Macroeconomic policy coordination in the global economy: 
An Estimated DSGE Model* 

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Abstract

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, signalling either complementarity or competitive effects. In this paper, using both traditional VAR and estimated DSGE models, we show that impulse responses and variance decomposition estimations are similar in both models, but the latter model provides theoretical and structural reasons for the linkages. Comparing two key shocks, we find that whilst technological shocks (domestic and global) are complementary, the external demand shocks (monetary and fiscal) are competitive between a major economy and an emerging market economy. Spill-overs following a risk-premium shock are also similar to technology shocks. Policy measures to mitigate competitive demand shocks thus require better policy coordination to avoid growing imbalances in the future.

Keywords: macro policy coordination, growth, India, US

JEL classification: C61, E61, C32

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1 Introduction

Global economy is interdependent. Policy actions taken in one country have spill over effects in other economies. Bilateral and multilateral negotiations are common. Global, regional and national organisations are involved in organising summits or high level meetings for policy coordination regularly (G7, G20, UN, EU, APEC, ASEAN, SAARC, ECOWAS, OPEC, BRICS, IMF, World Bank, WTO are some examples). Both the demand and supply sides of emerging or developing countries are affected when advanced countries change fiscal, monetary and trade policies. Those economies also are influenced by policies adopted in emerging or developing countries. The macroeconomic policy coordination models aim to explain the nature of such interactions and find out strategic solutions to deal with such problems. While interdependence among these economies are studied using bargaining, signalling and mechanism designing concepts of cooperative and non-cooperative games with complete or incomplete information among nations, households and firms at the micro level, or the multicounty or multi-region growth and global economy business cycle models at macro level are applied to evaluate gains or losses of economies in the broader global economy. Contributions in the policy coordination literature have tried to measure policy spillover effects from one set of countries to others in the context of the evolving events in the global economy. Picketty (2014) has studied implications of such interactions on growth and inequality among nations.

The literature in the policy coordination can be divided into three generations according to the impacts of policy coordination activities in the partner economies. First generation models include studies such as Kydland and Prescott (1977), Driffl (1988), Currie and Levine (1986) and Obstfeld and Rogoff (2000). These had found gains from coordination to be small. Lucas (1976) and Kydland and Prescott (1977) used rational expectations and argued for the advantage of rule-
based policies to create rational expectations equilibrium solutions. Petit (1989) used differential games as did the studies of Obstfeld (1994), Sutherland (1996), Senay (1998), Martin and Rey (2000). Obstfeld (2001) and Rogoff (2002) provide an excellent review of some of the models used for policy coordination with Mundell-Fleming-Dornbush type models with little gains from coordination. Aarle et.al. (2001) examine the impact of fiscal policies of member countries with their own labor market distortions on the stability and growth of EMU. They identified the need for coordination such as the stability and growth pact (SGP) that EMU had adopted earlier. They use a differential game, with Mundell-Fleming type model. Aarle et.al. (2002) examine the coalition formation in the EMU. Asymmetries in labor market rigidities and public infrastructure can create different sorts of repercussions of common economic policies among states.

Second generation models of policy coordination analysis contained in Pappa (2004), Canzoneri, Cumby and Diba (2005), Clerc, Dellas and Loisel (2011), Juillard and Villemot (2011) and Goyal (2007) find pay off from monetary and fiscal policy coordination to be bigger. These were extensions of the post-Keynesian models in which micro foundations were added by assuming monopolistic competition, nominal and real rigidities, individual representative agents with utility functions. But they retained the short run dynamics and ignored the truly dynamic long run growth aspects. For a review one may see Conzoneri et al. (2005). These models of macroeconomic policy coordination introduce disequilibrium dynamics but they focus on short run dynamics or business fluctuations. They are devoid of capturing the medium and long term trends in the pursuit and evasion games being played between nations. Supply and strategic modelling has much improved in recent literature on the policy coordination showing more gains from coordination as stated by Conzoneri et al. (2005), Evans and Hnatkovska (2007), Douglas and Laxton in dynare. Aarle et.al. (2002) examine the coalition formation in the EMU. Then Kempf and von Thadden (2013), Dedola et al. (2013) add asymmetric information and commitment where the welfare gains can be bigger as the number of countries increase in such deals. Nordhous (2015) provides an excellent example on how club membership requirement could be used as a coordination mechanism to control pollution to mitigate global warming across nations.

Literature on international policy coordination dates back to the late 1960’s and 70’s. Then two of the most noted studies done in this area were by Cooper (1969) and Hamada (1976). Cooper (1969) examined economic policy formulation in an open economy by allowing international capital movements. He observed that with international capital movement and increase in the interdependencies between the countries, effectiveness of decentralized policies declines, and coordination of policies between different countries becomes compelling. Assuming a two-country model, he specifies the targets of economic policy as the level of unemployment and the rate of economic growth. For instruments of economic policy he chooses government expenditures or open market operations, which were controlled by the nation’s economic authorities, and which in turn influenced the values taken by the target variables. The effectiveness of policy formulation was measured by the speed at which the target variables were restored to their target levels, in the presence of interdependencies among countries.

Hamada (1976) used a game theoretic formulation to explain the same problem. Hamada’s study became the pioneering work in using economic policy games to explain the gains from coordination. Hamada (1976) highlighted the importance of monetary interdependencies between different countries while examining the gains from policy coordination. He constructed an n-country game in which the monetary policy of each country was conducted in such a way as to maximize the objective function of its monetary authority, the primary objectives being price stability and balance of payment equilibrium. In the process, he also shows that if there were differences in national
preferences concerning inflation and balance of payment policies, they affect the realized outcome of the world inflation rate. Hamada (1979) extended a fixed exchange rate case to the analysis for flexible exchange rate.

Cooper (1985) gives a detailed exposition of economic interdependence between different countries. He defines economic interdependence as a multidimensional economic transaction between two countries, or a country and the rest of the world. Following Hamada, many studies were carried out using multiple-country macroeconomic policy games, with countries maximizing their respective welfare functions defining the strategic positions of the countries. Corden (1985) defined a case of bilateral monopoly between two governments, whose objective functions were to manage the aggregate nominal demand of its own country. Under flexible exchange rate system he showed that non-cooperative solutions will have deflationary biases relative to cooperative policies. But this remains valid only in the short run as it does not take into account the effects of expectation formation on inflation and unemployment in the later periods. Most of these studies use static macroeconomic models.

Other seminal studies on strategic policy coordination include Canzoneri and Gray (1985), Currie and Levine (1985), Kehoe (1986), Ploeg (1988). In general these studies show that when authorities ignore interdependence, the solutions will not be efficient and conclude that when authorities cooperate the result would be Pareto superior. While there are some studies suggesting cooperation as a superior strategy, there are other studies which show that there are no clear benefits of international cooperation. Studies like Oudiz and Sachs (1984) use a dynamic game model to show possible time inconsistency in the solution. Thus they bring out the importance of credibility of the policies of the players. Frankel and Rockett (1988) suggest that in order to maximize the gains from cooperation, policymakers often come out with incorrect models of policy coordination. This happens primarily because different governments subscribe to different economic philosophies. Lack of knowledge of the true model leads to movement of the target variables in the wrong direction and hence lowers equilibrium rates.

Obstfeld (2001) and Rogoff (2002) provide an excellent review of some of the models used for policy coordination with Mundell-Fleming-Dornbush type models. These models invariably had one spatial equilibrium condition for the output and another spatial equilibrium condition for the prices, and one more for the capital flows or exchange rate. While Mundell-Fleming model is an open economy IS-LM model, Dornbusch included the assumption of sticky prices for wages, and introduced disequilibrium dynamics into the model. This post Keynesian assumption was difficult to uphold among macroeconomists those days by anyone other than Dornbusch (see Rogoff’s Mundell-Fleming lecture (Rogoff (2002))).

The financial meltdown of September 2008 and the prolonged recession that followed in the EU and USA raised concerns on the adverse impacts non-cooperation and need for macroeconomic policy coordination on bilateral and multilateral basis. Cooperative mechanism should be structured along with evaluation of likely scenarios in order to illustrate the degree of interactions and interdependence in the global economy.

