163185, 2003.

C. A. Sims and T. Zha. Were there regime switches in u.s. monetary policy? *American Economic Review*, 96(1):54–81, 2005.

F. Smets and R. Wouters. Shocks and frictions in US business cycles: A Bayesian DSGE approach. *American Economic Review*, 97(3):586–606, 2007.

J. E. Stiglitz. Where modern macroeconomics went wrong. *Oxford Review of Economic Policy*, 34 (1-2):70–106, 2018.

J. H. Stock and M. Watson. Dynamic factor models. Chapter in the Oxford Handbook on Economic Forecasting, eds. Michael P. Clements and David F. Hendry. Oxford: Oxford University Press, 2011.

John B Taylor. Discretion versus policy rules in practice. In *Carnegie-Rochester conference series on public policy*, volume 39, pages 195–214. Elsevier, 1993.

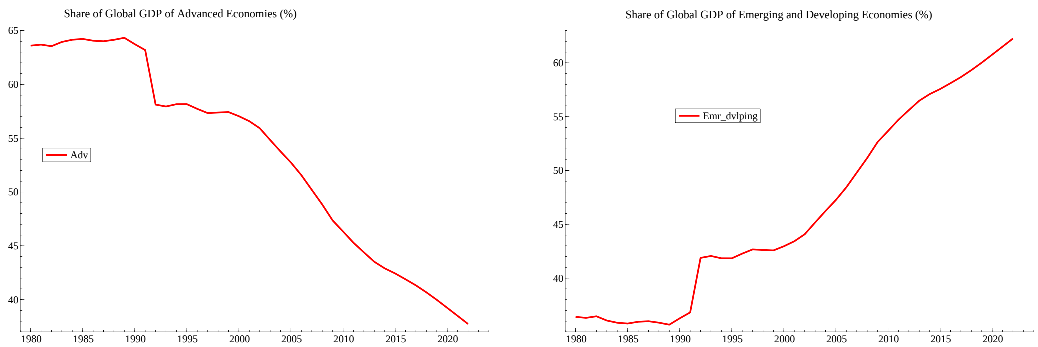
H. Uhlig. What are the effects of monetary policy on output? results from an agnostic identification procedure. *Journal of Monetary Economics*, 52:381419, 2005.

Martin Weale and Tomasz Wieladek. What are the macroeconomic effects of asset purchases? *Journal of monetary Economics*, 79:81–93, 2016.

J. C. Wu and F. D. Xia. Measuring the macroeconomic impact of monetary policy at the zero lower bound. *Journal of Money, Credit, and Banking*, 48(2-3):253–291, 2016.

Appendix

A Shares in the Global GDP



(a) Advanced Economies

(b) Emerging and Developing Economies

Figure 9: Shares of Advanced Economies and Emerging and Developing Economies in the Global GDP in PPP Terms (1980-2018)

Note: The y-axis shows percentage share. The x-axis shows years. Data source: the IMF.

B Global Spillovers for the Growth Rates

	US	UK	France	German	Japan	Brazil	Mexico	Turkey	South Africa	India	From Others
US	53.6	27.1	0.8	6.1	1.4	0.8	3.6	1.1	2.4	3.2	46
UK	17.7	69.1	0.4	5.9	0.6	0.8	2.5	0.6	0.7	1.7	31
France	22	22.6	32.9	5.8	1.2	7.4	1.4	0.3	0.6	5.8	67
German	13.3	19.6	8.4	43.8	3.1	5.6	0.9	0.6	0.6	4.1	56
Japan	10.3	16.8	0.3	11.9	53.7	3.9	0.5	0.7	0.3	1.6	46
Brazil	16.1	16.1	11.5	5.3	2.6	36.8	1.9	0.3	0.2	9.2	63
Mexico	17.1	16	3.6	8.4	4.2	6.3	34.6	2.7	0.5	6.6	65
Turkey	10.8	5.2	12.6	1.3	5.5	5.1	7.3	44.9	2	5.4	55
South Africa	12.5	16.7	2	4.2	3	16.9	1.4	2.1	38.2	2.9	62
India	4.2	2.8	2.3	13	1.3	1.5	0.5	3.2	4.4	66.7	33
Contribution to others	124	143	42	62	23	48	20	12	12	40	526
Contribution with own	178	212	75	106	77	85	55	56	50	107	52.6

Table 5: Growth Spillovers in Advanced and Emerging Economies, 1998:1-2014:4

Note: The global spillover index (in percent) is constructed using Diebold and Yilmaz (2009).

