Technology Shocks and Business Cycles in India

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Abstract

In this paper, we develop a small open economy New Keynesian DSGE model to understand the relative importance of two key technology shocks, Hicks neutral total factor productivity (TFP) shock and investment specific technology (IST) shock for an emerging market economy like India. In addition to these two shocks, our model includes three demand side shocks such as fiscal spending, home interest rate, and foreign interest rate. Using a Bayesian approach, we estimate our DSGE model using Indian annual data for key macroeconomic variables over the period 1971–2010, and for sub-samples of pre-liberalization (1971–1990) and post-liberalization (1991–2010) periods. Our study reveals three main results. First, output correlates positively with TFP, but negatively with IST. Second, TFP and IST shocks are the first and the second most important contributors to aggregate fluctuations in India. In contrast, the demand side disturbances play a limited role. Third, although TFP plays a major role in determining aggregate fluctuations, its importance vis-à-vis IST has declined during the post liberalization era. We find that structural shifts of nominal friction and relative home bias for consumption to investment in the post-liberalization period can account for the rising importance of the IST shocks in India.

Key words:
Business cycles, IST and TFP Shocks, Small Open Economy DSGE Model.

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1. Introduction

In dynamic stochastic general equilibrium (DSGE) models, one of the most contentious issues is the source of economic fluctuations. Following the seminal works of Kydland and Prescott (1982), and Prescott (1986), a wave of literature emerged emphasizing the role of technology shock as the source of business cycle fluctuations (Cooley and Prescott, 1995; King and Rebelo, 1999). The technology shock is modelled as a Hicks neutral disturbance to the aggregate production function known as the Total Factor Productivity (TFP). A dominant role is attributed to this TFP shock for contributing to aggregate fluctuations.

In recent years, however, there is increased skepticism about the role of TFP shock in driving the business cycle fluctuations. The structural VAR literature indicates that neutral technology shocks can hardly explain more than a quarter of output fluctuations. Other disturbances can play crucial roles for business cycles (Justiniano et al., 2011). Gali (1999) summarizes that the TFP shock accounts for roughly 5% and 7% of the fluctuations of labour hours and output in the US during the post war period. A number of other studies (e.g., Francis, 2001; Basu et al., 1999; Shea, 1998; Kiley, 1997) echo similar concern. Several studies shifted the focus from TFP shocks to shocks to investment technology known as the Investment Specific Technology (IST) shock as the driver of aggregate fluctuations. Greenwood, Hercowitz and Krussell (1997, 2000) argue that about 30% of US output fluctuations is explained by the IST shock which is relatively modest compared to the TFP shock. Similar evidence is provided in Fisher (2006), which shows the predominance of IST shock over TFP shock.

While the role of IST shock for business cycle has been well explored for advanced economies, evidence of its importance is sparse in the context of emerging economies. Some recent papers, such as Aguiar and Gopinath (2007) and Garcia-Cicco et al. (2010) study the role of transitory and permanent technology shocks for business cycles in emerging countries. However, none of these papers address the role of IST shocks in driving emerging market business cycles. The only exception is Araujo (2012) for the Brazilian economy who finds that 50% of output variations are caused by the IST shocks during the period of post 1990's. On the whole, there is no conclusive evidence as to which shock is the prime driver of business cycles. The state of the literature, as it stands now, suggests that the relative importance of IST shock vis-à-vis TFP shock depends on the structure of the economy which includes nominal and real frictions and the nature of the monetary and fiscal policy rules.

In this paper, we use the Indian economy as a test bed to answer two key questions: (i) how do the TFP and IST shocks impact the level of aggregate output and its fluctuations? and (ii) what determines the shift in the relative importance of TFP and IST shocks in business cycles? There has been a growing interest in DSGE modeling of the Indian economy in recent years (e.g., Anand et al. 2010; Goyal 2011; Bhattacharya and Pattnaik 2013). Most notable and comprehensive modeling exercises were undertaken by Gabriel et al. (2010) and Levine and Pearlman (2011). However, none of these papers examine the relative importance of TFP and IST shocks in an open economy and the related research questions. These questions could be potentially important for policy making in emerging market economies. Since TFP and IST shocks have very different short run effects on the behaviour of aggregate output, the Central Banks in emerging markets need to take this differential output effects of TFP and IST into account while designing an optimal monetary policy. Likewise, the fiscal authority may be interested in knowing the contrasting effects of TFP and IST shocks on the economy while formulating an optimal production and investment tax-subsidy programme.

Our model builds on Basu and Thoenissen (2011) by introducing frictions which pertain to a typical small open economy like India. The model features standard New-Keynesian frictions such as external habit formation (Abel, 1990), investment adjustment cost (Christiano et al., 2005), home bias in consumption and investment (Backus et al., 1994), imperfect capital mobility in terms of transaction cost of foreign asset holding (Benigno, 2009) and staggered price setting behaviour of firms (Calvo, 1983). Monetary policy is modelled by the forward looking inflation targeting Taylor rule. Our model includes five types of shocks. Two of them are technology shocks, namely TFP and IST. The rest three are demand-side shocks related to fiscal spending, home interest rate, and foreign interest rate. These features are typical of a 'small' open emerging economy like India.