2 Growth Spillover across the Globe

Growth spill overs occurs in the global economy. For instance about 46 percent of growth in the US are due to external factors compared 31 percent for the UK. External factors are more imporatn for all major countries ranging from 46 for Japna (JPN) to 67 percent for France (FRA).
<table>
<thead>
<tr>
<th>Country</th>
<th>US</th>
<th>UK</th>
<th>FRA</th>
<th>GER</th>
<th>JPN</th>
<th>BRA</th>
<th>MEX</th>
<th>TUR</th>
<th>SAF</th>
<th>IND</th>
<th>From Others</th>
</tr>
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<tr>
<td>US</td>
<td>53.6</td>
<td>27.1</td>
<td>0.8</td>
<td>6.1</td>
<td>1.4</td>
<td>0.8</td>
<td>3.6</td>
<td>1.1</td>
<td>2.4</td>
<td>3.2</td>
<td>46</td>
</tr>
<tr>
<td>UK</td>
<td>17.7</td>
<td>60.1</td>
<td>0.4</td>
<td>5.8</td>
<td>0.6</td>
<td>0.8</td>
<td>2.5</td>
<td>0.6</td>
<td>0.7</td>
<td>1.7</td>
<td>31</td>
</tr>
<tr>
<td>FRA</td>
<td>22.2</td>
<td>22.6</td>
<td>52.9</td>
<td>5.8</td>
<td>1.2</td>
<td>7.4</td>
<td>1.4</td>
<td>0.3</td>
<td>0.6</td>
<td>5.3</td>
<td>67</td>
</tr>
<tr>
<td>GER</td>
<td>13.3</td>
<td>19.6</td>
<td>8.4</td>
<td>43.8</td>
<td>3.1</td>
<td>5.6</td>
<td>0.9</td>
<td>0.6</td>
<td>0.6</td>
<td>4.1</td>
<td>56</td>
</tr>
<tr>
<td>JPN</td>
<td>10.3</td>
<td>10.8</td>
<td>0.3</td>
<td>11.9</td>
<td>51.7</td>
<td>3.9</td>
<td>0.5</td>
<td>0.7</td>
<td>0.3</td>
<td>1.8</td>
<td>46</td>
</tr>
<tr>
<td>BRA</td>
<td>16.4</td>
<td>16.1</td>
<td>11.5</td>
<td>5.3</td>
<td>2.6</td>
<td>36.8</td>
<td>1.9</td>
<td>0.3</td>
<td>0.2</td>
<td>9.2</td>
<td>63</td>
</tr>
<tr>
<td>MEX</td>
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<td>16.3</td>
<td>8.4</td>
<td>4.2</td>
<td>6.3</td>
<td>34.6</td>
<td>4.7</td>
<td>0.5</td>
<td>6.4</td>
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<td></td>
</tr>
<tr>
<td>TUR</td>
<td>10.8</td>
<td>5.2</td>
<td>12.6</td>
<td>1.3</td>
<td>5.5</td>
<td>5.1</td>
<td>7.3</td>
<td>44.9</td>
<td>2</td>
<td>5.4</td>
<td>55</td>
</tr>
<tr>
<td>SAF</td>
<td>12.5</td>
<td>16.7</td>
<td>2</td>
<td>4.2</td>
<td>3</td>
<td>16.9</td>
<td>1.4</td>
<td>3.1</td>
<td>38.2</td>
<td>2.9</td>
<td>62</td>
</tr>
<tr>
<td>IND</td>
<td>4.3</td>
<td>2.8</td>
<td>2.3</td>
<td>13</td>
<td>1.3</td>
<td>1.5</td>
<td>0.5</td>
<td>3.2</td>
<td>4.4</td>
<td>46.7</td>
<td>33</td>
</tr>
<tr>
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<td>42</td>
<td>92</td>
<td>23</td>
<td>48</td>
<td>20</td>
<td>12</td>
<td>12</td>
<td>49</td>
<td>526</td>
</tr>
<tr>
<td>Contribution with own</td>
<td>178</td>
<td>212</td>
<td>75</td>
<td>100</td>
<td>77</td>
<td>85</td>
<td>55</td>
<td>56</td>
<td>50</td>
<td>107</td>
<td>52.60%</td>
</tr>
</tbody>
</table>

Global spill over index measures the degree of spill over effect to a particular country from various economies in the World (Diebold and Yilmaz(2009)). These effects vary from time to time. As can be seen from the figure below the negative spill over effect on the global economy increased substantially after the 2008 financial crisis and has come to below the pre-crisis level as a result of the adoption of fiscal and monetary policies around the world.

![Figure 1: Global growth spill-over](image)

## 3 A strategic model for policy coordination

One of the major policy issues facing nations in a global economy today is to shield each country from external shocks as such shocks can lower growth or cause inflation. These shocks could arise from fluctuations in output growth, inflation and domestic rate of interest. Such shocks could be transmitted through trade in goods and services, international capital mobility etc. Some of these speculations or expectations arise due to long term trends as well as short run fluctuations. The existing literature was mostly limited to policy coordination between countries of EMU or between the US and the UK, as in Frankel and Rockett (1986). The type of models to use, and the type of problems one faces, will radically be different if the macroeconomic policy coordination is between
the US and China or between the US and India. The policy coordination in such cases must deal with growth, investment, and distortions in both product and factor markets.

One may note the recent trends and the political dialogue between the USA and China regarding devaluation of the Chinese currency. Likewise one may expect more trade in ICT services between the US and India, and one may also expect trade in manufacturing with US shifting from China to India. With these emerging trends the macroeconomic policy coordination between US and China and US and India is not just for academic curiosity but is of great political and economic significance. Macroeconomic policy coordination in such cases must be strategic in nature and the underlying models should incorporate both long run growth as well as short run fluctuations.

The review of literature given above shows that the models existing in the literature on macroeconomic policy coordination requires updating to fit into the evolving structural features of the national economies. We establish connections and complementarity between time series econometric models, such as Vector Auto Regression (VAR) models of the macro economies to the open economy DSGE model. First we estimate, test and validate a VAR model and apply it to study the impulse responses of shocks to aggregate demand and monetary policy between India and the USA. Then we apply the two country global economy DSGE model to study the impact of demand supply and policy side shocks in these two economies. These analysis fit well in the context of the most recent Modi-Obama policy coordination debates of Fall 2014 and Winter 2015. These time series and DSGE model based analyses identify policy measures to mitigate the adverse consequences of shocks to technology, aggregate demand and economic policies applicable in case of many other situations.

To motivate the policy coordination problem, let us consider three countries aiming for a policy coordination with the Nash utility frontier \( (N_t) \) in which each country aims to maximise its own utility \( (U_{i,t}) \):

\[
N_t = U_{1,t}U_{2,t}U_{3,t}
\]  

Each receive utility from consuming products \( (y_{i,t}) \) produced in each country:

\[
U_{i,t} = F(y_{1,t},y_{2,t},y_{3,t})
\]  

Let the supply process of goods be determined simultaneously as:

\[
y_{1,t} = \alpha_{1,0} + \alpha_{1,2}y_{2,t} + \alpha_{1,3}y_{3,t} + \beta_{1,1}y_{1,t-1} + \beta_{1,2}y_{2,t-1} + \beta_{1,3}y_{3,t-1} + \epsilon_{1,t}
\]

\[
y_{2,t} = \alpha_{2,0} + \alpha_{2,1}y_{1,t} + \alpha_{2,3}y_{3,t} + \beta_{2,1}y_{1,t-1} + \beta_{2,2}y_{2,t-1} + \beta_{2,3}y_{3,t-1} + \epsilon_{2,t}
\]

\[
y_{3,t} = \alpha_{3,0} + \alpha_{3,1}y_{1,t} + \alpha_{3,2}y_{2,t} + \beta_{3,1}y_{1,t-1} + \beta_{3,2}y_{2,t-1} + \beta_{3,3}y_{3,t-1} + \epsilon_{3,t}
\]

solving this simultaneously:

