Macroeconomic policy coordination in the global economy: VAR and BVAR-DSGE analyses*

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Abstract

Impulse response and variance decomposition estimations are similar in traditional VAR (1) and BVAR-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 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. Analysis of business cycle results from the VAR and BVAR-DSGE models illustrate the degree of interactions and interdependence in the global economy in the short to medium runs.

Keywords: macro policy coordination, growth, India, US, China

JEL classicfication: 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 by Currie and Levine (1986), Marquez (1988) Garfinkel (1989) , Sheen (1992), Cooper et al. (1992), Levine and Brociner (1994) Chang (1997), Goodfriend, King and Robert (1997), Obstfeld and Rogoff (2000), Hansen and Sargent (2003), Evi (2004) Beetsma and Jensen (2005), Canzoneri et al. (2005) Bullard and Singh (2008) Kose , Otrok and Whiteman (2008), Conconi and Perroni (2009), Fratzscher (2009), Juillard and Villemot (2011), Clerc, Dellas and Loisel (2011) Dedola, Karadi and Lombardo (2013) 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 partner economies[1]. First generation models include studies such as Kydland and Prescott (1977), Driffil (1988), Currie and Levine (1986) and Obstfeld

[1]Kydland (1975) in his doctoral dissertation used differential game theory in macroeconomic policy showed the inferiority of the non-cooperative Nash equilibrium compared to a cooperative solution. He interprets the policy maker as the dominant player and the typical individual citizen as the non-dominant player. He shows (Kydland (1977)) that in such a game with a dominant player the open loop control policy is time-inconsistent and attributes it to lack of credibility. He also establishes that in order to get time consistency one must go for a feedback control policy. Lucas (1976), and Kydland and Prescott (1977) are other papers on the same topic that use the concept of rational expectations and argue for the advantage of rule-based policies to create rational expectations equilibrium solution.

There is considerable literature on the interplay between monetary policy and fiscal policy and arguments are often advanced for an independent monetary authority. One can apply the above differential game framework with linear differential equation system with quadratic objective functions, and the monetary authority and the fiscal authority being the two players of the game. It can then be argued that if the monetary authority is truly independent and if one obtains the non-cooperative solution with each policy maker having his own objective function, the corresponding Nash equilibrium is Pareto inferior to a cooperative solution. Using differential games Petit established this result for Italy (Petit (1989)).

There is a similarity between the policy coordination in European Monetary Union and that of states within a country. The EMU has a common monetary policy and all the 19 member countries have their own fiscal policies. There is a need to put restrictions on large deficit spending by some of the countries as they will have serious adverse repercussions otherwise on other countries. Now referring to a single country for a comparison, the states within a country have their own fiscal policies with their own budgets and taxing powers, while they have a common fiscal policy at the country level and a common monetary policy by an independent central bank. There seems to be a need for fiscal policy coordination between the states of a country, such as need for such coordination between the countries within EMU.

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 model, with Mundell-Fleming type model. Aarle et.al. (2002) examine the coalition formation in EMU. The analogy in a single country is, although there may not be symmetries in labor market rigidities there could be asymmetries in public infrastructure that create repercussions of a state's fiscal policy on other 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 are dynamic only by introduction of disequilibrium dynamics. In other words these models only capture short run dynamics or business fluctuations and 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 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 are by Cooper (1969) and Hamada (1976). Cooper (1969) examined economic policy formulation in an open economy by allowing international capital movements. The paper 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. The paper assumed 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 chose 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 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-coopeeration and need for macroeconomic policy coordination on bilateral and multilateral basis.

2 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 and must satisfy the following criteria:

1. It must have a model that captures the salient features of economies that are of interest to policy makers, such as how output and prices are determined for traded and not traded goods, and how the general price level is a weighted average of the prices of traded and non-traded goods.

2. It must describe both the long term growth and short run fluctuations.

3. It must address the issue of credibility of a policy in terms of its enforceability by having transparency in model specification and its validity. There must also be a mechanism to share information. There must be an ongoing continuous activity in each country for specifying, estimating, testing, validating and improving the model.

4. The policies should evolve with time and be based on feedbacks from the model performance from period to period; these must not be decided at the beginning of a policy dialogue and frozen at those levels.

5. The model formulation must be such that the solution must be operationally computable given an estimated dynamic model of macroeconomic interactions

6. There must be an institutional mechanism that will ensure the model assumptions are maintained that include data availability, common model, enforcing the adoption of cooperative solution, imposition of penalties for departing from a coordinated policy.(Reorganization of the existing multilateral policy coordination institutions such as the IMF and World Bank or initiation of new institutions such as the BRICKS bank should follow from these monitoring).

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 impulses 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. Finally we study interdependence among a set of emerging and advanced countries on growth in spirit of the World Economic Forum in Davos in last 15 years. 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 ($U_{i,t}$):

$$N_t = U_{1,t}U_{2,t}U_{3,t} \tag{1}$$

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

$$U_{i,t} = F\left(y_{1,t}, y_{2,t}, y_{3,t}\right) \tag{2}$$

Let the supply process of goods be determined simultaneously as:

$$y_{1,t} = \alpha_{1,0} + \alpha_{1,2}y_{2,t} + \alpha_{1,3}y_{3,t} + \beta_{1,1}y_{1,t-1} + \beta_{1,2}y_{2,t-1} + \beta_{1,3}y_{3,t-1} + e_{1,t} \tag{3}$$

$$y_{2,t} = \alpha_{2,0} + \alpha_{2,1}y_{1,t} + \alpha_{2,3}y_{3,t} + \beta_{2,1}y_{1,t-1} + \beta_{2,2}y_{2,t-1} + \beta_{2,3}y_{3,t-1} + e_{2,t} \tag{4}$$

$$y_{3,t} = \alpha_{3,0} + \alpha_{3,1}y_{1,t} + \alpha_{3,2}y_{2,t} + \beta_{3,1}y_{1,t-1} + \beta_{3,2}y_{2,t-1} + \beta_{3,3}y_{3,t-1} + e_{3,t} \tag{5}$$

solving this simultaneously:

$$\begin{pmatrix} 1 & -\alpha_{1,2} & -\alpha_{1,3} \\ -\alpha_{2,1} & 1 & -\alpha_{2,3} \\ -\alpha_{3,1} & -\alpha_{3,2} & 1 \end{pmatrix} \begin{pmatrix} y_{1,t} \\ y_{2,t} \\ y_{3,t} \end{pmatrix} = \begin{pmatrix} \alpha_{1,0} \\ \alpha_{2,0} \\ \alpha_{3,0} \end{pmatrix} + \begin{pmatrix} \beta_{1,1} & \beta_{1,2} & \beta_{1,3} \\ \beta_{2,1} & \beta_{2,2} & \beta_{2,3} \\ \beta_{3,1} & \beta_{3,2} & \beta_{3,3} \end{pmatrix} \begin{pmatrix} y_{1,t-1} \\ y_{2,t-2} \\ y_{3,t-3} \end{pmatrix} + \begin{pmatrix} e_{1,t} \\ e_{2,t} \\ e_{3,t} \end{pmatrix} \tag{6}$$

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

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 idiosyncractic 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.

3 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:

$$Y_t = B^{-1}\Gamma_0 + B^{-1}\Gamma_1 Y_{t-1} + B^{-1}\varepsilon_t \tag{8}$$

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

$$Y_t = A_0 + A_1 Y_{t-1} + e_t \tag{9}$$

where $A_0 = B^{-1}\Gamma_0,\ A_1 = B^{-1}\Gamma_1,\ e_t = B^{-1}\varepsilon_t$

Then select seven macro time series for this model as in the BVAR-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.