Using the Bayesian methodology, we estimate our DSGE model using Indian annual data for key macroeconomic variables over the sample period 1971–2010, and for the sub-sample periods of pre-liberalization (1971-1990) and post-liberalization (1991-2010) taking the official year of liberalization as a cutoff. Our estimated DSGE model reveals three key results. First, the impulse responses and analysis of second moments show that output correlates positively with TFP, but negatively with IST. Second, the forecast error variance decomposition analysis suggests that technology shocks, consisting of TFP and IST are the primary drivers of cyclical fluctuations in India with TFP and IST occupying the first and second most important roles in determining aggregate fluctuations. In contrast, the demand side disturbances such as home monetary and fiscal policy shocks and external foreign interest rate shock play minor roles. The low importance of demand side shocks in the context of the Indian economy is in line with RBI (2013) and Mishra, et al.(2016). Finally, our sub-sample estimation of the DSGE model for pre- and post-liberalization periods reveals that the relative importance of the IST shocks increased during the post-liberalization era.

In our model, reversal of the signs of output-TFP correlation and output-IST correlation arises due to contrasting movements of the real marginal cost and the relative price of tradeable home intermediate goods to TFP and IST shocks. A positive TFP shock boosts the marginal products of labour and capital, and thus positively impacts the real wage and real rental price of capital. For our baseline calibrated model, the resulting rise in wage and rental price outweighs the rise in TFP. This raises the real marginal cost which translates into a higher relative price of home tradeable intermediate goods and a lower external terms of trade (the ratio of import to export prices). Since the real GDP is inversely related to the terms of trade, the real GDP rises. On the other hand, a positive IST shock by lowering the Tobin's q and the real marginal cost lowers the relative price of home intermediate goods and makes importables more expensive (higher terms of trade) for the home country. Given that the home country's investment goods sector is more import intensive than consumption, a positive IST shock depresses home output by escalating the relative price of investment goods. To the best of our knowledge, exploring the differential propagations of IST and TFP shocks in an open economy with this terms of trade channel is new in the literature.

To understand the reasons for the rising relative importance of IST shocks in the Indian economy, we perform a sensitivity analysis of our model with respect to a few key parameters which show structural shifts between pre- and post-liberalization periods. The estimation of DSGE model parameters reveals that the nominal rigidity increased by 30% accompanied by a 6.25% decline in the relative home bias in consumption. The model sensitivity analysis confirms that these key parameters account for the rising relative importance of IST shocks.

The rest of the paper is organized as follows. Section 2 lays out the model. Section 3 reports the quantitative analyses and results from the baseline model. Section 4 presents a discussion of our quantitative results. Section 5 concludes.

2. The Model

Our model builds on Basu and Thoenissen (2011) and Banerjee and Basu (2015). Consider a small open economy with incomplete financial markets. As in Backus et al. (1994), Heathcote and Perri (2002), Thoenissen (2011), and Basu and Thoenissen (2011), home country produces a tradeable intermediate good that is used in the home and foreign consumption and investment goods baskets. Following Kollmann (2002), Smets and Wouters (2007), Christiano, Eichenbaum and Evans (2005), we bring various frictions and shocks to address the business cycle features of the emerging market or developing economy like India. For example, our model has frictions in the form of external habit formation in consumption, investment adjustment costs, transaction cost of foreign bond holding and staggered price setting of the intermediate goods producing firms.

2.1. Description of the Economy

Two kinds of firms exist in this economy, namely final and intermediate goods firms. Final goods firms produce consumption and investment goods which are not internationally traded. Intermediate goods firms produce differentiated traded goods that can be used for processing consumption and investment goods. Each intermediate goods producer has some monopoly power of price setting because of its differentiated goods status. There is a government which spends final consumption goods financed by lump-sum taxes and domestic borrowing. The Central Bank follows a Taylor type interest rate rule to target inflation and business cycle conditions.

2.2. Representative Household

In the home economy, there are continuum of identical households in the unit interval. The representative household owns the physical capital, supplies labour and rents capital to the intermediate goods firms. At date t, the household receives its proceeds from wage income, rental income, profit from the ownership of firms and interest income from domestic and foreign bond holding. The household uses its income at date t by consuming final consumption goods, investing in physical capital, and buying new bonds (domestic as well as foreign).

The j-th home-consumer has the following expected utility functional over an infinite horizon.

$$E_0 \sum_{t=0}^{\infty} \beta^t V \left[(C_t^j - \gamma_c C_{t-1}), L_t^j \right] \tag{1}$$

where E_0 denotes the conditional expectation at date t, β is the subjective discount factor with $0 < \beta < 1$. Due to aggregate habit formation, the consumer receives utility from current consumption, C_t^j after adjusting for the previous period's aggregate level of consumption, C_{t-1} upto a fraction, γ_c. The consumer also suffers disutility from supplying labour, L_t^j. Utility function is additively separable in consumption and labour, and is given the following functional form similar to Basu and Thoenissen (2011):

$$V\left(C_t^j, L_t^j\right) = \left[\frac{1}{1-\sigma_c}\left(C_t^j - \gamma_c C_{t-1}\right)^{1-\sigma_c} - \frac{1}{1+\sigma_l}\left(L_t^j\right)^{1+\sigma_l}\right] \tag{2}$$

where σ_c is the inverse of the intertemporal elasticity of substitution in consumption and σ_l is the inverse of Frisch labour supply elasticity.

Home residents trade two nominal one period riskless bonds denominated in the domestic and foreign currency respectively. As in Benigno (2009), we assume that home bonds are only traded nationally while foreign residents can allocate their wealth in foreign bonds denominated in the foreign currency. This asymmetry in the financial market structure is brought to reflect the capital control facing a developing country like India. Since only a riskless foreign currency denominated bond is internationally traded, the international financial market is incomplete. Home households face a transaction cost when they take a position in the foreign bond market. This cost is positively related to the net foreign asset position of the home economy.