\[
\begin{pmatrix}
1 & -\alpha_{1,2} & -\alpha_{1,3} \\
-\alpha_{2,1} & 1 & -\alpha_{2,3} \\
-\alpha_{3,1} & -\alpha_{3,2} & 1
\end{pmatrix}
\begin{pmatrix}
y_{1,t} \\
y_{2,t} \\
y_{3,t}
\end{pmatrix}
= 
\begin{pmatrix}
\alpha_{1,0} \\
\alpha_{2,0} \\
\alpha_{3,0}
\end{pmatrix}
+ 
\begin{pmatrix}
\beta_{1,1} & \beta_{1,2} & \beta_{1,3} \\
\beta_{2,1} & \beta_{2,2} & \beta_{2,3} \\
\beta_{3,1} & \beta_{3,2} & \beta_{3,3}
\end{pmatrix}
\begin{pmatrix}
y_{1,t-1} \\
y_{2,t-1} \\
y_{3,t-1}
\end{pmatrix}
+ 
\begin{pmatrix}
\epsilon_{1,t} \\
\epsilon_{2,t} \\
\epsilon_{3,t}
\end{pmatrix}
\]
\[
\begin{pmatrix}
y_{1,t} \\
y_{2,t} \\
y_{3,t}
\end{pmatrix}
= \begin{pmatrix}
1 & -\alpha_{1,2} & -\alpha_{1,3} \\
-\alpha_{2,1} & 1 & -\alpha_{2,3} \\
-\alpha_{3,1} & -\alpha_{3,2} & 1
\end{pmatrix}^{-1}
\begin{pmatrix}
\alpha_{1,0} \\
\alpha_{2,0} \\
\alpha_{3,0}
\end{pmatrix}
+ \begin{pmatrix}
1 & -\alpha_{1,2} & -\alpha_{1,3} \\
-\alpha_{2,1} & 1 & -\alpha_{2,3} \\
-\alpha_{3,1} & -\alpha_{3,2} & 1
\end{pmatrix}^{-1}
\begin{pmatrix}
\beta_{1,1} & \beta_{1,2} & \beta_{1,3} \\
\beta_{2,1} & \beta_{2,2} & \beta_{2,3} \\
\beta_{3,1} & \beta_{3,2} & \beta_{3,3}
\end{pmatrix}
\begin{pmatrix}
y_{1,t-1} \\
y_{2,t-1} \\
y_{3,t-1}
\end{pmatrix}
+ \begin{pmatrix}
1 & -\alpha_{1,2} & -\alpha_{1,3} \\
-\alpha_{2,1} & 1 & -\alpha_{2,3} \\
-\alpha_{3,1} & -\alpha_{3,2} & 1
\end{pmatrix}^{-1}
\begin{pmatrix}
e_{1,t} \\
e_{2,t} \\
e_{3,t}
\end{pmatrix}
\tag{7}
\]

In common meetings or summits policy makers decide policies given by \(\alpha_{1,0}, \alpha_{2,0}\) and \(\alpha_{3,0}\) but each of them face idiosyncratic shocks \(e_{1,t}, e_{2,t}\) and \(e_{3,t}\). Then each country determines its action \(y_{i,t}\) taking account of actions taken by others \(y_{j,t}\) and its own history. Such response patterns are given by parameters \(\alpha_{1,2}, \alpha_{1,3}, \alpha_{2,1}, \alpha_{2,3}, \alpha_{3,1}, \alpha_{3,2}\) and shocks \(e_{1,t}, e_{2,t}\) and \(e_{3,t}\). Each would like to get more utility and this opens the opportunities for bargain and policy coordination. The optimal solution of this game should fulfill symmetric, efficient, linear invariance and IIA properties of the Nash bargaining game. This provides theoretical justification for using a VAR model for policy coordination. We specify one such model to study the features of policy coordination between India and the USA in the next section.

4 VAR model for domestic and foreign shocks to growth, inflation and interest rate policy

Let us begin empirical investigations of policy coordination model formulating a VAR(1) for the USA and India, two large countries representing advanced and developing economies. They have recently reinforced economic relations for growth and development including transfer of advanced technologies, FDI and trade. In general a VAR (1) for endogenous variables \(Y_t\) can be represented as:

\[
Y_t = B^{-1}\Gamma_0 + B^{-1}\Gamma_1 Y_{t-1} + B^{-1}\epsilon_t 
\tag{8}
\]

The reduced form of this VAR system is then given by:

\[
Y_t = A_0 + A_1 Y_{t-1} + \epsilon_t 
\tag{9}
\]

where \(A_0 = B^{-1}\Gamma_0\), \(A_1 = B^{-1}\Gamma_1\), \(\epsilon_t = B^{-1}\epsilon_t\).

Then select seven macro time series for this model as in the DSGE formulation of the two country global economy model in the next section. These variables are growth rates, inflation and interest rates in India and the USA and the change in the real exchange rates as shown below.
This system is subject to shocks. The term \( \varepsilon_t = \{ \varepsilon_{j,t} \} \) is column vector of shocks for country \( j \) and endogenous variable \( x \) at time \( t \). Then the parameters \( B, \Gamma_0 \) and \( \Gamma_1 \) are as given by:

\[
B^{-1} = \begin{bmatrix}
    b_{11} & b_{12} & b_{13} & b_{14} & b_{15} & b_{16} & b_{17} \\
    b_{21} & b_{22} & b_{23} & b_{24} & b_{25} & b_{26} & b_{27} \\
    b_{31} & b_{32} & b_{33} & b_{34} & b_{35} & b_{36} & b_{37} \\
    b_{41} & b_{42} & b_{43} & b_{44} & b_{45} & b_{46} & b_{47} \\
    b_{51} & b_{52} & b_{53} & b_{54} & b_{55} & b_{56} & b_{57} \\
    b_{61} & b_{62} & b_{63} & b_{64} & b_{65} & b_{66} & b_{67} \\
    b_{71} & b_{72} & b_{73} & b_{74} & b_{75} & b_{76} & b_{77} \\
\end{bmatrix}^{-1}
\]

; \( \Gamma_0 = \begin{bmatrix}
    b_{10} \\
    b_{20} \\
    b_{30} \\
    b_{40} \\
    b_{50} \\
    b_{60} \\
    b_{70} \\
\end{bmatrix} \); \( \Gamma_1 = \begin{bmatrix}
    \gamma_{11} & \gamma_{12} & \gamma_{13} & \gamma_{14} & \gamma_{15} & \gamma_{16} & \gamma_{17} \\
    \gamma_{21} & \gamma_{22} & \gamma_{23} & \gamma_{24} & \gamma_{25} & \gamma_{26} & \gamma_{27} \\
    \gamma_{31} & \gamma_{32} & \gamma_{33} & \gamma_{34} & \gamma_{35} & \gamma_{36} & \gamma_{37} \\
    \gamma_{41} & \gamma_{42} & \gamma_{43} & \gamma_{44} & \gamma_{45} & \gamma_{46} & \gamma_{47} \\
    \gamma_{51} & \gamma_{52} & \gamma_{53} & \gamma_{54} & \gamma_{55} & \gamma_{56} & \gamma_{57} \\
    \gamma_{61} & \gamma_{62} & \gamma_{63} & \gamma_{64} & \gamma_{65} & \gamma_{66} & \gamma_{67} \\
    \gamma_{71} & \gamma_{72} & \gamma_{73} & \gamma_{74} & \gamma_{75} & \gamma_{76} & \gamma_{77} \\
\end{bmatrix} \)

This VAR(1) model is estimated in Eviews using the quarterly time series data of India and the USA from 1981:1 to 2014:2 as given in Figure 2.

Figure 2: Quarterly data series of US and India
Now let us focus on shocks to foreign and domestic demands and monetary policy on the basis of responses to shocks as presented in Figures 3 to 6. Increase in the growth rate of the US causes an increase in the interest rate and inflation in the US. Higher interest rate triggers capital outflow and lowers the interest rate in India. US growth rate has very small impact on growth or inflation in India and has very insignificant impact on the real exchange rate.

Figure 3: Impulses of aggregate demand shocks in the US

Higher growth rate in India does not impact on growth rates or inflation significantly in the US but raises the US interest rate. This must also follow from the capital account channel. Increase in growth rate in India promotes FDI to India from the US; outflow of capital raises interest rate in the short run in the US.
Monetary policy shock in the form of higher interest rate in the USA induces more saving. Given the productive potentials it raises investment and aggregate supply. Greater demand also translates into higher inflation. Higher growth rate in the US leads to a temporary increase in output and inflation in India. It also lowers the interest in India because of increased potential for capital inflows. The US monetary policy does not seem to have significant impact on the exchange rate of Indian Rupee.
Higher interest rate in India raises the cost of capital and lowers the growth rate but does not have significant impact on inflation. This problem is further deteriorated because of appreciation of Rupee which leads 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 allow raises the interest in US.