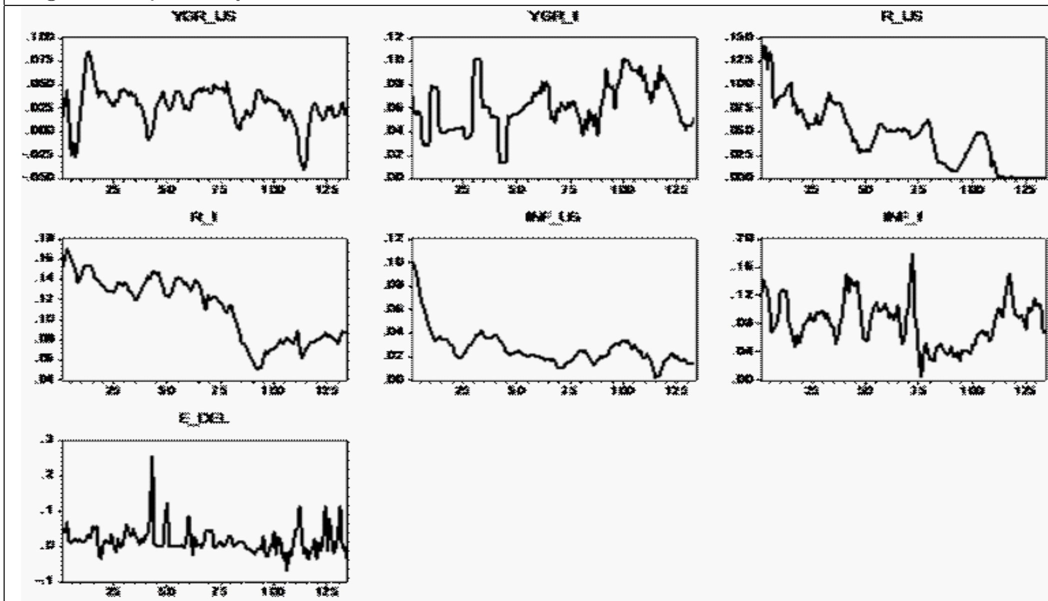
$$Y_t = \begin{bmatrix} g_{us,t} \\ \pi_{us,t} \\ r_{us,t} \\ g_{I,t} \\ \pi_{I,t} \\ r_{I,t} \\ d\Delta_t \end{bmatrix};\ Y_{t-1} = \begin{bmatrix} g_{us,t-1} \\ \pi_{us,t-1} \\ r_{us,t-1} \\ g_{I,t-1} \\ \pi_{I,t-1} \\ r_{I,t-1} \\ d\Delta_{t-1} \end{bmatrix};\ \varepsilon_t = \begin{bmatrix} \varepsilon_{us,gt} \\ \varepsilon_{us,\pi t} \\ \varepsilon_{us,rt} \\ \varepsilon_{I,gt} \\ \varepsilon_{I,\pi t} \\ \varepsilon_{I,rt} \\ \varepsilon_{\Delta,rt} \end{bmatrix} \tag{10}$$

This system is subject to shocks. The term $\varepsilon_t = \{\varepsilon_{j,xt}\}$ is column vector of shocks for country j and endogenous variable x at time t. Then the parameters B, Γ_0 and Γ_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 1.

Figure 1: Quarterly data series of US and India

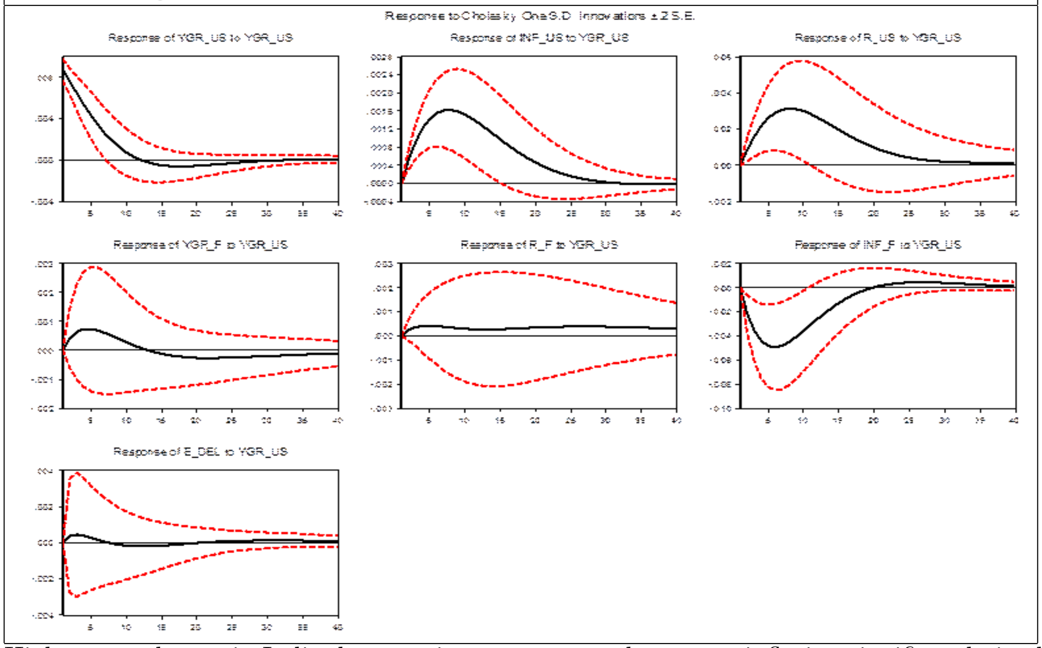


Estimation of VAR (1) for above equations gives estimates of parameters and variance decompositions as presented in a table in the appendix. We impose structural restrictions for recursive estimation for identification of the model, thus the reduced form error and structural errors become related as:

$$\begin{bmatrix} b_{11} & 0 & 0 & 0 & 0 & 0 & 0 \\ b_{21} & b_{22} & 0 & 0 & 0 & 0 & 0 \\ b_{31} & b_{32} & b_{33} & 0 & 0 & 0 & 0 \\ b_{41} & b_{42} & b_{43} & b_{44} & 0 & 0 & 0 \\ b_{51} & b_{52} & b_{53} & b_{54} & b_{55} & 0 & 0 \\ b_{61} & b_{62} & b_{63} & b_{64} & b_{65} & b_{66} & 0 \\ b_{71} & b_{72} & b_{73} & b_{74} & b_{75} & b_{76} & b_{77} \end{bmatrix}^{-1} \begin{bmatrix} \varepsilon_{us,gt} \\ \varepsilon_{us,\pi t} \\ \varepsilon_{us,rt} \\ \varepsilon_{I,gt} \\ \varepsilon_{I,\pi t} \\ \varepsilon_{I,rt} \\ \varepsilon_{\Delta,rt} \end{bmatrix} = \begin{bmatrix} e_{us,gt} \\ e_{us,\pi t} \\ e_{us,rt} \\ e_{I,gt} \\ e_{I,\pi t} \\ e_{I,rt} \\ e_{\Delta,rt} \end{bmatrix} \tag{11}$$

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 2 to 5. 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 2: 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.