The household purchases investment goods (X_t^j) at a price $P_{x,t}$ to undertake capital accumulation facing the investment technology:

$$K_{t+1}^j = (1-\delta)K_t^j + [1 - S(X_t^j / X_{t-1}^j)]X_t^j \tag{3}$$

where δ is the physical rate of depreciation of the capital stock and $S(.)$ captures investment adjustment costs as in Christiano et al. (2005). We make the standard assumption that $S(1) = S'(1) = 0$ and $S''(1) = \varkappa > 0$ implying that the adjustment cost disappears in the long run.

The following budget constraint summarizes the choice set facing the representative home consumer:

$$P_tC_t^j+P_{x,t}X_t^j+\frac{B_{H,t}^j}{(1+i_t)}+\frac{\xi_tB_{F,t}^j}{(1+i_t^*)\,\Theta\left(\frac{\xi_tB_{F,t}^j}{P_t}\right)}=W_tL_t^j+R_{k,t}K_t^j+B_{H,t-1}^j+\xi_tB_{F,t-1}^j+\Omega_t^{d,j}-T_t^j \tag{4}$$

where $B_{H,t}^j$ and $B_{F,t}^j$ are the individual's domestic and foreign nominal bond holdings denominated in the local currency, i_t is the home country's nominal interest rate, i_t^* is the foreign country's nominal interest rate, ξ_t is the nominal exchange rate expressed as the price of one unit of foreign currency in terms of home currency, P_t is the price of final consumption goods and W_t is the nominal wage. The household supplies labour and rents capital to the domestic intermediate goods firms which explains the remaining wage and rental income terms, $W_tL_t^j$ and $R_{k,t}K_t^j$ respectively in the household's flow budget constraint. In addition, $\Omega_t^{d,j}$ is the monopoly profit of the domestic intermediate goods firms which are evenly distributed among domestic agents owning these firms. Positive profit arises from the ownership of monopolistic intermediate goods firms only because retail firms are all competitive and their profits are driven to zero in equilibrium. T_t^j is the nominal lump sum taxes net of transfer from the government.

As in Benigno (2009), the cost function $\Theta(.)$ drives a wedge between the returns on foreign and home bonds. This cost is ascribed to the existence of foreign-owned intermediaries in the foreign asset market who apply a mark-up over the risk-free rate of interest when home agents borrow or lend in foreign currency. This implies that the home country borrows from the foreign country at a premium but lends at a discount. The spread between the borrowing and lending rates depends on the net foreign asset position of the home economy. Profits from this activity in the foreign asset market are divided equally among the foreign residents. In the steady state this spread is zero. The cost function $\Theta\,(.)$ is unity only when the net foreign asset position is at its steady state level, i.e. $B_{F,t}=\overline{B}$, and it is a differentiable decreasing function in the neighbourhood of $\overline{B}$.

Defining $V_{1,t}$ and $V_{2,t}$ as the derivative of the utility function with respect to C_t^j and L_t^j respectively, household's first order conditions can be written as:

$$C_t^j : V_{1,t}-\lambda_tP_t=0 \tag{5}$$

$$L_t^j : -V_{2,t}+\lambda_tP_t(W_t/P_t)=0 \tag{6}$$

$$K_{t+1}^j : -\mu_t + E_t\mu_{t+1}(1-\delta) + E_t\lambda_{t+1}P_{t+1}(R_{k,t+1}/P_{t+1}) = 0 \tag{7}$$

$$X_t^j : \mu_t \left[(1 - s(X_t^j/X_{t-1}^j)) - s'(X_t^j/X_{t-1}^j)(X_t^j/X_{t-1}^j)\right]$$

$$+E_t\mu_{t+1}s'(X_{t+1}^j/X_t^j)(X_{t+1}^j/X_t^j)^2 - \lambda_t P_t(P_{x,t}/P_t) = 0 \tag{8}$$

$$B_{H,t+1}^j : -\lambda_t\left(\frac{1}{1+i_t}\right) + E_t\lambda_{t+1} = 0 \tag{9}$$

$$B_{F,t+1}^j : \frac{-\xi_t\lambda_t}{(1+i_t^*)\,\Theta\left(\frac{\xi_t B_{F,t}^j}{P_t}\right)} + E_t\xi_{t+1}\lambda_{t+1} = 0 \tag{10}$$

where λ_t and μ_t are the Lagrangian multipliers associated with the nominal flow budget constraint (4), and the capital accumulation technology (3) respectively.

The Tobin's q (the opportunity cost of investment in terms of foregoing consumption) is defined as:

$$q_t = \frac{\mu_t}{\lambda_t P_t}$$

Using this definition of q rewrite the Euler equation (8) as:

$$q_t\left[(1 - s(X_t^j/X_{t-1}^j)) - s'(X_t^j/X_{t-1}^j)(X_t^j/X_{t-1}^j)\right]$$

$$+E_t q_{t+1}s'(X_{t+1}^j/X_t^j)(X_{t+1}^j/X_t^j)^2 m_{t+1} = P_{x,t}/P_t \tag{11}$$

where m_{t+1} is the stochastic discount factor and expressed as: $m_{t+1} = \beta\left(\frac{V_{1,t+1}}{V_{1,t}}\right)$

The equation (7) can be written as:

$$q_t = E_t q_{t+1}(1-\delta)m_{t+1} + E_t m_{t+1}(R_{k,t+1}/P_{t+1}) \tag{12}$$

All individuals belonging to the same country are assumed to have the same level of initial wealth. This together with the fact that all individuals face the same labour demand and own an equal share of all firms, implies that within the same country all individuals face the same budget constraint. Thus, they will choose identical paths for consumption. For this reason of symmetry, hereafter we drop the suffix j.