5 Two country global economy model for macro policy co-ordination

We incorporate risk premium element in the Lubik and Schorfheide (2005) two country dynamic stochastic general equilibrium global economy model (DSGEGEM) in order to assess how the policy spillover effects spread from an advanced to an emerging economy or the other way round. It is a global dynamic stochastic general equilibrium (DSGE) model (also called new open economy model (NEOM)) in the sense that the market in goods and factors clear at the global level - adjustment in domestic and foreign prices and the real exchange rates make this happen. It is a stochastic model as it focuses on business cycle impacts of shocks to the technology as well as fiscal and monetary policy instruments.

5.0.1 Households

As is a standard in the most macroeconomic model households in this model receive utility from consumption \( (C_t) \) and disutility from work \( (N_t) \). Discount factor \( (\beta) \) and expectation operator \( (E_0) \) are used to compute life time utility of representative households in each country \( (U_0) \).
intertemporal elasticity of substitution (τ) measures the relative rate of risk aversion of consumers between current and future consumptions.

\[
U_0 = E_0 \left[ \sum_{t=0}^{\infty} \beta^t \left( \frac{C_t}{A_{Wt}} \right)^{1-\tau} \left( \frac{1}{1 - \tau} - N_t \right) \right]
\]

(12)

Consumers are subject to habit persistent conditions as given by \( \tilde{C}_t = C_t - h\gamma C_{t-1} \); they also benefit from technological growth \( z_t = \frac{A_{Wt}}{A_{Wt+1}} \). Here \( \gamma \) is the growth rate of technology in the steady state and the habit parameter \( h \) is positive but less than one, \( 0 < h < 1 \). The composite consumption good is made of (subscript \( H \) for home, the US in the current model) and foreign (subscript \( F \) refers to India here) consumption goods \( C_{H,t} \) and \( C_{F,t} \) (the US and Indian) respectively as:

\[
C_t = \left( 1 - \alpha \right)^{\frac{1}{\eta}} C_{H,t}^{\frac{\alpha-1}{\eta}} + \alpha^{\frac{1}{\eta}} C_{F,t}^{\frac{\alpha-1}{\eta}}
\]

(13)

Where \( \eta \) is the elasticity of substitution between the US and Indian consumption goods. Under the new Keynesian supply assumption the demand for consumption goods are linked to home, foreign and aggregate prices levels, \( P_{H,t} \), \( P_{F,t} \) and \( P_t \) as:

\[
C_{H,t} = \left( 1 - \alpha \right) \left( \frac{P_{H,t}}{P_t} \right)^{-\eta} C_t
\]

(14)

\[
C_{F,t} = \left( 1 - \alpha \right) \left( \frac{P_{F,t}}{P_t} \right)^{-\eta} C_t
\]

(15)

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

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

(16)

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

\[
P_{H,t}C_{H,t} + P_{F,t}C_{F,t} + E_t (Q_{t,t+1}D_{t+1}) = W_t N_t + D_t - T_t
\]

(17)

Here \( D_t \) denotes the debt and \( T_t \) is the transfer that households receive. Then \( Q_{t,t+1} \) is the price of bonds. The optimal choices of households regarding the commodity and asset markets are given by the standard first order conditions (FOC) as:

\[
A_{Wt} \lambda_t P_t = C_t^{-\tau} - h\gamma \beta E_t \left( \frac{A_{Wt}}{A_{Wt+1}} C_{t-1}^{-\tau} \right)
\]

(18)

This Euler equation (18) states relation between current and future effective consumption where \( \lambda_t \) is the marginal utility of income, and \( \tau \) the elasticity of substitution between the current and future consumptions.
\[ Q_{t,t+1} = \beta E_t \left[ \frac{\lambda_{t+1}}{\lambda_t} \frac{P_t}{P_{t+1}} \right] \]  

The stochastic discount factor \( Q_{t,t+1} \) 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.

\[ R^{-1} = \beta E_t \left[ \frac{\lambda_{t+1}}{\lambda_t} \frac{P_t}{P_{t+1}} \right] \]  

Here \( R \) is the nominal interest rate implied by this system.

### 5.1 Firms

This model assumes a linear production function where output \( (Y_{H,t}(j)) \) is a function of technological progress at home and abroad \( (A_{W,t}, A_{H,t}) \) and the labour input \( (N_t(j)) \):

\[ Y_{H,t}(j) = A_{W,t} A_{H,t} N_t(j) \]  

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

\[ E_t \left[ \sum_{t=T}^{\infty} \theta_{t} Q_{H}^{t-\theta} Y_{H,t}(j) \right] \left[ P_{H,t}(j) \pi_{H,t}^{-T} - P_{H,t} MC_{H,t} \right] ; \quad MC_{H,t} = \frac{W_t}{P_{H,t}} \]  

Supply function for each commodity \( j \) is given by:

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

Where \( \omega \) is the elasticity of substitution among domestic commodities. Real exchange rate measures the degree of pass-through between domestic and foreign prices:

\[ \psi_{F,t} = \frac{e_t}{P_{F,t}} \]  

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

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

\[ C_{F,t} = (1 - \alpha) \left[ \frac{P_{F,t}}{P_t} \right]^{-\omega} C_t \]
5.2 International links and global market clearing

Home economy is connected to foreign economy through relative prices of home to foreign commodities. The real exchange rate is \( s_t = \frac{P_{F,t}}{P_{H,t}} \) which reflects the terms of trade at 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 \( \frac{q_t}{q_t} = \frac{q_t^*}{q_t^*} \).

\[
\begin{align*}
s_t &= \frac{e_t P_t}{P_t}, \quad q_t = \frac{P_{H,t}}{P_{F,t}}, \quad q_t^* = \frac{P_{F,t}}{P_{H,t}} \quad \psi_{F,t} = \frac{\psi_{F,t}}{q_t^*}.
\end{align*}
\]

Market clearing implies that domestic and foreign asset markets clear:

\[
\beta \frac{\lambda_{t+1}}{\lambda_t} \frac{P_t}{P_{t+1}} = Q_{t,t+1} = \beta \frac{\lambda_{t+1}^*}{\lambda_t^*} \frac{P_t^*}{P_{t+1}^*} \frac{e_t}{e_{t+1}}
\]

Similarly markets also clear for home and foreign goods as:

\[
Y_{H,t} = C_{H,t} + G_{H,t} + C_t^*
\]

\[
Y_{F,t} = C_{F,t} + G_{F,t} + C_t^*
\]

5.3 Log-linearisation for the solution of the model

Model solved using Sim(2002) algorithm. First define variables as:

\[
\bar{x}_t = \ln x_t - \ln \pi
\]

Linearisation of price (inflation to marginal cost):

\[
\tilde{\pi}_{H,t} = \beta E_t \tilde{\pi}_{H,t+1} + k_{H,t} \tilde{m} c_t
\]

where \( k_{H,t} = \frac{1-\theta_H}{\theta_H} (1-\theta_H \beta) \) is Calvo price adjustment factor and \( \tilde{m} c_t = -\bar{\lambda}_t - a q_t - \bar{A}_t \) is marginal cost of production. Similarly the changes in the marginal utility of income \( (\bar{\lambda}_t) \) relates to changes in consumption between two periods are given by Euler relation:

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

Habits evolves according to (for \( h = 0 \)) it is a standard Euler equation:

\[
(1-h) \tilde{C}_t = \bar{c}_t - h \bar{c}_{t+1} + h \bar{z}_{t+1}
\]

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

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

\[
\tilde{\pi}_{F,t} = \beta E_t \tilde{\pi}_{F,t+1} + k_{F,t} \tilde{\psi}_{F,t}; \quad k_{F,t} = \frac{1-\theta_F}{\theta_F} (1-\theta_F \beta)
\]
This domestic inflation has domestic and foreign components:

\[ \pi_t = \alpha \pi_{F,t} + (1 - \alpha) \pi_{H,t} \]  

Terms of trade according to changes in domestic relative to foreign inflation:

\[ q_t = \bar{q}_{t-1} + \pi_{H,t} - \pi_{F,t} \]  

Thus the real exchange rate evolves according to the lop and terms of trade effects as:

\[ \bar{s}_t = \psi_{F,t} - (1 - \alpha) \bar{q}_{t-1} - \alpha \bar{q}_{t-1} \]  

Purchasing power parity condition implies that changes in the exchange rate reflect the difference on changes in domestic and foreign inflation and real exchange rates:

\[ \Delta \bar{e}_t = \pi_t - \pi_t^* + \Delta \bar{s}_t \]  

Interest rate differential relate to changes in the exchange rate dynamics as:

\[ \bar{R}_t - \bar{R}_t^* = E_t \Delta \bar{e}_{t+1} \]  

Marginal utilities of income between trading nations relate to purchasing power parity:

\[ \bar{\lambda}_t = \bar{\lambda}_t^* - \bar{s}_t \]  

goods market clearing:

\[ \bar{y}_{H,t} = \bar{c}_t - \bar{g}_t - \alpha \bar{s}_t + \alpha (1 - \alpha) \bar{\psi}_t (\bar{q}_t - \bar{q}_t^*) \]  

This output relates to aggregate demand and relative price from this condition.