C Households, Firms and Market Clearing

C.1 Households

As is standard in most macroeconomic models, households in country k receive utility from consumption ($C_{k,t}$) and dis-utility from work ($N_{k,t}$) in each t period. Discount factor (β_k) and expectation operator ($E_{k,0}$) are used to compute lifetime utility of representative households in each country ($U_{k,0}$). The inter-temporal elasticity of substitution (τ_k) measures the relative rate of risk aversion of consumers between current and future consumption.

$$U_{k,0} = E_{k,0}\left[\sum_{t=0}^{\infty}\beta_k^t\left[\frac{\left(\widetilde{C}_{k.t}/A_{W_t}\right)^{1-\tau_k}}{1-\tau_k} - N_{k,t}\right]\right]$$

Consumers are subject to habit persistent conditions as given by $\widetilde{C}_{k,t} = C_{k,t} - h_k\gamma_k C_{k,t-1}$; they also benefit from global technological innovations $z_t = \frac{A_{Wt}}{A_{Wt-1}}$. Here γ_k is the growth rate of technology in the steady state and the habit parameter is positive but less than one, $0 < h_k < 1$. The composite consumption good is made of home and foreign consumption goods $C_{k,H,t}$ and $C_{k,F,t}$ for each country k as

$$C_{k,t} = \left[(1-\alpha_k)^{\frac{1}{\eta_k}} C_{k,H,t}^{\frac{\eta_k-1}{\eta_k}} + \alpha_k^{\frac{1}{\eta_k}} C_{k,F,t}^{\frac{\eta_k-1}{\eta}}\right]^{\frac{\eta_k}{\eta_k-1}}$$

where η_k is the elasticity of substitution between the US and Indian consumption goods. Under the New Keynesian supply assumption, the demands for consumption goods are linked to home, foreign and aggregate prices levels, $P_{k,H,t}$, $P_{k,F,t}$ and $P_{k,t}$ as

$$\begin{aligned} C_{k,H,t} &= (1-\alpha_k)\left[\frac{P_{k.H,t}}{P_{k,t}}\right]^{-\eta_k} C_{k,t} \\ C_{k,F,t} &= \alpha_k\left[\frac{P_{k,F,t}}{P_{k,t}}\right]^{-\eta_k} C_{k.t} \end{aligned}$$

Similarly the aggregate price ($P_{k,t}$) is composite of home and foreign prices ($P_{k,H,t}$ and $P_{k,F,t}$)

$$P_{k,t} = \left[(1-\alpha_k) P_{k,H,t}^{\eta_k-1} + \alpha_k^{\frac{1}{\eta_k}} P_{k,F,t}^{\eta_k-1}\right]^{\frac{1}{\eta_k-1}}$$

Representative consumers spend on domestic and imported goods and purchase bonds ($D_{k,t}$) from the income and endowment they possess. Budget constraint shows how the labour income and receipts from bonds, net of taxes equal expenditure on home and foreign commodities and expected value of bonds to be purchased, $E_t\left(Q_{k.t,t+1}D_{k,t+1}\right)$.

$$P_{k,H,t}C_{k,H,t} + P_{k,F,t}C_{k,F,t} + E_t\left(Q_{k,t,t+1}D_{k,t+1}\right) = W_{k,t}N_{k,t} + D_{k,t} - T_{k,t}$$

where $D_{k,t}$ denotes the debt and $T_{k,t}$ is the transfer that households receive. Then $Q_{k,t,t+1}$ is the price of bonds. The optimal choices of households regarding the commodity and asset markets are given by the standard first order conditions as

$$A_{Wt}\lambda_t P_{k,t} = C_{k,t}^{-\tau} - h_k\gamma_k\beta_k E_t\left[\frac{A_{Wt}}{A_{Wt+1}}C_{k,t-1}^{-\tau_k}\right]$$

This is the Euler equation which states the relation between current and future effective consumption where $\lambda_{k,t}$ is the marginal utility of income, and τ_k the elasticity of substitution between the current and future consumption.

$$Q_{k,t,t+1} = \beta_k E_t\left[\frac{\lambda_{k,t+1}}{\lambda_{k,t}}\frac{P_{k,t}}{P_{k,t+1}}\right]$$

This is the stochastic discount factor which equals the discounted return on investment. This also equals the market interest rate that clears the capital (or the bond) market. This is the condition for an optimal portfolio

$$R_{k,t}^{-1} = \beta_k E_t\left[\frac{\lambda_{k,t+1}}{\lambda_{k,t}}\frac{P_{k,t}}{P_{k,t+1}}\right]$$

where $R_{k,t}$ is the nominal interest rate implied by this system.