Figure 3: Impulses of aggregate demand shocks in India

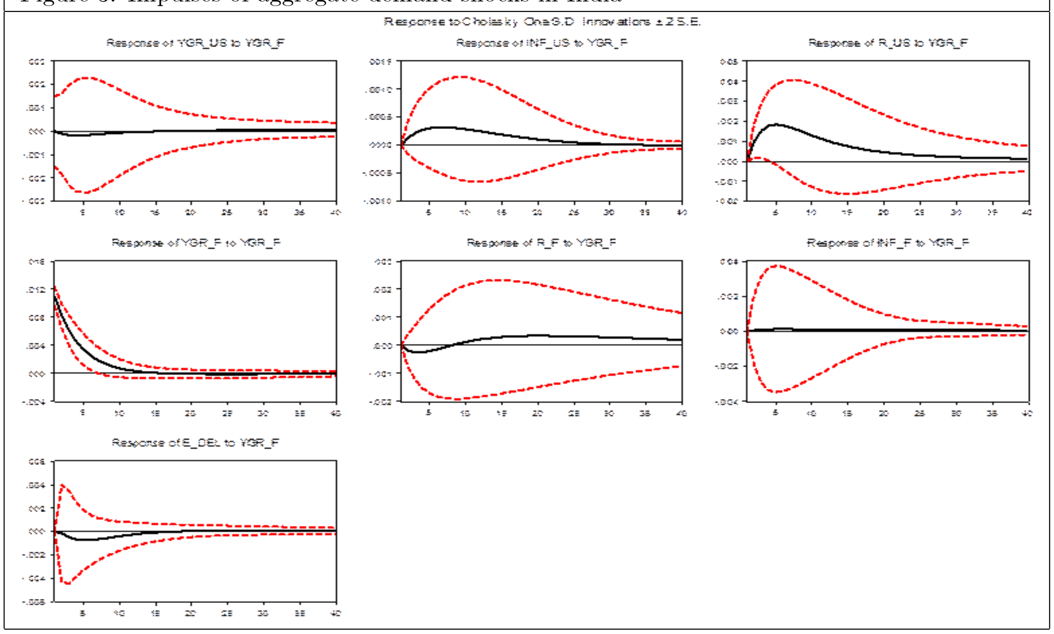
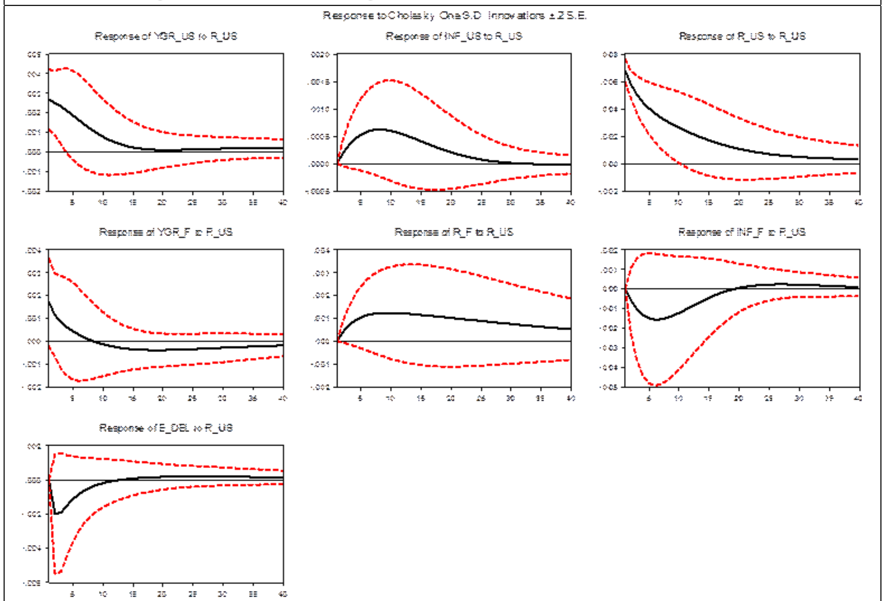
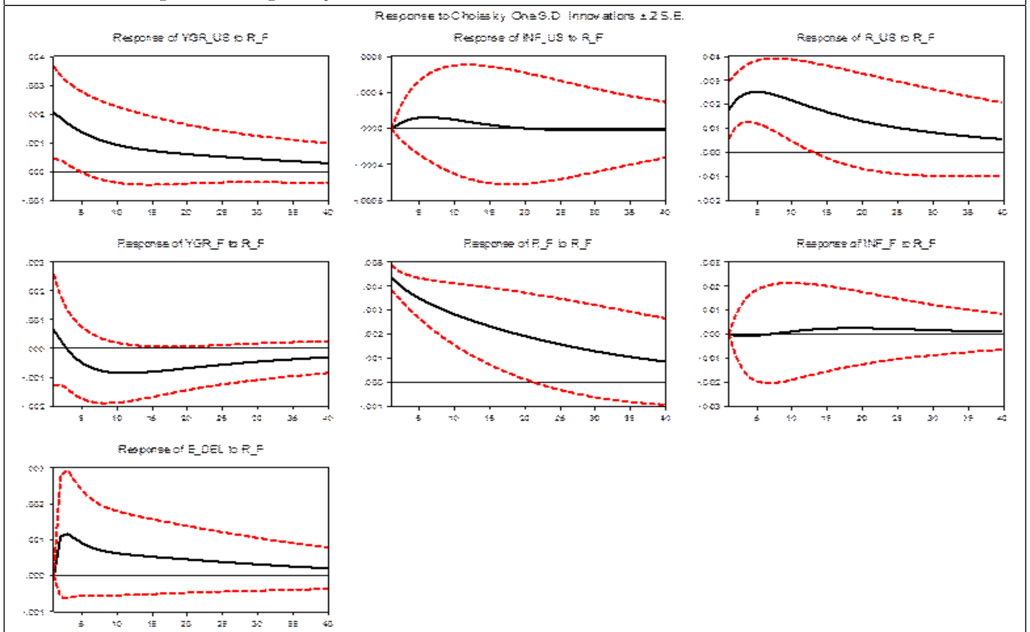


Figure 4: Impulses of monetary policy shocks in the US



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.

Figure 5: Impulses of policy shocks in India



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.

4 Two country global economy model for macro policy coordination

We adapt 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 stochastic model as it focuses on business cycle impacts of shocks to the technology as well as fiscal and monetary policy instruments.

4.0.1 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 (β) and expectation operator (E_0) are used to compute life time utility of representative households in each country (U_0). The intertemporal elasticity of substitution (τ) measures the relative rate of risk aversion of consumers between current and future consumptions.

$$U_0 = E_0 \left[\sum_{t=0}^{\infty} \beta^t \left[\frac{\left(\widetilde{C}_t / A_{w_t} \right)^{1-\tau}}{1-\tau} - N_t \right] \right] \tag{12}$$

Consumers are subject to habit persistent conditions as given by $\widetilde{C}_t = C_t - h\gamma C_{t-1}$; they also benefit from technological growth $z_t = \frac{A_{Wt}}{A_{Wt-1}}$. Here γ 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:

$$C_t = \left[(1-\alpha)^{\frac{1}{\eta}} C_{H,t}^{\frac{\eta-1}{\eta}} + \alpha^{\frac{1}{\eta}} C_{F,t}^{\frac{\eta-1}{\eta}} \right]^{\frac{\eta}{\eta-1}} \tag{13}$$

Where η 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:

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

$$C_{F,t} = (1-\alpha) \left[\frac{P_{F,t}}{P_t} \right]^{-\eta} C_t \tag{15}$$

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

$$P_t = \left[(1-\alpha) P_{H,t}^{\eta-1} + \alpha^{\frac{1}{\eta}} P_{F,t}^{\eta-1} \right]^{\frac{1}{\eta-1}} \tag{16}$$

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, $E_t \left(Q_{t,t+1} D_{t+1} \right)$.

$$P_{H,t} C_{H,t} + P_{F,t} C_{F,t} + E_t \left(Q_{t,t+1} D_{t+1} \right) = W_t N_t + D_t - T_t \tag{17}$$

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:

$$A_{Wt} \lambda_t P_t = C_t^{-\tau} - h\gamma\beta E_t \left[\frac{A_{Wt}}{A_{Wt+1}} C_{t-1}^{-\tau} \right] \tag{18}$$

This Euler equation (18) states relation between current and future effective consumption where λ_t is the marginal utility of income, and τ the elasticity of substitution between the current and future consumptions.

$$Q_{t,t+1} = \beta E_t \left[\frac{\lambda_{t+1}}{\lambda_t} \frac{P_t}{P_{t+1}} \right] \tag{19}$$

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.

$$R^{-1} = \beta E_t \left[\frac{\lambda_{t+1}}{\lambda_t} \frac{P_t}{P_{t+1}} \right] \tag{20}$$

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

4.1 Firms

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

$$Y_{H,t}(j) = A_{Wt}A_{Ht}N_t(j) \tag{21}$$

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

$$E_t \left[\sum_{t=T}^{\infty} \theta_H^{t-T} Q_H^{t-T} Y_{H,t}(j) \left[P_{H,t}(j) \pi_H^{t-T} - P_{H,t} MC_{H,t} \right];\ MC_{H,t} = \frac{W_t}{P_{H,t}} \right] \tag{22}$$

Supply function for each commodity j is given by:

$$Y_{H,t}(j) = \left[\frac{P_{H,t}(j)}{P_{H,t}} \right]^{-\omega} \left(C_{H,t} + G_{H,t} + C^*_{H,t} \right) \tag{23}$$

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

$$\left[\psi_{F,t} = \frac{e_t P_{H,t}}{P_{F,t}} \right] \tag{24}$$

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:

$$E_t \left[\sum_{t=T}^{\infty} \theta_I^{t-T} Q_T^{t-T} C_{F,t}(j) \left[P_{F,t}(j) \pi_I^{t-T} - e_t P^*_{F,t} \right] \right] \tag{25}$$

$$C_{F,t} = (1-\alpha) \left[\frac{P_{F,t}}{P_t} \right]^{-\omega} C_t \tag{26}$$

4.2 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 $s_t = \frac{e_t P_t^*}{P_t}$ 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 $\frac{\psi_{F,t}}{q_t} = \frac{\psi^*_{F,t}}{q_t^*}$.

$$\left[s_t = \frac{e_t P_t^*}{P_t};\ q_t = \frac{P_{H,t}}{P_{F,t}};\ q_t^* = \frac{P^*_{F,t}}{P^*_{H,t}};\ \frac{\psi_{F,t}}{q_t} = \frac{\psi^*_{F,t}}{q_t^*} \right] \tag{27}$$