Interest rate rule for this global economy includes adjustments to inflation, output gap and exchange rates and shocks to the monetary policy in the form of a Taylor equation as:

\[ \bar{R}_t = \rho_R \bar{R}_{t-1} + (1 - \rho_R) [\psi_1 \pi_t + \psi_2 (\Delta \bar{y}_t + \bar{z}_t) + \psi_3 \Delta \bar{e}_{t+1}] + \epsilon_{R,t} \]  

Here \( \epsilon_{R,t} \) represents the monetary policy shock.

This global economy is subject to five types of shocks. First three shocks represent productivity shocks in the global market (\( \bar{z}_t \)), home country (\( \bar{A}_t \)) and the foreign country (\( \bar{A}_t^* \)). All three productivity shocks are assumed to be autoregressive of order 1 (\( \rho_z, \rho_A, \rho_{A^*} \)) and subject to random shocks \( \epsilon_{z,t}, \epsilon_{A,t} \) and \( \epsilon_{A^*,t} \) respectively. These shocks affect both the consumption and production sides of the economy.

\[ \bar{z}_t = \rho_z \bar{z}_{t-1} + \epsilon_{z,t} \]  
\[ \bar{A}_t = \rho_A \bar{A}_{t-1} + \epsilon_{A,t} \]  
\[ \bar{A}_t^* = \rho_{A^*} \bar{A}_{t-1}^* + \epsilon_{A^*,t} \]
Then the model is subject to two types of fiscal policy shocks, the aggregate public spending shocks $G_t$ and $G_t^*$ respectively at home and abroad. Fiscal shocks are persistent with order 1 autoregression as measured by $\rho_G$ and $\rho_{G^*}$ but also subject to random fluctuations $\epsilon_G$ and $\epsilon_{G^*}$.

$$G_t = \rho_G G_{t-1} + \epsilon_{G,t} \quad (47)$$

$$G_t^* = \rho_{G^*} G_{t-1}^* + \epsilon_{G^*,t} \quad (48)$$

### 6 Risk Premium and UIP

The above model is set out without financial frictions where UIP holds, this means perfect international risk-sharing. Next we consider a modified UIP condition assuming that households face a risk premium on international asset markets. One departure from the representative household behaviour is that we incorporate a world financial friction facing households as in Benigno (2001). In particular, there are two risk-free one-period bonds denominated in home and foreign currencies with payments in period $t$, $B_{H,t}$ and $B_{F,t}^*$ respectively, in per capita or aggregate terms. The prices of these bonds are given by

$$P_{B,t} = R_t^{-1}$$

$$P_{B,t}^* = R_t^{*-1} \phi \left( \frac{e_t B_{F,t}^*}{P_{H,t} Y_t} \right)^{-1} \quad (50)$$

where $\phi(\cdot)$ captures the cost in the form of a risk premium for home households to hold foreign (US) bonds, $e_t B_{F,t}^*$ is the aggregate foreign asset position of the economy denominated in home currency, $e_t$ is the nominal exchange rate and $P_{H,t} Y_t$ is nominal GDP. We assume $\phi(0) = 1$ and $\phi' < 0$. The risk premium term is strictly decreasing in aggregate foreign asset position of the home economy. $R_t$ and $R_t^*$ 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 (US), but foreign households cannot hold home bonds. Then the net and gross foreign assets in the home bloc are equal.

The standard intertemporal optimality conditions for the consumption allocation and the consumption decision of the households are:

$$P_{B,t} = \beta E_t \left[ \frac{\lambda_{t+1}}{\lambda_t \Pi_{t+1}} \right]$$

$$P_{B,t}^* = \beta E_t \left[ \frac{\lambda_{t+1} e_{t+1}}{\lambda_t \Pi_{t+1} e_t} \right] \quad (52)$$

where

$$\Pi_t = \frac{P_t}{P_{t-1}}$$

in the open economy $\Pi_t$ is consumer price inflation (CPI) and $\lambda_t$ is the marginal utility of income. The producers’ decisions are as before except $\Pi_t$ is replaced with domestic price inflation $\Pi_{H,t} = \ldots$
\( \frac{P_{H,t}}{P_{H,t-1}} \) which differs from consumer price inflation. Same for the importers so import price inflation is \( \Pi_{F,t} = \frac{P_{F,t}}{P_{F,t-1}} \).

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

\[
P_B = \frac{E_t \left[ \frac{\lambda_{t+1} P_t}{P_{t+1}} \right]}{E_t \left[ \frac{\lambda_{t+1} \Pi_{t+1} + P_t}{\Pi_{t+1}} \right]} \tag{53}
\]

then add a risk premium shock in period \( t-1 \), \( \exp(\epsilon_{UIP,t}) \) that captures stochastic deviations from the UIP condition and use (49), (50), (51), (52) and

\[
R_t^{*,-1} = \beta E_t \left[ \frac{\lambda_{t+1}^*}{\lambda_t^* \Pi_{t+1}^*} \right] \tag{54}
\]

to obtain

\[
\phi \left( \frac{e_t B_{F,t}^*}{P_{H,t} Y_t} \right) \exp(\epsilon_{UIP,t}) E_t \left[ \frac{\lambda_{t+1}^*}{\lambda_t^* \Pi_{t+1}^*} \right] = E_t \left[ \frac{\lambda_{t+1}^* e_{t+1}}{\lambda_t^* \Pi_{t+1}^*} \right] \tag{55}
\]

Now define the risk sharing condition

\[
s_t^* = \frac{\lambda_t^*}{\lambda_t} \tag{56}
\]

noting that \( \frac{e_{t+1}}{\Pi_{t+1}^*} = \frac{e_{t+1}}{P_{t+1}^*} \frac{P_t}{s_t \Pi_{t+1}^*} \), and using (56), we then obtain the real exchange rate \( s_t \) as

\[
s_t = s_t^r s_t^d
\]

where the deviation of the real exchange rate from its risk-sharing value, \( s_t^d \) is given by

\[
E_t \left[ \frac{\lambda_{t+1}^* s_{t+1}^*}{\lambda_t^*} \frac{1}{\Pi_{t+1}^*} \left( \frac{1}{\phi \left( \frac{e_t B_{F,t}^*}{P_{H,t} Y_t} \right) \exp(\epsilon_{UIP,t})} - \frac{s_{t+1}^d}{s_t^d} \right) \right] = 0
\]

The real exchange rate is the same as before

\[
s_t = \frac{e_t P_{t}^*}{P_t}
\]

Finally current account dynamics are given by

\[
R_t^{*,-1} \phi \left( \frac{e_t B_{F,t}^*}{P_{H,t} Y_t} \right) e_t B_{F,t} = S_t B_{F,t-1} + TB_t \tag{57}
\]

\[
\phi \left( \frac{e_t B_{F,t}^*}{P_{H,t} Y_t} \right) = \exp \left( \frac{\chi B e_t B_{F,t}^*}{P_{H,t} Y_t} \right); \quad \chi_B < 0 \tag{58}
\]

\[
TB_t = P_{H,t} Y_t - P_t C_t - P_{H,t} G_t \tag{59}
\]

This part of model is complete by identifying the foreign assets or equivalently the trade balance \( (TB_t = P_{H,t} e_t B_{F,t} - e_t B_{F,t-1}) \) at home.
Linearization of Foreign Asset Accumulation and Modified UIP: linearizing around \( B_F = TB = 0 \) we define

\[
\tilde{b}_{F,t} = \frac{S_t B_{F,t}}{P_{H,t} Y_t}
\]

\[
\tilde{\theta}_t = \frac{T B_t}{P_{H,t} Y_t}
\]

Then we have in linearized form

\[
\beta \tilde{b}_{F,t} = \tilde{b}_{F,t-1} + \tilde{b}_t
\]

\[
\tilde{\theta}_t = y_{H,t} - \tilde{c}_t - \tilde{q}_t + \frac{\alpha}{\tau} \tilde{\lambda}_t + \alpha (1 - \alpha) \eta (\tilde{q}_t - \tilde{q}_t^*)
\]