C.2 Firms

This model assumes a linear production function where output $(Y_{k,H,t}(j))$ is a function of technological progress at home and abroad (A_{Ht}, A_{Wt}) and the labour input $(N_{k,t}(j))$

$$Y_{k,H,t}(j) = A_{Wt}A_{k,Ht}N_{k,t}(j)$$

Firms operate under the monopolistic market and assume certain market power given by

$$E_t\left[\sum_{t=T}^{\infty}\theta_{k,H}^{t-T}Q_{k,H}^{t-T}Y_{k,H,t}(j)\left[P_{k,H,t}(j)\,\pi_{k,H}^{t-T} - P_{k,H,t}MC_{k,H,t}\right]\right]$$

$$MC_{k,H,t} = \frac{W_{k,t}}{P_{k,H,t}}$$

The supply function for each commodity j is as follows

$$Y_{k,H,t}(j) = \left[\frac{P_{k,H,t}(j)}{P_{k,H,t}}\right]^{-\omega_k}\left(C_{k,H,t} + G_{k,H,t} + C_{k,H,t}^{*}\right)$$

where ω_k is the elasticity of substitution among domestic commodities. The real exchange rate measures the degree of pass-through between domestic and foreign prices

$$\psi_{k,F,t} = \frac{e_t P_{k,H,t}}{P_{k,F,t}}$$

The law of one price condition is satisfied when $\psi_{k,F,t} = 1$. In each period some firms are able to change prices and others stick to current prices as given by the Calvo pricing mechanism

$$E_t \left[\sum_{t=T}^{\infty} \theta_{k,F}^{t-T} Q_{k,T}^{t-T} C_{k,F,t}(j) \left[P_{k,F,t}(j) \pi_{k,F}^{t-T} - e_t P_{k,F,t}^{*} \right] \right]$$

$$C_{k,F,t} = (1 - \alpha_k) \left[\frac{P_{k,F,t}}{P_{k,t}} \right]^{-\omega_k} C_{k,t}$$

Thus both demand and supply functions follow the New Keynesian assumptions on real and nominal rigidities and shocks.

C.3 International Links and Global Market Clearing

The home economy is connected to the foreign economy through relative prices of home to foreign commodities. The real exchange rate $s_t = \frac{e_t P_t^*}{P_t}$ reflects the terms of trade between home $q_t = \frac{P_{H,t}}{P_{F,t}}$ and the foreign economy $q_t^* = \frac{P_{F,t}}{P_{H,t}}$. Pass-through is perfect when $\frac{\psi_{F,t}}{q_t} = \frac{\psi_{F,t}^*}{q_t^*}$.

$$s_{k,t} = \frac{e_t P_{k,t}^*}{P_{k,t}};\ q_{k,t} = \frac{P_{k,H,t}}{P_{k,F,t}};\ q_{k,t}^* = \frac{P_{k,F,t}^*}{P_{k,H,t}^*};\ \frac{\psi_{k,F,t}}{q_{k,t}} = \frac{\psi_{k,F,t}^*}{q_{k,t}^*}$$

Market clearing implies that the domestic and foreign asset markets clear

$$\beta_k \frac{\lambda_{k,t+1}}{\lambda_{k,t}} \frac{P_{k,t}}{P_{k,t+1}} = Q_{k,t,t+1} = \beta_k \frac{\lambda_{k,t+1}^*}{\lambda_{k,t}^*} \frac{P_{k,t}^*}{P_{k,t+1}^*} \frac{e_t}{e_{t+1}}$$

Similarly markets also clear for the home and foreign goods as

$$\begin{aligned} Y_{k,H,t} &= C_{k,H,t} + G_{k,H,t} + C_{k,F,t}^* \\ Y_{k,F,t}^* &= C_{k,F,t}^* + G_{k,F,t}^* + C_{k,H,t} \end{aligned}$$

so that, in each country k, the total supply equals the private and public demands for home and foreign goods.

C.4 Shocks

The model economy is subject to five types of shocks (in addition to the monetary policy and risk premium shocks described in Section 3). First three shocks represent productivity shocks in the global market ($\widetilde{z}_t$), home country ($\widetilde{A}_t$) and the foreign country ($\widetilde{A}_t^*$). All three productivity shocks are assumed to be AR(1) (ρ_z, ρ_A, ρ_{A^*} are the AR coefficients) and subject to zero mean iid errors $\epsilon_{z,t}$, $\epsilon_{A,t}$ and $\epsilon_{A^*,t}$ respectively. These shocks affect both the consumption and production sides of the economy

$$\begin{aligned} \widetilde{z}_t &= \rho_z \widetilde{z}_{t-1} + \epsilon_{z,t} \\ \widetilde{A}_t &= \rho_A \widetilde{A}_{t-1} + \epsilon_{A,t} \\ \widetilde{A}_t^* &= \rho_{A^*} \widetilde{A}_{t-1}^* + \epsilon_{A^*,t} \end{aligned}$$