Market clearing implies that domestic and foreign asset markets clear:

$$\beta\frac{\lambda_{t+1}}{\lambda_t}\frac{P_t}{P_{t+1}} = Q_{t,t+1} = \beta\frac{\lambda^*_{t+1}}{\lambda^*_t}\frac{P^*_t}{P^*_{t+1}}\frac{e_t}{e_{t+1}} \tag{28}$$

Similarly markets also clear for home and foreign goods as:

$$Y_{H,t} = C_{H,t} + G_{H,t} + C^*_{H,t} \tag{29}$$

$$Y^*_{F,t} = C^*_{F,t} + G^*_{F,t} + C_{F,t} \tag{30}$$

4.3 Log-linearisation for the solution of the model

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

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

Linearlisation of price (inflation to marginal cost):

$$\widetilde{\pi}_{H,t} = \beta E_t \widetilde{\pi}_{H,t+1} + k_{H,t}\widetilde{mc}_t \tag{31}$$

where $k_{H,t} = \frac{1-\theta_H}{\theta_H}(1-\theta_H\beta)$ is Calvo price adjustment factor and $\widetilde{mc}_t = -\widetilde{\lambda}_t - a\widetilde{q}_t - \widetilde{A}_t$ is 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 are given by Euler relation:

$$-\widetilde{\lambda}_t = \frac{\tau}{1-h\beta}\widetilde{C}_t - \frac{h\beta}{1-h\beta}E_t\left[\tau\widetilde{C}_{t+1} + \widetilde{z}_{t+1}\right] \tag{32}$$

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

$$(1-h)\widetilde{C}_t = \widetilde{c}_t - h\widetilde{c}_{t+1} + h\widetilde{z}_{t+1} \tag{33}$$

$$-\widetilde{\lambda}_t = -E_t\widetilde{\lambda}_{t-1} - \left[\widetilde{R}_t - E_t\widetilde{\pi}_{t-1}\right] + E_t\widetilde{z}_{t+1} \tag{34}$$

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

$$\widetilde{\pi}_{F,t} = \beta E_t\widetilde{\pi}_{F,t+1} + k_{F,t}\widetilde{\psi}_{F,t}; \quad k_{F,t} = \frac{1-\theta_I}{\theta_I}(1-\theta_I\beta) \tag{35}$$

This domestic inflation has domestic and foreign components:

$$\widetilde{\pi}_t = \alpha\widetilde{\pi}_{F,t} + (1-\alpha)\widetilde{\pi}_{H,t} \tag{36}$$

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

$$\widetilde{q}_t = \widetilde{q}_{t-1} + \widetilde{\pi}_{H,t} - \widetilde{\pi}_{F,t} \tag{37}$$

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

$$\widetilde{s}_t = \widetilde{\psi}_{F,t} - (1-\alpha)\,\widetilde{q}_{t-1} - \alpha\widetilde{q}^*_{t-1} \tag{38}$$

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:

$$\Delta\widetilde{e}_t = \widetilde{\pi}_t - \widetilde{\pi}^*_t + \Delta\widetilde{s}_t \tag{39}$$

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

$$\widetilde{R}_t - \widetilde{R}^*_t = E_t\Delta\widetilde{e}_{t+1} \tag{40}$$

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

$$\widetilde{\lambda}_t = \widetilde{\lambda}^*_t - \widetilde{s}_t \tag{41}$$

goods market clearing:

$$\widetilde{y}_{H,t} = \widetilde{c}_t - \widetilde{g}_t - \frac{\alpha}{\tau}\widetilde{s}_t + \alpha\,(1-\alpha)\,\eta\,(\widetilde{q}_t - \widetilde{q}^*_t) \tag{42}$$

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:

$$\widetilde{R}_t = \rho_R\widetilde{R}_{t-1} + (1-\rho_R)\left[\psi_1\widetilde{\pi}_t + \psi_2\left(\Delta\widetilde{y}_t + \widetilde{z}_t\right) + \psi_3\Delta\widetilde{e}_{t+1}\right] + \epsilon_{R,t} \tag{43}$$

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 $(\widetilde{z}_t)$, home country $\left(\widetilde{A}_t\right)$ and the foreign country $\left(\widetilde{A}^*_t\right)$. 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.

$$\widetilde{z}_t = \rho_z\widetilde{z}_{t-1} + \epsilon_{z,t} \tag{44}$$

$$\widetilde{A}_t = \rho_A\widetilde{A}_{t-1} + \epsilon_{A,t} \tag{45}$$

$$\widetilde{A}^*_t = \rho_{A^*}\widetilde{A}^*_{t-1} + \epsilon_{A^*,t} \tag{46}$$

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

$$\widetilde{G}_t = \rho_G\widetilde{G}_{t-1} + \epsilon_{G,t} \tag{47}$$

$$\widetilde{G}^*_t = \rho_{G^*}\widetilde{G}^*_{t-1} + \epsilon_{G^*,t} \tag{48}$$

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

Lubik and Schorfheide (2005) has applied this model to study interactions between the US and Euro are 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 the last 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. The next 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.

4.3.1 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 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 about and higher inflation at home.

Table 1: Matrix Of Correlations

Variables	Ygr_US	INF_US	R_US	Ygr_F	INF_F	R_F	E_del
Ygr_US	1	-0.0319	0.4775	0.2943	0.1877	0.4495	-0.2693
INF_US	-0.0319	1	0.1133	-0.1084	0.2419	0.0688	0.0567
R_US	0.4775	0.1133	1	0.553	0.5146	0.9033	-0.0748
Ygr_F	0.2943	-0.1084	0.553	1	-0.0994	0.6377	0.2427
INF_F	0.1877	0.2419	0.5146	-0.0994	1	0.4548	-0.0154
R_F	0.4495	0.0688	0.9033	0.6377	0.4548	1	-0.066
E_del	-0.2693	0.0567	-0.0748	0.2427	-0.0154	-0.066	1

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 auotcorrelation coefficient is almost zero.

Table 2: Coefficients of Autocorrelation

Order	1	2	3	4	5
Ygr_US	0.1322	0.1289	0.107	0.088	0.0727
INF_US	0.9032	0.8679	0.8519	0.8425	0.8355
R_US	0.745	0.6148	0.5181	0.4404	0.3772
Ygr_F	0.248	0.2116	0.1584	0.1152	0.0819
INF_F	0.9546	0.9077	0.8612	0.816	0.7725
R_F	0.7687	0.6311	0.5246	0.4395	0.3716
E_del	-0.0014	0.0011	0.0014	0.0013	0.0011

4.3.2 Prior and posterior estimations

According to An and Schorfeide (2007) the Bayesian estimation process involves search through the space of θ using appropriate size of steps. The Bayes' theorem is used in order to get posterior on parameter θ, $p\left(\theta|Y^T\right)$, which can be derived from the definition of conditional probability: $p\left(\theta|Y^T\right) \propto p\left(Y^T|\theta\right)p\left(\theta\right) \equiv \Bbbk\left(\theta|Y^T\right)$ where $p\left(Y^T|\theta\right)$ stands for maximum likelihood function and $p\left(\theta\right)$ stands for prior probability distributions, and $\Bbbk\left(\theta|Y^T\right)$ stands for the posterior kernel. Likelihood function is estimated with the help of the Kalman filter in the form of Metropolis-Hestings 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.

4.3.3 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.

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."