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

\[
\tilde{s}_t = s_t^* + s_t^d
\]

\[
\tilde{s}_t^* = \lambda_t - \tilde{\lambda}_t
\]

\[
E_t [s_t^d(t+1)] = s_t^d + \gamma_t \tilde{b}_{F,t} + \tilde{\epsilon}_{UIP,t}
\]

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

\[
\tilde{\epsilon}_{UIP,t} = \rho_{UIP} \tilde{\epsilon}_{UIP,t-1} + \epsilon_{UIP,t}
\]

7 Model Solutions and Analysis of Results

This model consists of six types of variables: 1) Prices: \( P_t, P_t^*, \bar{P}_t, \bar{P}_t^*, \bar{P}_t, \tilde{\lambda}_t, \tilde{\lambda}_t^*, \tilde{Q}_t, \tilde{Q}_t^* \) (PI , PI_star , PI_H , PI_Hstar , PI_F , PI_Fstar , LAM , LAM_star , Q, Q_star); 2) Growth and inflation: \( y_{H,t}, \bar{y}_{H,t}, \tilde{\pi}_t^*, \tilde{\pi}_t^*, \bar{\pi}_t, \bar{\pi}_t^*, (Ygr_US, Ygr_F, INF_US, INF_F) \); 3) Quantities: \( \tilde{C}_t, \bar{C}_t^*, \) calC ,calC_star, \( \bar{Y}_t, \bar{Y}_t^* \); 4) Interest rate and exchange rates: \( R_t, R_t^*, S, R_{US,t}, R_{US,F} \) (R_US, R_F), \( E_{-\Delta} (E_{-del}) \); 5) Interest rate and exchange rates (ER) pass-through: \( \psi_{F,t} \) and \( \psi_{F,t}^* \) (PSI_F, PSI_Hstar) and 6) shocks: \( A_t, A_t^*, G_t, G_t^*, Z \).

Lubik and Schorfheide (2005) and Schurfheide (2005) applied this model to study interactions between the US and Euro area and found it good to study the business cycle policy spillover effects across nations. We apply it to study interaction between the US and the Indian economy, particularly to see if this model generates patterns as we observed in the structural VAR(1) earlier. This model is estimated with time varying parameters based on the same quarterly data set from 1981:I to 2014:II as presented in Figure 1 and used in VAR(1) analysis in that section. Variables have 134 time series observations on growth, inflation and interest rate in India and the US and the real exchange rate. This Bayesian DSGE VAR (BVAR) model is applied to estimate the time profile of model parameters and for the various decomposition analysis. This section presents the estimates of correlation and autoregressions among variables, priors and posterior means and confidence interval of parameters along with their priors on their mean and standard deviations.

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7.0.1 Correlation and autocorrelations

Correlations between pairs of seven model variables have expected signs except those with the US inflation. Positive correlation between growth rate and interest rate is indicative of increased demand for money and more capital flows to a country which has higher growth rates. Inflation in the US is negatively related to growth rates as it brings uncertainty not only for the US but also in the global economy. US growth rate is lower with depreciation of Indian currency but it raises the growth rate in India as it can export more with such depreciation. Interest rates are higher with higher growth rates and inflations. Currency appreciates with higher growth rate abroad and higher inflation at home.

<table>
<thead>
<tr>
<th>Variables</th>
<th>$g_{us,t}$</th>
<th>$\pi_{us,t}$</th>
<th>$r_{us,t}$</th>
<th>$g_{I,t}$</th>
<th>$\pi_{I,t}$</th>
<th>$r_{I,t}$</th>
<th>$d\Delta_t$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$g_{us,t}$</td>
<td>1</td>
<td>-0.3701</td>
<td>0.2762</td>
<td>0.0503</td>
<td>-0.176</td>
<td>-0.0917</td>
<td>0.0195</td>
</tr>
<tr>
<td>$\pi_{us,t}$</td>
<td>-0.3701</td>
<td>1</td>
<td>0.3199</td>
<td>0.0465</td>
<td>0.1208</td>
<td>0.4148</td>
<td>-0.0439</td>
</tr>
<tr>
<td>$r_{us,t}$</td>
<td>0.2762</td>
<td>0.3199</td>
<td>1</td>
<td>0.1508</td>
<td>-0.0839</td>
<td>0.4232</td>
<td>0.0467</td>
</tr>
<tr>
<td>$g_{I,t}$</td>
<td>0.0503</td>
<td>0.0465</td>
<td>0.1508</td>
<td>1</td>
<td>-0.3514</td>
<td>-0.3485</td>
<td>0.0833</td>
</tr>
<tr>
<td>$\pi_{I,t}$</td>
<td>-0.176</td>
<td>0.1208</td>
<td>-0.0839</td>
<td>-0.3514</td>
<td>1</td>
<td>0.5892</td>
<td>-0.1876</td>
</tr>
<tr>
<td>$r_{I,t}$</td>
<td>-0.0917</td>
<td>0.4148</td>
<td>0.4232</td>
<td>-0.3485</td>
<td>0.5892</td>
<td>1</td>
<td>-0.1117</td>
</tr>
<tr>
<td>$d\Delta_t$</td>
<td>0.0195</td>
<td>-0.0439</td>
<td>0.0467</td>
<td>0.0833</td>
<td>-0.1876</td>
<td>-0.1117</td>
<td>1</td>
</tr>
</tbody>
</table>

Autocorrelations show persistency of variables. We report here only up to order of five. All variables are persistent but revert to their mean in the long run. Inflation is most persistent of the seven variables in the model followed by the interest rate and growth rates. Exchange rates are random, cyclical and the least persistent as the autocorrelation coefficient is almost zero.

<table>
<thead>
<tr>
<th>Order</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>$g_{us,t}$</td>
<td>0.5781</td>
<td>0.5007</td>
<td>0.4294</td>
<td>0.3654</td>
<td>0.3089</td>
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<tr>
<td>$\pi_{us,t}$</td>
<td>0.7317</td>
<td>0.5414</td>
<td>0.4053</td>
<td>0.3075</td>
<td>0.2367</td>
</tr>
<tr>
<td>$r_{us,t}$</td>
<td>0.9379</td>
<td>0.8682</td>
<td>0.7963</td>
<td>0.7256</td>
<td>0.6583</td>
</tr>
<tr>
<td>$g_{I,t}$</td>
<td>0.2646</td>
<td>0.233</td>
<td>0.2063</td>
<td>0.1838</td>
<td>0.1647</td>
</tr>
<tr>
<td>$\pi_{I,t}$</td>
<td>0.8662</td>
<td>0.7659</td>
<td>0.6867</td>
<td>0.6216</td>
<td>0.5665</td>
</tr>
<tr>
<td>$r_{I,t}$</td>
<td>0.9695</td>
<td>0.9374</td>
<td>0.9043</td>
<td>0.8708</td>
<td>0.8374</td>
</tr>
<tr>
<td>$d\Delta_t$</td>
<td>0.0234</td>
<td>0.0237</td>
<td>0.0235</td>
<td>0.023</td>
<td>0.0223</td>
</tr>
</tbody>
</table>

7.0.2 Prior and posterior estimations

According to An and Schorfheide (2007) the Bayesian estimation process involves search through the space of $\theta$ using appropriate size of steps. The Bayes’ theorem is used in order to get posterior on parameter $\theta$, $p(\theta|Y^T)$, which can be derived from the definition of conditional probability: $p(\theta|Y^T) \propto p(Y^T|\theta) p(\theta)$, which is maximum likelihood function and $p(\theta)$ stands for prior probability distributions, and $p(Y^T|\theta)$ is posterior kernel. Likelihood function is estimated with the help of the Kalman filter in the form of Metropolis-Hastings MCMC algorithm (estimated in the dynare). It generates time varying profiles of model
parameters. The priors and posterior means along with the confidence intervals of these model parameters are given in Table 3.