2.3. Final Goods Producing Firms

2.3.1. Consumption Goods Sector

Competitive distributors package home and foreign intermediate consumption goods ($C_{H,t}$ and $C_{F,t}$) to deliver final consumption goods (C_t) to the household using the following CES technology.

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

where θ is the elasticity of intratemporal substitution between $C_{H,t}$ and $C_{F,t}$ and v is the home bias in consumption.

A continuum of intermediate goods in the unit interval produce the home and foreign consumption goods based on the following CES technology:

$$C_{H,t} = \left[\int_0^1 C_{H,t}^{\frac{\varepsilon-1}{\varepsilon}}(i) di \right]^{\frac{\varepsilon}{\varepsilon-1}} \tag{14}$$

$$C_{F,t} = \left[\int_0^1 C_{F,t}^{\frac{\varepsilon-1}{\varepsilon}}(i) di \right]^{\frac{\varepsilon}{\varepsilon-1}} \tag{15}$$

Cost minimization by final consumption goods firms yields the following input demand functions for the home economy (similar conditions hold for foreign producers).

$$C_{H,t}(i) = v \left(\frac{P_{H,t}(i)}{P_{H,t}} \right)^{-\varepsilon} \left(\frac{P_{H,t}}{P_t} \right)^{-\theta} C_t \tag{16}$$

$$C_{F,t}(i) = (1-v) \left(\frac{P_{F,t}(i)}{P_{F,t}} \right)^{-\varepsilon} \left(\frac{P_{F,t}}{P_t} \right)^{-\theta} C_t \tag{17}$$

where the consumer price index (CPI) is defined as:

$$P_t = [vP_{H,t}^{1-\theta} + (1-v)P_{F,t}^{1-\theta}]^{\frac{1}{1-\theta}} \tag{18}$$

while

$$P_{H,t} = \left[\int_0^1 P_{H,t}^{1-\varepsilon}(i) di \right]^{\frac{1}{1-\varepsilon}} \tag{19}$$

and

$$P_{F,t} = \left[\int_0^1 P_{F,t}^{1-\varepsilon}(i) di \right]^{\frac{1}{1-\varepsilon}} \tag{20}$$

The ratio of $P_{F,t}$ to $P_{H,t}$ is the terms of trade facing the home country which is determined by the price setting behaviour of the home intermediate goods producers as we will see later.

2.3.2. Investment Goods Sector

Final investment goods (X_t) are produced by combining home and foreign-produced intermediate goods ($X_{H,t}$ and $X_{F,t}$) in an analogous manner:

$$X_t = Z_{x,t}\left[\varphi^{\frac{1}{\tau}} X_{H,t}^{\frac{\tau-1}{\tau}} + (1-\varphi)^{\frac{1}{\tau}} X_{F,t}^{\frac{\tau-1}{\tau}}\right]^{\frac{\tau}{\tau-1}} \tag{21}$$

where φ is the home bias in investment, τ is the elasticity of substitution between home and foreign intermediate inputs. $Z_{x,t}$ is investment specific technology shock (IST) and it appears in the investment goods production function as in Basu and Thoenissen (2011).

$$X_{H,t} = \left[\int_0^1 X_{H,t}^{\frac{\varepsilon-1}{\varepsilon}}(i)di\right]^{\frac{\varepsilon}{\varepsilon-1}} \tag{22}$$

$$X_{F,t} = \left[\int_0^1 X_{F,t}^{\frac{\varepsilon-1}{\varepsilon}}(i)di\right]^{\frac{\varepsilon}{\varepsilon-1}} \tag{23}$$

The analogous cost minimization by investment goods firms yields the demand functions:

$$X_{H,t}(i) = \varphi\left(\frac{P_{H,t}(i)}{P_{H,t}}\right)^{-\varepsilon}\left(\frac{P_{H,t}}{P_{x,t}}\right)^{-\tau} X_t \tag{24}$$

$$X_{F,t}(i) = (1-\varphi)\left(\frac{P_{F,t}(i)}{P_{F,t}}\right)^{-\varepsilon}\left(\frac{P_{F,t}}{P_{x,t}}\right)^{-\tau} X_t \tag{25}$$

where the investment goods price index (or the producer price index, PPI) is given by:

$$P_{x,t} = \left[\varphi P_{H,t}^{1-\tau} + (1-\varphi)P_{F,t}^{1-\tau}\right]^{\frac{1}{1-\tau}}\left(\frac{1}{Z_{x,t}}\right) \tag{26}$$

The PPI is a function of the price of home and foreign-produced intermediate goods prices. It differs from the CPI due to different substitution elasticities, different degrees of home biases in consumption and investment.