4.3.4 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

Table 3: Estimation of Parameters in open economy model

	prior mean	post. mean	conf.interval		prior	pstdev
theta_H	0.5	0.9901	0.9896	0.9907	beta	0.15
theta_F	0.5	0.3655	0.3559	0.3727	beta	0.15
theta_Hstar	0.75	0.9985	0.9977	0.999	beta	0.15
theta_Fstar	0.75	0.9149	0.9082	0.9209	beta	0.15
tau	2	2.2585	2.2339	2.2928	gamma	0.5
h	0.3	0.1891	0.1868	0.1923	beta	0.1
alp	0.12	0.0323	0.0283	0.0369	beta	0.05
eta	1	0.7896	0.7473	0.8348	gamma	0.5
psi1	1.5	1.6074	1.5978	1.6196	gamma	0.25
psi2	0.5	1.3696	1.3545	1.3833	gamma	0.25
psi3	0.1	0.1075	0.1051	0.1109	gamma	0.05
psi1star	1.5	1.4688	1.4542	1.4863	gamma	0.25
psi2star	0.5	1.234	1.2118	1.2494	gamma	0.25
psi3star	0.1	0.0889	0.0866	0.0911	gamma	0.05
rhoA	0.8	0.8706	0.8639	0.8797	beta	0.10
rhoR	0.5	0.5255	0.5195	0.5316	beta	0.2
rhoG	0.8	0.9959	0.9955	0.9962	beta	0.1
rhoAstar	0.6	0.8783	0.871	0.8853	beta	0.2
rhoRstar	0.5	0.4553	0.4477	0.4665	beta	0.2
rhoGstar	0.8	0.9887	0.9869	0.991	beta	0.1
rhoZ	0.66	0.2335	0.2303	0.2367	beta	0.15
rr_steady	0.5	0.0251	0.0198	0.0299	gamma	0.5
gam_steady	0.4	0.0819	0.072	0.0912	norm	0.2
pi_steady	7	0.7091	0.6778	0.731	gamma	2

rates in India and the US indicating close integration in the capital markets. Inflation also reacts differently between these two countries.

4.3.5 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.

4.3.6 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 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

Table 4: Standard deviation of shocks

	prior mean	post. mean	conf. interval		prior	pstdev
EPS_A	1.253	2.2741	2.1925	2.343	invg	0.6551
EPS_G	1.253	0.2799	0.2756	0.2844	invg	0.6551
EPS_R	0.501	0.124	0.1221	0.1256	invg	0.2621
EPS_Astar	0.501	0.1323	0.1287	0.1389	invg	0.2621
EPS_Gstar	1.253	0.29	0.2848	0.2943	invg	0.6551
EPS_Rstar	0.251	0.056	0.0551	0.0571	invg	0.131
EPS_Z	0.627	0.1413	0.1378	0.1455	invg	0.3276
EPS_Edel	4.387	0.9788	0.9646	0.9907	invg	2.293

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.

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

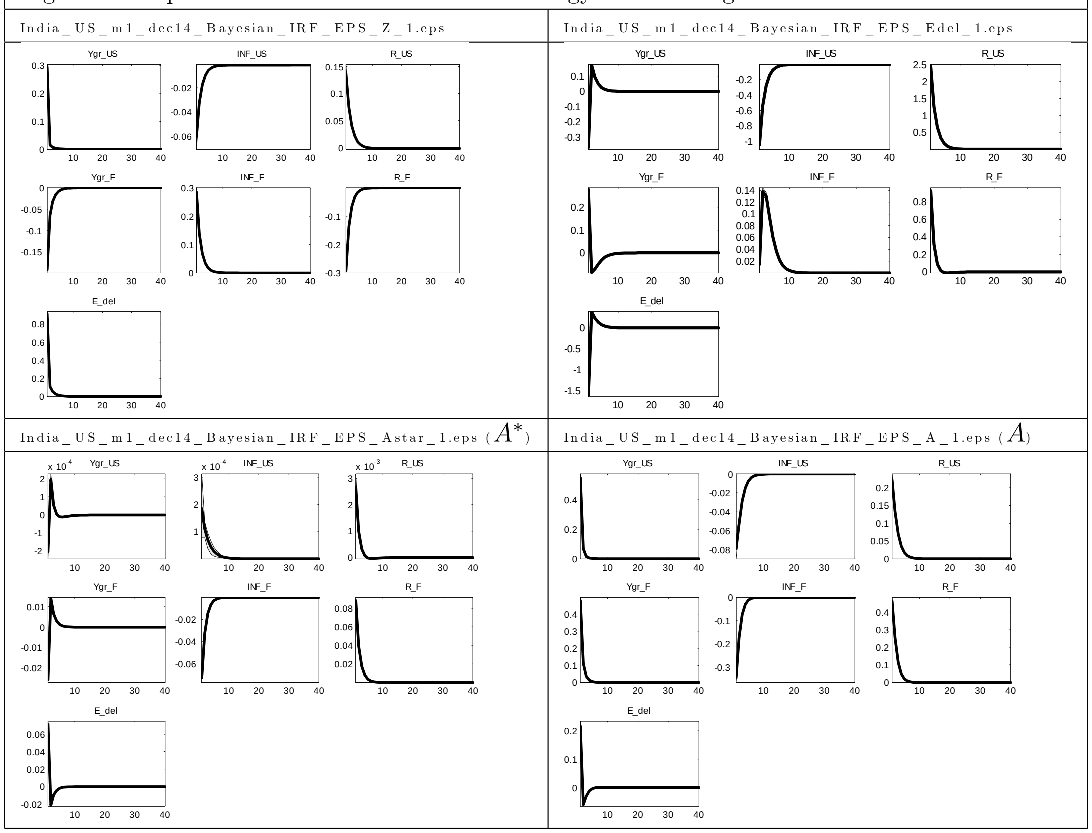


Table 5: Policy And Transition Functions

	Ygr_US	INF_US	R_US	Ygr_F	INF_F	R_F	E_del
Constant	0.095353	0.704263	1.108322	0.095353	0.704263	1.108322	0
C(-1)	0.19448	0.00023	0.468766	0.029578	-0.00517	0.080452	-0.03671
C_star(-1)	0.001329	0.000327	0.010283	0.16372	0.02227	0.440648	0.035793
R(-1)	-0.38763	-0.07275	1.014496	0.244222	0.103109	0.880421	-0.83278
R_star(-1)	-0.01231	0.048023	0.122758	-0.46012	-0.16627	0.374699	0.620458
Y(-1)	-0.56391	0.081842	-1.14133	-0.27476	-0.116	-0.99049	0.936898
Y_star(-1)	0.017631	-0.0688	-0.17588	-0.34079	0.238218	-0.53684	-0.88894
Q(-1)	-0.02688	0.086012	-0.00345	0.014109	0.007064	0.043191	-0.00286
Q_star(-1)	0.017621	-0.00166	0.031195	0.003737	0.001483	0.021625	-0.05628
A(-1)	0.001392	-0.00241	0.001747	0.000376	0.000052	0.000925	0.000543
A_star(-1)	-0.00143	-0.00799	-0.0136	0.053015	-0.15656	0.018803	-0.02247
G(-1)	0.599105	-0.04913	1.255879	0.28628	0.176204	1.064071	-0.91268
G_star(-1)	0.004119	0.074741	0.226778	0.35224	-0.11231	0.673687	0.854058
S(-1)	0.032583	0.011308	-0.07593	-0.0688	-0.02616	-0.03823	-0.86326
Z(-1)	0.075082	-0.00431	0.177696	0.097544	-0.04454	0.223314	-0.01453
EPS_R	-0.71334	-0.13388	1.866959	0.449437	0.18975	1.620224	-1.53256
EPS_Rstar	-0.02687	0.104861	0.268047	-1.00469	-0.36306	0.818175	1.354803
EPS_A	0.001601	-0.00277	0.00201	0.000432	0.000059	0.001064	0.000624
EPS_Astar	-0.00162	-0.00905	-0.0154	0.060022	-0.17725	0.021288	-0.02543
EPS_G	0.601645	-0.04934	1.261204	0.287494	0.176951	1.068583	-0.91655
EPS_Gstar	0.004168	0.075622	0.229452	0.356393	-0.11363	0.68163	0.864128
EPS_Z	0.312484	-0.01793	0.739553	0.405969	-0.18536	0.92941	-0.06046
EPS_Edel	-0.03258	-0.01131	0.075934	0.0688	0.026159	0.038231	0.863256