Table 4: Estimation of Parameters in open economy model

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Prior Mean</th>
<th>Post. Mean</th>
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<th>Postdev</th>
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<td>0.8089</td>
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<td>2.1594</td>
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<td>0.3759</td>
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<td>1.4299</td>
<td>2.2204</td>
<td>gamma</td>
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<td>$\psi_5$</td>
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<td>1.3963</td>
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<td>0.2020</td>
<td>0.0972</td>
<td>0.3086</td>
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<tr>
<td>$R$</td>
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<td>0.4602</td>
<td>0.7867</td>
<td>gamma</td>
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<td>$\gamma$</td>
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<td>0.1738</td>
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<td>norm</td>
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<tr>
<td>$\overline{\pi}_H$</td>
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<td>0.4772</td>
<td>0.3995</td>
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<td>gamma</td>
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<tr>
<td>$\overline{R}_h$</td>
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<td>2.3057</td>
<td>2.9103</td>
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</tr>
<tr>
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<td>1.1472</td>
<td>1.4339</td>
<td>norm</td>
</tr>
<tr>
<td>$\overline{\pi}_H$</td>
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<td>2.0147</td>
<td>2.6848</td>
<td>gamma</td>
</tr>
<tr>
<td>$\rho_A$</td>
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<td>0.8417</td>
<td>0.9431</td>
<td>beta</td>
</tr>
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<td>0.8293</td>
<td>0.8006</td>
<td>0.8583</td>
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<td>$\rho_C$</td>
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<td>0.8802</td>
<td>0.7855</td>
<td>0.9744</td>
<td>beta</td>
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<tr>
<td>$\rho_{\Delta}^*$</td>
<td>0.50</td>
<td>0.9504</td>
<td>0.9162</td>
<td>0.9867</td>
<td>beta</td>
</tr>
<tr>
<td>$\rho_R^*$</td>
<td>0.50</td>
<td>0.9053</td>
<td>0.8848</td>
<td>0.9266</td>
<td>beta</td>
</tr>
<tr>
<td>$\rho_C^*$</td>
<td>0.50</td>
<td>0.9504</td>
<td>0.8922</td>
<td>0.9987</td>
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<tr>
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<tr>
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<td>0.8821</td>
<td>0.7966</td>
<td>0.9662</td>
<td>beta</td>
</tr>
</tbody>
</table>

7.0.3 Prior and posterior means of stochastic shocks

Major elements of fluctuations in a DSGE model originate from shocks. This model contains eight different shocks. Each country is subject to country specific technology, public spending and interest rate shocks. Then there is a global technology shock and shocks to the changes in the exchange rates between the US and India. Prior and posterior mean along with confidence interval and standard
deviation of posterior density function are given in table 4. Each of these distributions is assumed to have inverse gamma (invg) distribution on its prior.

<table>
<thead>
<tr>
<th></th>
<th>prior mean</th>
<th>post. mean</th>
<th>90% HPD interval</th>
<th>prior</th>
<th>pstdev</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \epsilon_A )</td>
<td>1</td>
<td>2.2789</td>
<td>1.5976</td>
<td>invg</td>
<td>4</td>
</tr>
<tr>
<td>( \epsilon_R )</td>
<td>1</td>
<td>0.4618</td>
<td>0.3815</td>
<td>invg</td>
<td>4</td>
</tr>
<tr>
<td>( \epsilon_{GJ} )</td>
<td>0.4</td>
<td>0.1358</td>
<td>0.1182</td>
<td>invg</td>
<td>4</td>
</tr>
<tr>
<td>( \epsilon_A^2 )</td>
<td>2</td>
<td>7.2373</td>
<td>4.811</td>
<td>invg</td>
<td>4</td>
</tr>
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<td>0.2736</td>
<td>invg</td>
<td>4</td>
</tr>
<tr>
<td>( \epsilon_{GJ}^2 )</td>
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<td>0.2714</td>
<td>0.2579</td>
<td>invg</td>
<td>4</td>
</tr>
<tr>
<td>( \epsilon_z^2 )</td>
<td>0.5</td>
<td>0.2854</td>
<td>0.1419</td>
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<td>4</td>
</tr>
<tr>
<td>( \epsilon_{\Delta_{11}} )</td>
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<td>3.7654</td>
<td>invg</td>
<td>4</td>
</tr>
<tr>
<td>( \epsilon_{w})</td>
<td>2</td>
<td>2.0334</td>
<td>0.5962</td>
<td>invg</td>
<td>4</td>
</tr>
</tbody>
</table>

In this context consider the modelling approach from the Dynare Guide (Chapter 8) "At its most basic level, Bayesian estimation is a bridge between calibration and maximum likelihood. The tradition of calibrating models is inherited through the specification of priors. And the maximum likelihood approach enters through the estimation process based on confronting the model with data.

Together, priors can be seen as weights on the likelihood function in order to give more importance to certain areas of the parameter subspace. More technically, these two building blocks - priors and likelihood functions - are tied together by Bayes’ rule.

### 7.0.4 Policy transition functions

Policy transition functions show how endogenous variables relate to predetermined variables in the model. Numbers in the 2nd and 4th column of Table 5 show the growth rates of output in the US and India both move positively to consumption in the previous periods, technical innovations and the growth in the public spending. However they react differently to the lagged values of interest rates or the exchange rates. There is a very striking resemblance for the coefficients of the interest rates in India and the US indicating close integration in the capital markets. Inflation also reacts differently between these two countries.

### 7.0.5 Theoretical Moments

There is striking similarity in the theoretical moment used in the model though it could be argued that the mean quarterly growth rate of 0.095 seems about right for the US but it should be a bit higher for India. Similarly inflation rate in India is above 0.70 percent than used in this model.

Discrepancy between these theoretical moments and actual moments cause the reverse in the patterns of responses to macroeconomic variables of six shocks as shown in the impulse response functions in the next section.

### 7.0.6 Bayesian impulse response functions

Impulse responses of macro variables to shocks to domestic, foreign and global technologies and public spending vary between the USA and India. For instance when global technology improves
<table>
<thead>
<tr>
<th></th>
<th>$g_{us,t}$</th>
<th>$\pi_{us,t}$</th>
<th>$T_{us,t}$</th>
<th>$g_{I,t}$</th>
<th>$\pi_{I,t}$</th>
<th>$r_{I,t}$</th>
<th>$d\Delta_t$</th>
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</thead>
<tbody>
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<td>Constant</td>
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<td>1.299305</td>
<td>2.596687</td>
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<tr>
<td>$C_{t-1}$</td>
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<td>0.064732</td>
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<td>0.004937</td>
<td>0.008392</td>
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<tr>
<td>$C^*_{t-1}$</td>
<td>-0.00067</td>
<td>0.032548</td>
<td>0.018005</td>
<td>0.660638</td>
<td>-0.1845</td>
<td>0.130655</td>
<td>1.056419</td>
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<tr>
<td>$R_{t-1}$</td>
<td>-0.18003</td>
<td>-0.45024</td>
<td>0.626462</td>
<td>0.682462</td>
<td>0.200493</td>
<td>0.268395</td>
<td>-2.58803</td>
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<tr>
<td>$R^*_{t-1}$</td>
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<td>0.120003</td>
<td>0.06936</td>
<td>-0.0514</td>
<td>-0.94581</td>
<td>0.303086</td>
<td>4.32693</td>
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<tr>
<td>$Y_{t-1}$</td>
<td>-0.00749</td>
<td>0.056302</td>
<td>-0.07834</td>
<td>-0.08534</td>
<td>-0.02507</td>
<td>-0.03556</td>
<td>0.323632</td>
</tr>
<tr>
<td>$Y^*_{t-1}$</td>
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<td>-0.03682</td>
<td>-0.20128</td>
<td>-0.61123</td>
<td>0.29021</td>
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<tr>
<td>$Q_{t-1}$</td>
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<td>-0.01418</td>
<td>0.057742</td>
<td>0.017231</td>
<td>0.017781</td>
<td>0.067365</td>
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<tr>
<td>$Q^*_{t-1}$</td>
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<td>0.007851</td>
<td>0.014974</td>
<td>-0.06987</td>
<td>0.057577</td>
<td>-0.00822</td>
<td>-0.04437</td>
</tr>
<tr>
<td>$A_{t-1}$</td>
<td>0.066705</td>
<td>-0.06779</td>
<td>-0.01788</td>
<td>-0.04384</td>
<td>-0.02877</td>
<td>-0.018</td>
<td>0.047462</td>
</tr>
<tr>
<td>$A^*_{t-1}$</td>
<td>-0.00532</td>
<td>0.003917</td>
<td>0.00136</td>
<td>0.004351</td>
<td>-0.05154</td>
<td>-0.00924</td>
<td>0.073892</td>
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<tr>
<td>$G_{t-1}$</td>
<td>0.90008</td>
<td>-0.01657</td>
<td>0.085671</td>
<td>0.064325</td>
<td>0.021488</td>
<td>0.025336</td>
<td>-0.2197</td>
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<tr>
<td>$G^*_{t-1}$</td>
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<td>0.029531</td>
<td>0.015841</td>
<td>0.684976</td>
<td>-0.12804</td>
<td>0.150505</td>
<td>0.876816</td>
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<td>$UTP_{t-1}$</td>
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<td>0.001718</td>
<td>0.001092</td>
<td>-0.00972</td>
<td>0.02514</td>
<td>0.00184</td>
<td>-0.00279</td>
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<tr>
<td>$b^t_{t-1}$</td>
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<td>-0.00196</td>
<td>-0.00059</td>
<td>-0.00456</td>
<td>0.007741</td>
<td>0.000155</td>
<td>-0.00197</td>
</tr>
<tr>
<td>$S_{t-1}$</td>
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<td>-0.02969</td>
<td>-0.01984</td>
<td>0.003849</td>
<td>-0.8946</td>
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<tr>
<td>$Z_{t-1}$</td>
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<td>0.003865</td>
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<td>0.103843</td>
<td>-0.10171</td>
<td>0.008719</td>
<td>0.102651</td>
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<tr>
<td>$\epsilon^*_R$</td>
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<td>0.138009</td>
<td>0.07734</td>
<td>-1.41279</td>
<td>-1.05462</td>
<td>0.333954</td>
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<tr>
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<td>-0.04975</td>
<td>-0.03265</td>
<td>-0.02043</td>
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<tr>
<td>$\epsilon^*_A$</td>
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<td>0.004042</td>
<td>0.001403</td>
<td>0.00449</td>
<td>-0.05319</td>
<td>-0.00954</td>
<td>0.076263</td>
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<td>0.093831</td>
<td>0.070451</td>
<td>0.023534</td>
<td>0.02775</td>
<td>-0.24062</td>
</tr>
<tr>
<td>$\epsilon^*_G$</td>
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<td>0.016627</td>
<td>0.718993</td>
<td>-0.1344</td>
<td>0.157979</td>
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<tr>
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<td>0.0087</td>
<td>0.003537</td>
<td>-0.00537</td>
<td>0.008798</td>
</tr>
</tbody>
</table>