2.3.3. Completing the Price Nexus

The price indices for consumption and investment goods are given by:

$$P_t = P_{H,t}\left[\nu + (1-\nu)\left(\frac{P_{F,t}}{P_{H,t}}\right)^{1-\theta}\right]^{\frac{1}{1-\theta}} \tag{27}$$

$$P_{x,t} = P_{H,t}\left[\varphi + (1-\varphi)\left(\frac{P_{F,t}}{P_{H,t}}\right)^{1-\tau}\right]^{\frac{1}{1-\tau}}\left(\frac{1}{Z_{x,t}}\right) \tag{28}$$

Thus, the relative price of investment is:

$$\frac{P_{x,t}}{P_t} = \frac{\left[\varphi + (1-\varphi)\left(\frac{P_{F,t}}{P_{H,t}}\right)^{1-\tau}\right]^{\frac{1}{1-\tau}}}{\left[\nu + (1-\nu)\left(\frac{P_{F,t}}{P_{H,t}}\right)^{1-\theta}\right]^{\frac{1}{1-\theta}}}\left(\frac{1}{Z_{x,t}}\right) \tag{29}$$

As in Basu and Thoenissen (2011), the terms of trade $\left(\frac{P_{F,t}}{P_{H,t}}\right)$ can create a wedge between the relative price of investment $\left(\frac{P_{x,t}}{P_t}\right)$ and the IST shock, $Z_{x,t}$. A change in $Z_{x,t}$ has a direct effect on the relative price of investment goods and an indirect effect working through the terms of trade. These two-pronged effects of IST on the relative price of investment make it a major driver in business cycle fluctuation which is explained later.

2.4. Intermediate Goods Producing Firms

As in Kollmann (2002), intermediate goods producing firms produce tradeable intermediate goods using rented capital and hired labour as primary factors of production supplied by the household. The following constant returns to scale production function describes the intermediate goods production technology,

$$Y_t(i) = A_t K_t(i)^{\alpha} L_t(i)^{1-\alpha} \tag{30}$$

where A_t is the shock to total factor productivity (TFP). Cost minimization means:

$$\frac{K_t(i)}{L_t(i)} = \frac{\alpha}{1-\alpha}\frac{W_t}{R_{k,t}} \tag{31}$$

where W_t and $R_{k,t}$ are the nominal wage and nominal rental price plus depreciation cost. The nominal marginal cost (MC_t) is:

$$MC_t = \frac{1}{A_t} R_{k,t}^{\alpha} W_t^{1-\alpha} \alpha^{-\alpha} (1-\alpha)^{\alpha-1} \tag{32}$$

The real marginal cost is denoted by lower case and written as:

$$mc_t = \frac{1}{A_t} r_{k,t}^{\alpha} w_t^{1-\alpha} \alpha^{-\alpha} (1-\alpha)^{\alpha-1} \tag{33}$$

where $r_{k,t} = \left(\frac{R_{k,t}}{P_t}\right)$ and $w_t = \left(\frac{W_t}{P_t}\right)$. It is noteworthy that a positive TFP shock could raise or lower mc_t depending on its general equilibrium effect on the real wage and real rental prices of capital in an imperfectly competitive intermediate goods market while in a perfectly competitive scenario, mc_t is always unity.

2.5. Home and Foreign Demands

The aggregate home and foreign demands for home tradeable intermediate goods are given by:

$$Y_{H,t} = C_{H,t} + X_{H,t} \tag{34}$$

$$Y_{H,t}^{*} = C_{H,t}^{*} + X_{H,t}^{*} \tag{35}$$

Using (16), (24) and integrating across all firms and ignoring the price dispersion term as an approximation, the aggregate home demand for intermediate goods can be written more compactly as:

$$Y_{H,t} = \upsilon \left(\frac{P_{H,t}}{P_t}\right)^{-\theta} C_t + \varphi \left(\frac{P_{H,t}}{P_{x,t}}\right)^{-\tau} X_t \tag{36}$$

To get the aggregate foreign demand for home intermediate goods (35), following Kollmann (2002) we assume that the home country charges the price of its exportable in terms of foreign currency after indexing it for foreign inflation. Such a pricing behaviour is validated by the widespread pricing to market behaviour. Based on this assumption, export demand function for home intermediate goods can be written more compactly as:

$$Y_{H,t}^{*} = \lambda_1 \nu^{*} \left(\frac{\xi_t P_{H,t}^{*}}{P_t} . rx_t^{-1}\right)^{-\theta^{*}} + \lambda_2 \varphi^{*} \left(\frac{\xi_t P_{H,t}^{*}}{P_t} . rx_t^{-1} \frac{1}{Z_{x,t}^{*}}\right)^{-\tau^{*}} \tag{37}$$

where rx_t is the real exchange rate defined as $\left(\frac{\xi_t P_t^*}{P_t}\right)$ and $Z_{x,t}^*$ is the foreign IST shock. We normalize the aggregate foreign demand Y_t^* which means that λ_1 and λ_2 are fractions of foreign GDP devoted to consumption and investment respectively.[1]

2.6. Price setting Equations

The process of price setting is staggered as in Calvo (1983). Intermediate goods firms set $P_{H,t}$ after receiving a price signal that γ_p fraction of firms will keep the price unchanged in the next period. They also take the demand functions of their intermediate goods as given.

The profit function of the home intermediate goods firms is given by:

$$\Omega_t^d(P_{H,t}, P_{H,t}^*) = \left[(P_{H,t}(i)Y_{H,t}(i) + P_{H,t}^*(i)Y_{H,t}^*(i) - \Psi(Y_{H,t}(i) + Y_{H,t}^*(i))\right] \tag{38}$$

where $\Psi(.)$ is the nominal cost of production.

The dynamics of prices across two segmented markets (assuming identical nominal friction) can be written as:

$$P_{H,t} = \left[\gamma_p \left(P_{H,t-1}\Pi\right)^{1-\varepsilon} + (1-\gamma_p)\left(\widetilde{P}_{H,t}\right)^{1-\varepsilon}\right]^{\frac{1}{1-\varepsilon}} \tag{39}$$

$$P_{H,t}^* = \left[\gamma_p \left(P_{H,t-1}^*\Pi^*\right)^{1-\varepsilon^*} + (1-\gamma_p)\left(\widetilde{P}_{H,t}^*\right)^{1-\varepsilon^*}\right]^{\frac{1}{1-\varepsilon^*}} \tag{40}$$

where '~' stands for the optimal price, and Π and Π^* are steady state home and foreign inflation rates.