Then the model is subject to fiscal policy shocks in both countries, the aggregate public spending shocks $\widetilde{G}_t$ and $\widetilde{G}^*_t$, respectively, at home and abroad. The fiscal shocks are persistent with order 1 autoregression as measured by ρ_G and ρ_{G^*} but also subject to random innovations ϵ_G and ϵ_{G^*}

$$\begin{aligned} \widetilde{G}_t &= \rho_G \widetilde{G}_{t-1} + \epsilon_{G,t} \\ \widetilde{G}^*_t &= \rho_{G^*} \widetilde{G}^*_{t-1} + \epsilon_{G^*,t} \end{aligned}$$

D Log-linearization for the Baseline Model

To solve the model we log-linearize about the steady state. First define lower case variables $\widetilde{x}_t$

$$\widetilde{x}_t = \ln x_t - \ln \overline{x}$$

The linearization of price (inflation to marginal cost):

$$\widetilde{\pi}_{H,t} = \beta E_t \widetilde{\pi}_{H,t+1} + k_{H,t} \widetilde{mc}_t$$

where $k_{H,t} = \frac{1-\theta_H}{\theta_H} (1 - \theta_H \beta)$ is the Calvo price adjustment factor and $\widetilde{mc}_t = -\widetilde{\lambda}_t - a\widetilde{q}_t - \widetilde{A}_t$ is the marginal cost of production. Similarly the changes in the marginal utility of income $\left(\widetilde{\lambda}_t\right)$ relates to changes in consumption between two periods as given by the Euler relation

$$-\widetilde{\lambda}_t = \frac{\tau}{1-h\beta} \widetilde{C}_t - \frac{h\beta}{1-h\beta} E_t \left[\tau \widetilde{C}_{t+1} + \widetilde{z}_{t+1}\right]$$

The habit formation evolves according to

$$(1-h)\widetilde{C}_t = \widetilde{c}_t - h\widetilde{c}_{t+1} + h\widetilde{z}_{t+1}$$

(for $h = 0$ it is a standard Euler equation).

$$-\widetilde{\lambda}_t = -E_t \widetilde{\lambda}_{t-1} - \left[\widetilde{R}_t - E_t \widetilde{\pi}_{t-1}\right] + E_t \widetilde{z}_{t+1}$$

Changes in the inflation rate are due to the domestic and international factors (importer's Phillip's curve):

$$\widetilde{\pi}_{F,t} = \beta E_t \widetilde{\pi}_{F,t+1} + k_{F,t} \widetilde{\psi}_{F,t}; \quad k_{F,t} = \frac{1-\theta_F}{\theta_F} (1 - \theta_F \beta)$$

Inflation has domestic and foreign components:

$$\widetilde{\pi}_t = \alpha \widetilde{\pi}_{F,t} + (1-\alpha) \widetilde{\pi}_{H,t}$$

The terms of trade move according to the changes in domestic inflation relative to foreign inflation:

$$\widetilde{q}_t = \widetilde{q}_{t-1} + \widetilde{\pi}_{H,t} - \widetilde{\pi}_{F,t}$$

Thus the real exchange rate evolves according to the law of one price and terms of trade effects as:

$$\widetilde{s}_t = \widetilde{\psi}_{F,t} - (1-\alpha)\,\widetilde{q}_{t-1} - \alpha\widetilde{q}^*_{t-1}$$

The purchasing power parity condition implies that changes in the exchange rate reflect the differences in domestic and foreign inflation and changes in the real exchange rate as:

$$\Delta\widetilde{e}_t = \widetilde{\pi}_t - \widetilde{\pi}^*_t + \Delta\widetilde{s}_t$$

The interest rate differential relates to changes in the exchange rate dynamics as:

$$\widetilde{R}_t - \widetilde{R}^*_t = E_t\Delta\widetilde{e}_{t+1}$$

The marginal utilities of income between trading nations relate to the purchasing power parity condition:

$$\widetilde{\lambda}_t = \widetilde{\lambda}^*_t - \widetilde{s}_t$$

Thus output relates to aggregate demand and relative price from this condition as:

$$\widetilde{y}_{H,t} = \widetilde{c}_t - \widetilde{g}_t - \frac{\alpha}{\tau}\widetilde{s}_t + \alpha\,(1-\alpha)\,\eta\,(\widetilde{q}_t - \widetilde{q}^*_t)$$