Figure 7: Responses of macro variables to fiscal and monetary policy shocks

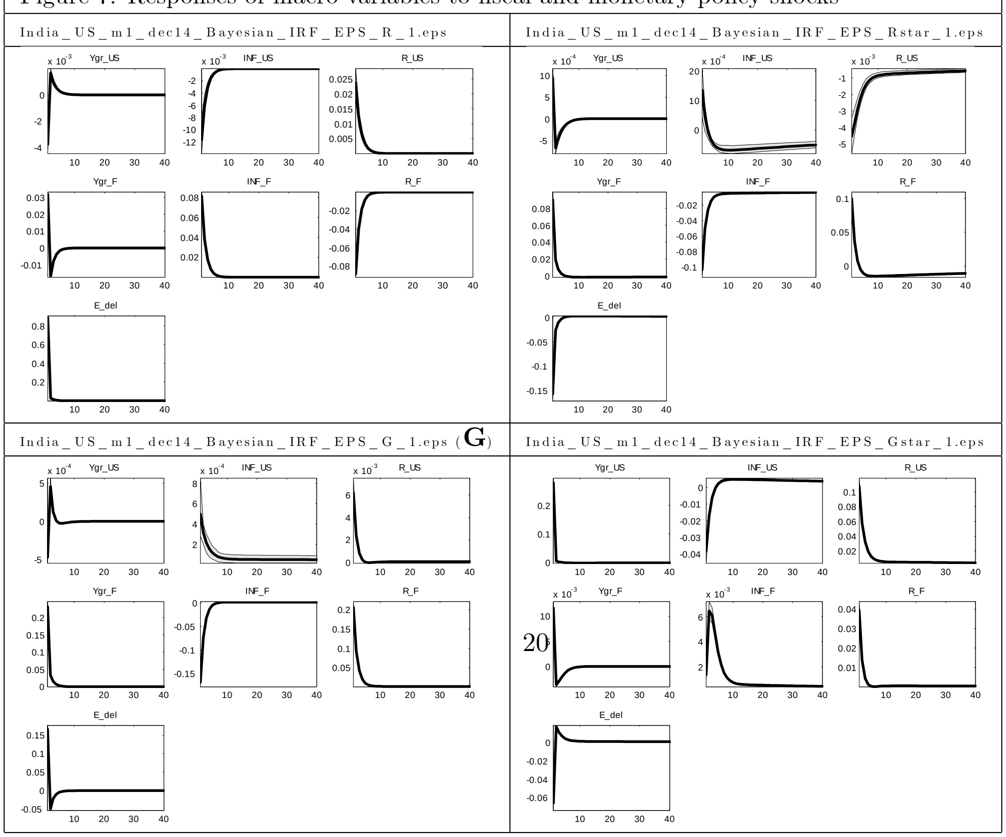


Table 6: Theoretical Moments

Variable	Mean	Std. Dev.	Variance
Ygr_US	0.0954	0.206	0.0424
INF_US	0.7043	0.0994	0.0099
R_US	1.1083	0.6807	0.4634
Ygr_F	0.0954	0.1926	0.0371
INF_F	0.7043	0.2759	0.0761
R_F	1.1083	0.6917	0.4785
E_del	0	0.9315	0.8677

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.

4.3.7 Variance Decomposition Analysis

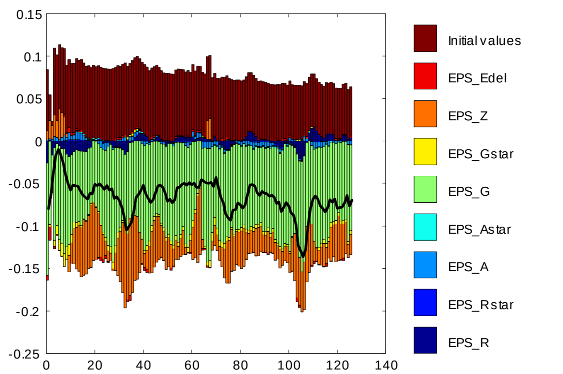
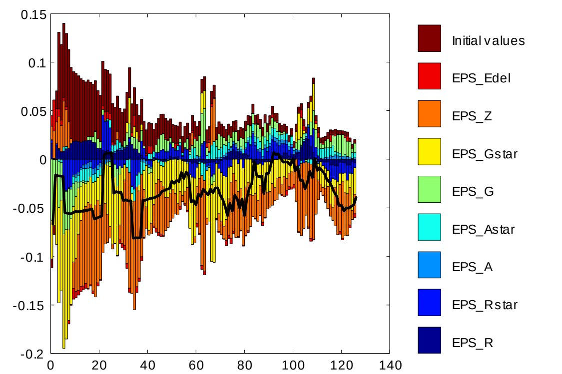
The variance decompositions in a VAR or DSGE-BVAR model imply finding the proportions of variances explained by shocks to the variable itself versus from the shocks to the other variables. For instance variance in the growth rate of the US is caused by its own monetary, fiscal policy and technology shocks and other shocks ϵ_{Rt}, ϵ_{At}, ϵ_{Gt} as well as corresponding shocks of foreign country ϵ^*_{Rt}, ϵ^*_{At}, ϵ^*_{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 the 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 7: Variance decomposition

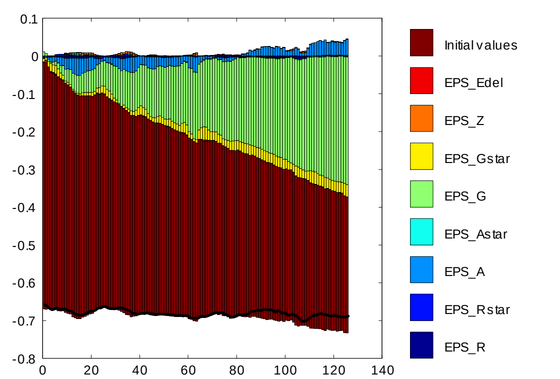
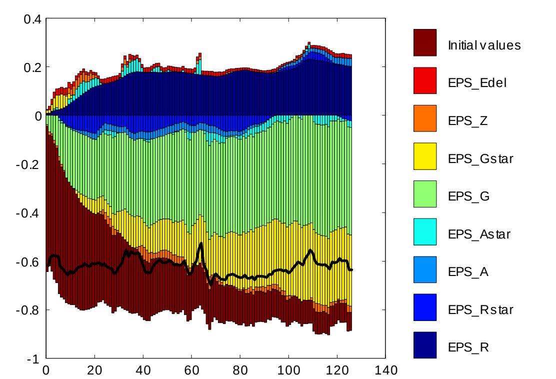
	EPS_R	EPS_Rstar	EPS_A	EPS_Astar	EPS_G	EPS_Gstar	EPS_Z	EPS_Edel
Ygr_US	7.77	0	6.47	0.01	67.44	0	18.16	0.16
INF_US	90.74	0	4.24	0.04	1.94	0	0.73	2.31
R_US	93.06	0.02	2.39	0.05	2.01	0.05	0.79	1.64
Ygr_F	10.21	0.27	4.9	3.17	0.22	63.9	14.92	2.41
INF_F	5.45	8.62	13.11	5.83	0.12	25.36	6.97	34.55
R_F	63.85	4.1	3.23	3.19	1.36	12.29	4.1	7.9
E_del	17.79	0.33	4.2	0.61	0.38	0.98	0.03	75.68

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).

Variance decompositions of growth rates

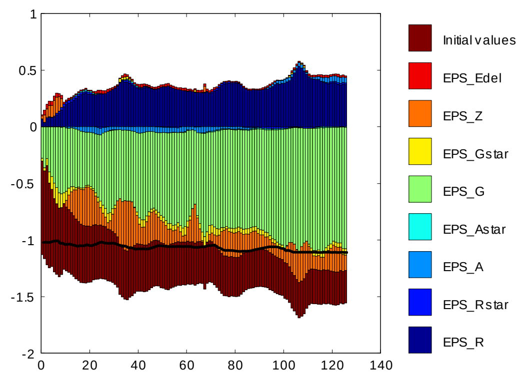
For the growth rates of the US	For the growth rates of India
	