Home price is determined by the following price setting problem:

$$\widetilde{P}_{H,t} = \arg\max_{\varrho_t} \sum_{k=0}^{\infty} \beta^k \gamma_p^k D_{t,t+k} E_t \left[\Pi^k \varrho_t \left(\frac{\Pi^k \varrho_t}{P_{H,t+k}}\right)^{-\varepsilon} Y_{H,t+k} - \Psi(Y_{t+k|t})\right] \tag{41}$$

where $D_{t,t+k}$ is the inflation adjusted stochastic discount factor equal to $(V_{1,t+k}/V_{1,t})(P_t/P_{t+k})$

[1] To see how one gets (37), use the fact that $\frac{P_{H,t}^*}{P_t^*} = \frac{\xi_t P_{H,t}^*}{P_t}.rx_t^{-1}$ and $\frac{P_{H,t}^*}{P_{x,t}^*} = \frac{\xi_t P_{H,t}^*}{P_t}.rx_t^{-1}.\frac{P_t^*}{P_{xt}^*}$. Next, note that: $\frac{P_{x,t}^*}{P_t^*} = \frac{\left[\varphi^*+(1-\varphi^*)(P_{F,t}^*/P_{H,t}^*)^{1-\tau^*}\right]^{1/(1-\tau^*)}}{\left[\nu^*+(1-\nu^*)(P_{F,t}^*/P_{H,t}^*)^{1-\theta^*}\right]^{1/(1-\theta^*)}}.\frac{1}{Z_{x,t}^*}$. In our calibration we assume that $\tau^* = \theta^*$ and $\nu^* = \varphi^*$ as the baseline, which means $\frac{P_{x,t}^*}{P_t^*} = \frac{1}{Z_{x,t}^*}$ where $Z_{x,t}^*$ is the foreign IST shock.

with the subscript of $V(.,.)$ representing the partial derivative with respect to the first argument of the utility function in (2).

Since prices are non-stationary, we deflate the domestic price by CPI deflator. By doing this, one can write the optimal relative home price in a standard form as follows:

$$\frac{\widetilde{P}_{H,t}}{P_t} = \frac{(\varepsilon/(\varepsilon-1))E_t \sum\limits_{k=0}^{\infty}(\beta\gamma_p)^k D_{t,t+k} mc_{t+k|t} Y_{H,t+k|t} \Pi_{t,t+k}}{E_t \sum\limits_{k=0}^{\infty}(\beta\gamma_p)^k D_{t,t+k} Y_{H,t+k|t}} \tag{42}$$

where $Y_{H,t+k|t}$ and $mc_{t+k|t}$ are the k-period ahead forecasts of home demand and real marginal cost respectively; $\Pi_{t,t+k} = P_{t+k}/P_t$. Eq (42) can be written in a recursive form as:

$$\frac{\widetilde{P}_{H,t}}{P_t} = \frac{\varepsilon}{\varepsilon-1}\left(\frac{Y_{H,t}}{F_t}\right) mc_t + \Pi^{-1}\left(1-\frac{Y_{H,t}}{F_t}\right) E_t \frac{\widetilde{P}_{H,t+1}}{P_{t+1}} \tag{43}$$

where F_t is the denominator of (42) which can be written as a recursion $Y_{H,t}+\beta\gamma_p\Pi E_t(F_{t+1})$. Greater nominal rigidity (higher γ_p) makes the shock to the current real marginal cost more persistent via the forward looking term F_t. Because home price is indexed for steady state home inflation, a higher Π is also passed through the staggered price adjustment via the forward looking term F_t.

The price setting problem for the export price is analogous to the domestic prices except that it takes into account that the home country sets its export price in foreign currency indexing it against foreign steady state inflation rate Π^* as in Kollmann (2002). It is given by:

$$\widetilde{P}^*_{H,t} = \arg\max_{\varkappa_t} \sum_{k=0}^{\infty} \beta^k \gamma_p^k D_{t,t+k} E_t \left[\xi_{t+k} {\Pi^*}^k \varkappa_t \left(\frac{\varkappa_t {\Pi^*}^k}{P^*_{t+k}}\right)^{-\varepsilon^*} Y^*_{H,t+k} - \Psi(Y_{t+k|t}) \right] \tag{44}$$

The optimal export price can be written analogously as:

$$\frac{\xi_t \widetilde{P}^*_{H,t}}{P_t} = \frac{(\varepsilon^*/(\varepsilon^*-1))E_t \sum_{k=0}^{\infty}(\beta\gamma_p)^k D_{t,t+k} mc_{t+k} Y^*_{H,t+k|t} \Pi_{t,t+k}}{E_t \sum_{k=0}^{\infty}(\beta\gamma_p\Pi^*)^k D_{t,t+k} Y^*_{H,t+k|t}(\xi_{t+k}/\xi_t)} \tag{45}$$

which gives rise to a recursive representation of the relative export price similar to (43):

$$\frac{\widetilde{P}^*_{H,t}\xi_t}{P_t} = \frac{\varepsilon^*}{\varepsilon^*-1}\left(\frac{Y^*_{H,t}}{F^*_t}\right)mc_t + \Pi^{*-1}\left(1-\frac{Y^*_{H,t}}{F^*_t}\right)E_t\frac{\widetilde{P}^*_{H,t+1}\xi_{t+1}}{P_{t+1}} \tag{46}$$

where F^*_t is the denominator of (45) which can be written as a recursion $Y^*_{H,t}+\beta\gamma_p\Pi^* E_t(F^*_{t+1})$. Not surprisingly, the relative domestic and export prices (43) and (46) depend positively on the current and anticipated real marginal cost via the staggered price setting rules. Because export price is set in foreign currency and it is indexed for foreign steady state inflation, a higher foreign inflation is passed through the staggered price adjustment via the forward looking term F^*_t.[2]