Responses of output, inflation and interest rates are just opposite between the US and India. Output and interest rates rise but inflation falls in the US but just opposite occurs in case of India. Similarly when interest increase in India inflation falls in India but rises in the US as it lowers the US interest rate. Increase of interest in India leads to an increase in output in the US.
Table 7: Theoretical Moments

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>St.Dev.</th>
<th>Variance</th>
</tr>
</thead>
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<tr>
<td>$g_{us,t}$</td>
<td>0.3073</td>
<td>0.783</td>
<td>0.6131</td>
</tr>
<tr>
<td>$\pi_{us,t}$</td>
<td>0.4774</td>
<td>0.323</td>
<td>0.1044</td>
</tr>
<tr>
<td>$r_{US,t}$</td>
<td>0.6468</td>
<td>0.4173</td>
<td>0.1742</td>
</tr>
<tr>
<td>$g_{I,t}$</td>
<td>1.2993</td>
<td>0.6918</td>
<td>0.4786</td>
</tr>
<tr>
<td>$\pi_{I,t}$</td>
<td>2.5967</td>
<td>1.0538</td>
<td>1.1106</td>
</tr>
<tr>
<td>$r_{I,t}$</td>
<td>2.9564</td>
<td>0.6791</td>
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<tr>
<td>$d\Delta_t$</td>
<td>0</td>
<td>4.0818</td>
<td>16.6608</td>
</tr>
</tbody>
</table>

Figure 6a: Responses of macro variables to technology and exchange rate shocks

![Image of graphs showing macro variables responses](image1.png)
Figure 6b: Responses of macro variables to technology and exchange rate shocks

Figure 7a: Responses of macro variables to fiscal and monetary policy shocks
Increase in public spending raises output. Appreciation of exchange rates in India raises output in the US and lowers it in India. Technology shocks at home and abroad raise output in the short run in both in India and the US.

7.0.7 Variance Decomposition Analysis

The variance decompositions in a VAR or DSGE-BVAR model imply finding the proportions of variances explained by shocks to the variable itself versus from the shocks to the other variables. For instance variance in the growth rate of the US is caused by its own monetary, fiscal policy and technology shocks and other shocks $\epsilon_{Rt}, \epsilon_{At}, \epsilon_{Gt}$ as well as corresponding shocks of foreign country $\epsilon_{Rt}, \epsilon_{At}, \epsilon_{Gt}$ and the global policy shock $z$. The variance decompositions for the DSGE model are
presented in Table 7. It is clear that nearly 67% of the variation in the US growth rate is explained by its public spending shocks. Then 18.2, 7.8 and 6.5 percents are explained by the shocks to the global technology, monetary policy and domestic technology. Increase in India’s public spending plays prominent role its growth rate similarly. It explains nearly 64 percent of variations on it. The global technology and the US monetary policy changes are also important in explaining these growth rates. Variance decomposition also shows that the variances in the domestic and foreign interest rates are more due to their own shocks as is the case for the real exchange rates.

Table 8: Variance decomposition

<table>
<thead>
<tr>
<th>g_{us,t}</th>
<th>\epsilon_R</th>
<th>\epsilon_R^*</th>
<th>\epsilon_A</th>
<th>\epsilon_A^*</th>
<th>\epsilon_G</th>
<th>\epsilon_e</th>
<th>\epsilon_d \Delta_t</th>
<th>\epsilon_{UP}</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.30</td>
<td>0.80</td>
<td>11.93</td>
<td>2.17</td>
<td>31.41</td>
<td>0.10</td>
<td>53.19</td>
<td>0.10</td>
<td>0.02</td>
</tr>
<tr>
<td>\pi_{us,t}</td>
<td>9.13</td>
<td>2.37</td>
<td>68.62</td>
<td>10.50</td>
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<td>0.41</td>
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<tr>
<td>r_{us,t}</td>
<td>9.46</td>
<td>4.17</td>
<td>45.40</td>
<td>18.57</td>
<td>2.16</td>
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<td>0.22</td>
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<tr>
<td>g_{I,t}</td>
<td>2.94</td>
<td>33.71</td>
<td>4.69</td>
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<td>25.63</td>
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<td>3.50</td>
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<tr>
<td>\pi_{I,t}</td>
<td>0.11</td>
<td>16.10</td>
<td>3.12</td>
<td>48.87</td>
<td>0.01</td>
<td>1.21</td>
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<tr>
<td>r_{I,t}</td>
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<td>16.52</td>
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<td>0.06</td>
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<td>40.71</td>
<td>0.13</td>
</tr>
<tr>
<td>d\Delta_t</td>
<td>1.05</td>
<td>10.86</td>
<td>0.11</td>
<td>2.48</td>
<td>0.08</td>
<td>1.32</td>
<td>1.63</td>
<td>82.47</td>
</tr>
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</table>

The time profile of these variances are more accurately shown in the series of diagrams. These decompositions are comparable to those estimated from the VAR(1) model as the decomposition are of similar magnitude in SVAR(1) as presented in the appendix and this table for growth rate of the US economy (details of the Variance decomposition is available upon request).
Policies of one country can have impact on growth in other countries. In addition to Lubik and Schorfheide (2005) style business cycle model analysis of trade and capital mobility and relating policies requires a multicountry dynamic general equilibrium problem in tradition of Ricardian comparative advantage, Hecksher-Ohlin-Samuelson factor price equalisation theorem or Krugman-Venable-Eaton Kharum type increasing returns to scales. Leontief’s dynamic input out model (Chakravarty (1965), and Eckaus and Parikh (1968)) and Bhattarai, Haughton and Tuerck (2015) model of the US economy could be extended further for such analysis in the future.
8 Conclusion

Impulse response and variance decomposition estimations are similar in traditional VAR (1) and DSGE models but the later model can provide theoretical and structural reasons behind those estimations. In the context of growth competition and spill over effects of policies, it is important to quantify such positive or complementary impacts from negative or competitive impacts so that appropriate actions could be taken for policy coordination. Cooperative mechanism should be structured based on these analysis and evaluation of likely scenarios in coming years. First two models in this paper illustrated how interactions and interdependence could be studied using VAR and DSGE models of India and the US.

References


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