Variance Decomposition of Inflation

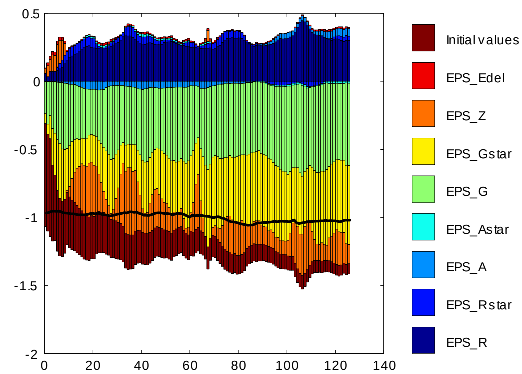
Inflation in the US	Inflation in India
	

Variance Decomposition of the interest rate rates

For the interest rate in the US



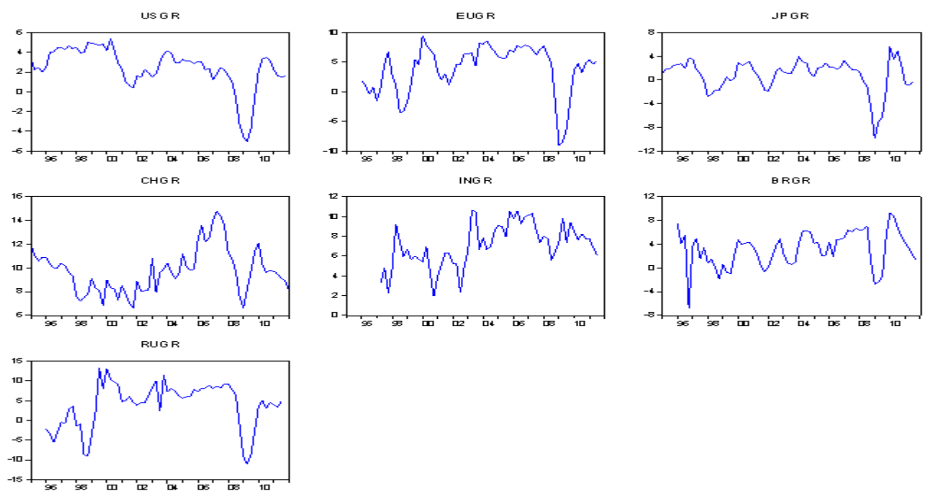
For the interest rate in India



5 Economic growth among BRICS, EU and USA

Now we extend VAR model to China, India, Germany, UK and the US for strategic analysis of macroeconomic policy coordination and interdependence estimated using the quarterly growth rates of these countries. Results show persistency as well as conditional dependencies among these economies. Estimates show that there is considerable growth competition among these countries. India's growth is influenced much by its fundamentals but slows down a bit when China, Germany, UK or US grow. In contrast China is able to absorb foreign growth to its benefit except that it competes on growth with the Germany. Germany's growth is more determined by its fundamentals and that of the US. Higher growth rates in other countries seem to lower it. Growth rates in the UK are positively related to the growth rates of Germany and the US but not related particularly to the growth rates of India and China. US growth seems to be linked to that of India, UK and the US itself. Impulse responses around the average growth rates are compared across countries.

Quarterly Growth Rates in Advanced and Emerging Countries 1995:1-2011:4



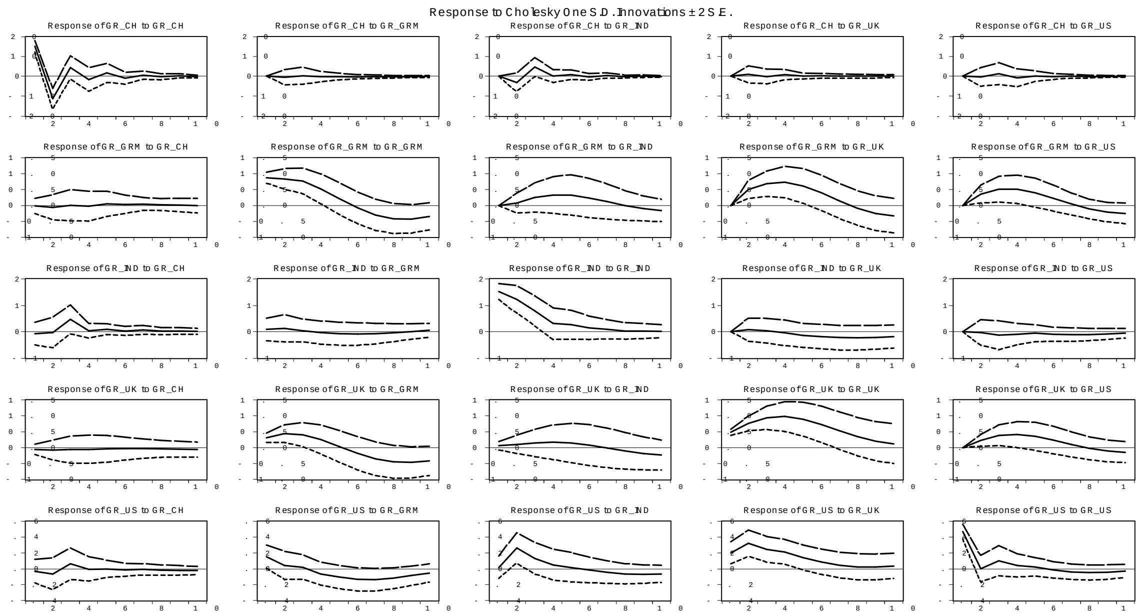
Let us consider the empirical evidence for the above model based on quarterly time series data for these five countries on the basis of the estimations of a system of five regression equation in which growth rate of one country depends on the growth of all other countries. These results are as given in table 8.

Table 8: Interdependence in Economic Growth between US, EU and BRIC Countries

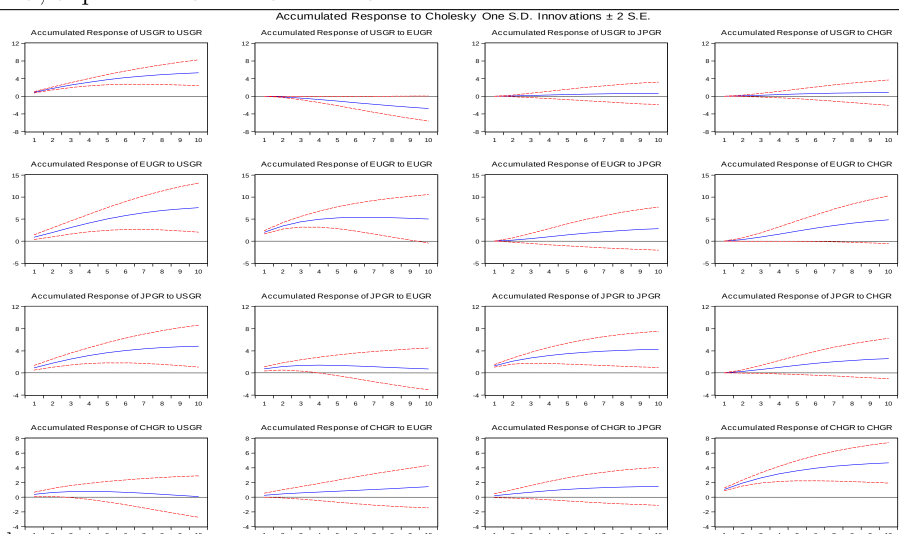
	USGR	EUGR	JPGR	CHGR	INGR	BRGR	RUGR
USGR_1	0.903(10.1)	0.222(1.06)	0.323(1.81)	-0.153(-1.39)	-0.203(-1.26)	0.004(0.02)	0.184(0.58)
EUGR_1	-0.049(-0.45)	0.388(1.54)	-0.241(-1.22)	0.118(0.89)	0.167(0.86)	-0.046(-0.20)	-0.358(-0.94)
JPGR_1	0.187(1.91)	0.538(2.34)	0.682(3.48)	0.153(1.27)	-0.023(-0.13)	0.084(0.40)	0.880(2.54)
CHGR_1	0.071(0.79)	0.543(2.59)	0.194(1.09)	0.645(5.84)	0.138(0.85)	0.027(0.18)	0.798(2.52)
INGR_1	0.072(1.07)	-0.052(-0.34)	0.167(1.24)	0.251(3.01)	0.562(4.60)	0.479(3.11)	-0.193(-0.81)
BRGR_1	-0.135(-1.91)	-0.356(-2.14)	-0.031 (-0.22)	-0.095(-1.08)	-0.052(-0.40)	0.479(3.11)	-0.543(-2.16)
RUGR_1	-0.499(-0.76)	0.086(-0.56)	0.117(0.88)	-0.095(-1.17)	-0.077(-0.64)	0.060(0.42)	0.719(3.08)
Constant	-0.270(-0.36)	-2.323(-1.28)	-2.322(-1.28)	2.119(2.22)	2.137(1.53)	-2.675(-1.60)	-2.706(-0.99)
RSq (Adj)	0.84	0.75	0.61	0.71	0.45	0.55	0.69
F-stat	45.9	24.9	13.5	20.7	7.6	10.7	18.7

T-values are in the parentheses.

Impulse Responses in Growth between US, EU and BRIC Countries



US, EU, Japan and China Growth Club



[Figure]

We also compare the growth complementarities among four BRIC countries in Table 9. Higher growth in China, India and Russia seem to raise growth in Brazil but higher growth rate in Brazil seem to lower the growth rates in all other three countries. This is very surprising. Growth rates in Russia does not help growths in China and India where their growth rates seem to be very complementary to themselves. Higher growth in India and China go together.