2.7. Fiscal Policy and Monetary Policy

The home government consumes an exogenously specified stream of spending $\{G_t\}$ of final consumption goods and finances this by lump sum taxes T_t. The Central Bank (CB) sets an interest rate rule (i_t) that follows a standard Taylor rule in the short run and is specified as follows:

$$\widehat{i_t} = \phi_i\widehat{i_{t-1}} + (1-\phi_i)\left[\phi_\pi E_t\left\{\widehat{\pi}_{t+1}\right\} + \phi_y\widehat{y}_{H,t}\right] + \xi^m_t \tag{47}$$

where '^' represents the proportional deviation from the steady state, ϕ_i is the interest rate smoothing parameter, ϕ_π and ϕ_y are the policy response to expected inflation $\widehat{\pi}_{t+1}$ and output gap, $\widehat{y}_{H,t}$. ξ^m_t is the monetary policy shock which is a white noise.[3] We assume that monetary authorities at both home and abroad target respective inflation rates which are achievable in the long run.

2.8. Market Equilibrium

The solution of our model satisfies the following market equilibrium conditions which must hold for the home and foreign countries:

1. Home-produced intermediate goods market clears:

$$Y_t = Y_{H,t} + Y^*_{H,t} \tag{48}$$

[2] Details of the derivation of (43) and (46) are available from the authors upon request.

[3] Although monetary policy shock is a white noise, the policy rate, i_t is serially correlated because of the presence of the interest rate smoothing term, $\widehat{i_{t-1}}$.

2. Foreign-produced intermediate goods market clears:

$$Y_t^* = Y_{F,t} + Y_{F,t}^* \tag{49}$$

3. Home and foreign bond markets clear which means that $B_{H,t} = 0$ as all government bonds are domestically held and the foreign bond holding $B_{F,t}$ satisfies the current account balance:

$$\frac{\xi_t B_{F,t}}{P_t(1+i_t^*)\Theta\left(\frac{\xi_t B_{F,t}}{P_t}\right)} - \frac{\xi_t B_{F,t-1}}{P_t} = \left(\frac{\xi_t P_{H,t}^*}{P_t}\right) Y_{H,t}^* - \left(\frac{P_{F,t}}{P_t}\right) Y_{F,t} \tag{50}$$

Note that the right hand side of (50) is the home country's net export.

2.9. National Income Accounting

It is straightforward to verify that the Walras law holds for the aggregate economy. Aggregation of the flow budget constraints of all home households and the use of the bond market clearing conditions in (50) we get:

$$P_t C_t + P_{x,t} X_t + P_{H,t}^* \xi_t Y_{H,t}^* - P_{F,t} Y_{F,t} = W_t L_t + R_{k,t} K_t + \Omega_t^d - T_t \tag{51}$$

However, the aggregate profit is given by (using the market clearing condition (48)):

$$\Omega_t^d = P_{H,t} Y_t - W_t L_t - R_{k,t} K_t \tag{52}$$

which after plugging into (51) together with the government budget constraint $P_t G_t = T_t$ yields:

$$P_t C_t + P_{x,t} X_t + P_t G_t + P_{H,t}^* \xi_t Y_{H,t}^* - P_{F,t} Y_{F,t} = P_{H,t} Y_t \tag{53}$$

2.10. Modified Uncovered Interest Parity Condition

Using (9) and (10), it is easy to verify that a modified uncovered interest parity (UIP) condition holds as follows:

$$\left(\frac{1+i_t}{1+i_t^*}\right) = E_t\left(\frac{\xi_{t+1}}{\xi_t}\right)\Theta\left(\frac{\xi_t B_{F,t}}{P_t}\right) \tag{54}$$

The bond holding cost function $\Theta(.)$ drives a wedge between home and foreign bond returns. Given an exogenous foreign interest rate, i_t^*, the home monetary policy (i_t) and the time path of foreign bond holding driven by the current account equation (50) determines the expected nominal rate of depreciation via this modified UIP condition (54).

2.11. Real Exchange Rate

The real exchange rate is defined as the ratio of foreign to home CPI ($\xi_t P_t^*/P_t$). It is straightforward to verify the following identity for the real exchange rate (call it RX_t):

$$RX_t = \left(\frac{P_{t-1}}{P_t}\right)\left(\frac{P_t^*}{P_{t-1}^*}\right)\left(\frac{\xi_t}{\xi_{t-1}}\right)RX_{t-1}$$

Assuming that the foreign inflation rate is constant, the loglinear version of the real exchange rate process is given by:

$$\widehat{RX_t} = \frac{\widehat{\xi_t}}{\xi_{t-1}} - \frac{\widehat{P_t}}{P_{t-1}} + \widehat{RX_{t-1}} \tag{55}$$

Thus, the real exchange rate fluctuates around its PPP level following the relationship (55).