Table 9: Rich Country Growth Club

	USGR	EUGR	JPGR	CHGR
USGR_1	0.961(12.8)	0.287 (1.06)	0.242 (1.67)	-0.103(-1.06)
EUGR_1	-0.103(-2.39)	0.617(1.54)	-0.046(-0.55)	-0.038(-0.68)
JPGR_1	0.045(0.57)	0.130(2.34)	0.624(4.13)	0.067(0.66)
CHGR_1	0.085(1.19)	0.336(2.59)	0.235(1.70)	0.813(8.73)
Constant	-0.401(-0.54)	-2.425(-1.32)	-2.473(-1.72)	2.147(2.21)
RSq (Adj)	0.84	0.71	0.61	0.65
F-stat	77.1	37.4	23.9	28.3
T-values are in the parentheses.				

Table 10: BRIC Country Growth Club

	CHGR	INGR	BRGR	RUGR
CHGR_1	0.679(6.35)	0.170(1.08)	0.409(2.23)	0.790(2.34)
INGR_1	0.272(3.36)	0.597(5.02)	0.025(0.18)	-0.247(-0.97)
BRGR_1	-0.014(-0.21)	-0.034(-0.33)	0.504(4.19)	-0.255(-1.15)
RUGR_1	-0.009(-0.31)	-0.013(-0.30)	0.053(1.03)	0.750(7.88)
Constant	1.225(1.62)	1.440(1.30)	-2.820(-2.17)	-3.822(-1.60)
RSq (Adj)	0.71	0.45	0.57	0.62
F-stat	35.9	12.6	19.7	24.3
T-values are in the parentheses.				

Policies of once country thus 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. Whalley (1985), Bhagwati (1992) and Bhattarai and Mallick (2013) structure of dynamic general equilibrium model thus can be extended for policy coordination. Leontieff'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.

6 Conclusion

Impulse response and variance decomposition estimations are similar in traditional VAR (1) and BVAR-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 BVAR-DSGE models of India and the US. Then strategic macroeconomic policy coordination and interdependence were studied strategically with VAR models of China, India, Germany, UK and the US estimated using the quarterly time series of growth rates.

Persistency and conditional dependencies are observed and fluctuations around the average growth rates are compared across countries. Estimates show that there is a considerable growth competition among these countries. India's growth is influenced much by its fundamentals but slows down a bit when China, Germany, UK or US grow. In contrast China is able to absorb foreign growth to its benefit except that it competes with Germany. Germany's growth is more determined by its fundamentals and that of the US. Higher growth rates in other countries seem to lower it. Growth rate in the UK are positively related to the growth of Germany, UK and US but not related to that of India and China. The US growth rate are positively linked to that of India, the UK and the US growth itself.

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A Appendix: Some estimated results of VAR(1) model

Table 11: Variance decomposition in the VAR(1) model for policy coordinationl

Period	S.E.	E_DEL	INF_F	INF_US	R_F	R_US	YGR_F	YGR_US
1	0.0096	3.2353	2.1899	0.3527	4.5702	7.6911	0.0000	81.9607
2	0.0130	4.6646	3.9071	0.2175	4.5417	7.8890	0.0083	78.7719
3	0.0152	5.1744	5.7482	0.1658	4.5629	8.1618	0.0194	76.1675
4	0.0166	5.3071	7.5854	0.1851	4.6265	8.4145	0.0291	73.8523
5	0.0176	5.2853	9.3307	0.2582	4.7218	8.6180	0.0364	71.7496
6	0.0183	5.2018	10.9266	0.3679	4.8393	8.7675	0.0412	69.8557
7	0.0188	5.0985	12.3386	0.4983	4.9707	8.8674	0.0441	68.1824
8	0.0191	4.9956	13.5514	0.6356	5.1087	8.9253	0.0458	66.7375
9	0.0193	4.9030	14.5647	0.7687	5.2478	8.9499	0.0467	65.5192
10	0.0195	4.8251	15.3896	0.8896	5.3836	8.9494	0.0471	64.5155
11	0.0196	4.7629	16.0456	0.9931	5.5134	8.9314	0.0472	63.7064
12	0.0197	4.7157	16.5562	1.0769	5.6356	8.9022	0.0471	63.0662
13	0.0198	4.6815	16.9468	1.1411	5.7496	8.8668	0.0469	62.5674
14	0.0199	4.6580	17.2417	1.1871	5.8554	8.8289	0.0467	62.1823
15	0.0199	4.6427	17.4627	1.2177	5.9537	8.7910	0.0464	61.8857

Table 12: Estimation of parameters in a VAR mode for policy coordinationl

	E_DEL	INF_F	INF_US	R_F	R_US	YGR_F	YGR_US
E_DEL(-1)	0.2316	0.0050	0.0029	-0.0022	-0.0253	-0.0512	-0.0236
	-0.0890	-0.0421	-0.0059	-0.0122	-0.0175	-0.0290	-0.0239
	[2.60129]	[0.11814]	[0.48719]	[-0.17807]	[-1.44289]	[-1.76763]	[-0.98794]
INF_F(-1)	0.0168	0.7964	0.0047	0.0475	-0.0048	-0.0042	0.0533
	-0.1257	-0.0595	-0.0083	-0.0172	-0.0248	-0.0409	-0.0337
	[0.13369]	[13.3962]	[0.56553]	[2.77044]	[-0.19540]	[-0.10206]	[1.58007]
INF_US(-1)	0.4529	-0.0612	0.9195	0.0054	0.2110	0.0289	-0.1322
	-0.3612	-0.1708	-0.0238	-0.0493	-0.0711	-0.1176	-0.0968
	[1.25392]	[-0.35826]	[38.7181]	[0.10965]	[2.96751]	[0.24583]	[-1.36511]
R_F(-1)	0.3605	0.0990	-0.0202	0.9051	0.1205	-0.0525	0.0059
	-0.2600	-0.1229	-0.0171	-0.0355	-0.0512	-0.0846	-0.0697
	[1.38685]	[0.80558]	[-1.18082]	[25.5064]	[2.35519]	[-0.61995]	[0.08440]
R_US(-1)	-0.3071	0.0044	0.0026	0.0531	0.7873	-0.0400	0.0284
	-0.2728	-0.1290	-0.0179	-0.0372	-0.0537	-0.0888	-0.0731
	[-1.12593]	[0.03393]	[0.14440]	[1.42542]	[14.6613]	[-0.45043]	[0.38794]
YGR_F(-1)	-0.0166	0.0054	0.0121	-0.0170	0.0905	0.7494	-0.0108
	-0.1909	-0.0903	-0.0126	-0.0261	-0.0376	-0.0622	-0.0512
	[-0.08709]	[0.06018]	[0.96341]	[-0.65101]	[2.40817]	[12.0569]	[-0.21087]
YGR_US(-1)	0.0440	-0.2442	0.0596	0.0276	0.0973	0.0489	0.8723
	-0.1815	-0.0858	-0.0119	-0.0248	-0.0357	-0.0591	-0.0487
	[0.24215]	[-2.84483]	[4.99318]	[1.11290]	[2.72267]	[0.82692]	[17.9245]
C	-0.0278	0.0132	0.0008	0.0039	-0.0177	0.0221	0.0018
	-0.0259	-0.0123	-0.0017	-0.0035	-0.0051	-0.0084	-0.0069
	[-1.07234]	[1.07877]	[0.49107]	[1.09561]	[-3.47710]	[2.62525]	[0.26475]
R-squared	0.1404	0.7472	0.9756	0.9768	0.9563	0.6931	0.8004
Adj. R-squared	0.0923	0.7330	0.9742	0.9755	0.9538	0.6759	0.7892
Sum sq. resids	0.1605	0.0359	0.0007	0.0030	0.0062	0.0170	0.0115
S.E. equation	0.0358	0.0169	0.0024	0.0049	0.0071	0.0117	0.0096
F-statistic	2.9169	52.7703	714.1089	750.4199	390.3697	40.3315	71.5904
Log likelihood	258.1348	357.7472	620.1355	523.0009	474.2919	407.3755	433.1979
Akaike AIC	-3.7614	-5.2594	-9.2050	-7.7444	-7.0119	-6.0056	-6.3940
Schwarz SC	-3.5876	-5.0855	-9.0312	-7.5705	-6.8381	-5.8318	-6.2201
Mean dependent	0.0158	0.0824	0.0263	0.1106	0.0450	0.0618	0.0276
S.D. dependent	0.0376	0.0328	0.0147	0.0312	0.0328	0.0205	0.0209