2.12. Forcing Processes

There are eight exogenous variables, namely, (i) TFP (A_t), (ii) IST ($Z_{x,t}$), (iii) monetary policy shock (ξ_t^m), (iv) fiscal policy shock (G_t), (v) foreign interest rate (i_t^*), (vi) foreign TFP shock (A_t^*) (vii) foreign IST shock ($Z_{x,t}^*$), (viii) foreign inflation rate (P_t^*/P_{t-1}^*). Since the focus of this paper is on the relative contributions of the domestic TFP and IST shocks, we limit to a single foreign shock, namely the foreign interest rate. The foreign TFP and IST shocks ($A_t^*, Z_{x,t}^*$) and the foreign inflation, P_t^*/P_{t-1}^* are assumed to be constant.[4] Rest of the four exogenous variables follow the processes as:

$$A_t = \overline{A}^{1-\rho_a} A_{t-1}^{\rho_a} \exp\{\varepsilon_{a,t}\}$$

$$Z_{x,t} = \overline{Z_x}^{1-\rho_z} A_{t-1}^{\rho_z} \exp\{\varepsilon_{z,t}\}$$

$$G_t = \overline{G}^{1-\rho_g} G_{t-1}^{\rho_g} \exp\{\varepsilon_{g,t}\}$$

$$i_t^* = \overline{i^*}^{1-\rho_{i^*}} i_{t-1}^{*\rho_{i^*}} \exp\{\varepsilon_{i^*,t}\}$$

[4] The foreign TFP shock has no effect on the home GDP in our model. The IST shock impacts the home economy via the export demand function $Y_{H,t}^*$ in (37). Foreign technology shocks have negligible contributions to the variance decomposition of home output and that is why we ignore these shocks.

where the variables with bar on the top represent the steady states and ρ_a, ρ_z, ρ_g, ρ_{i^*} are the serial correlation coefficients of the respective shocks.

3. Quantitative Analysis

The quantitative analysis is based on the model's loglinearized short run equation system around the steady state.[5] For the purpose of quantitative analysis, we construct the baseline parameterization of the model combining the methods of calibration and Bayesian estimation. Some of the well known deep parameters and policy relevant parameters are chosen from the existing studies. In contrast, the parameters of frictions, elasticities and shocks, which are deemed to be more country-specific in nature, are estimated using the Indian macroeconomic data over the sample period of 1971 - 2010. The Bayesian estimation procedure provides scope to exploit the prior information to identify the structural parameters and the behaviour of shocks using the cross-equation restrictions arising from the general equilibrium set-up. We blend the posterior means of the estimated parameters along with the well known calibrated parameters to create a baseline model for the Indian economy. Using this baseline model, we study the impulse response properties of output to TFP and IST shocks which are the key drivers of output fluctuations. We also analyze the structural factors that determine the relative importance of these two fundamental technology shocks in determining the business cycle fluctuations.

3.1. Baseline Parameterization

3.1.1. Calibrated Parameters

Following Kollmann (2002), we specialize to the following utility function:

$$V\left[(C_t^j - \gamma_c C_{t-1}), L_t^j\right] = \ln(C_t^j - \gamma_c C_{t-1}) - L_t^j \tag{56}$$

We take the subjective discount factor, β equal to 0.98 from Gabriel et al. (2010). The capital share, α and the depreciation rate, δ are fixed at the conventional levels 0.3 and 0.1 respectively given the annual frequency of the data. The Taylor rule parameters ϕ_i, ϕ_π and ϕ_y are fixed at 0.81, 1.64, and 0.5 respectively following Gabriel et al. (2010). The

[5] We set the steady state technology variables, $\bar{A}$, $\bar{Z}_x$ equal to unity and assume that the law of one price holds in the long run. Details of the steady state calculations are relegated to a technical appendix available from the journal website.

long run foreign inflation rate is set at a conventional 2% target inflation rate as observed for the major industrial countries. The home inflation target is set at 4% according to the Patel commission report.[6] This means a 2% steady state rate of nominal depreciation according to the relative purchasing power parity condition.

The steady state bond holding cost $-\Theta'(b_f)\overline{C} = 0.01$ is set at a relatively higher value than Basu and Thoenissen (2011) because India has undergone a phase of capital control that can raise the transaction cost of foreign bond holding significantly compared to an advanced country like the US. The foreign consumption and investment share parameters, λ_1 and λ_2, are computed as 0.67 and 0.24 respectively.[7] Table 1 summarizes the baseline values of the calibrated parameters.

< Insert Table 1 >

3.1.2. Data and Bayesian Estimation Procedure

Due to lack of consistent and reliable quarterly series dating back earlier, we use the annual data for the period of 1971-2010 to estimate the structural parameters of our model. Since there are five shocks, to identify the model parameters, we take five observable macroeconomic variables namely, real output, real stock of capital, consumer price inflation, external terms of trade, and the US real GDP as a proxy for the foreign output.[8]

We define prior distributions for the parameters to implement Bayesian estimation. We fall back on the DSGE literature to set the priors which would fit with the Indian data. For the parameter of nominal friction, in general, the value of prior mean is set at 0.5 or above for the advanced economies like the US or the EU countries.[9] However, the micro-

[6] According to the Patel commission report (2014), by the end of 2016, the target inflation rate in India needs to be brought down to 4%.

[7] Using a sample of 189 countries, we compute the time average of the percentage of household's consumption expenditure to GDP and gross capital formation to GDP to obtain estimates of λ_1 and λ_2. The 'rest of the world' with 189 countries is deemed to be a 'closed economy' which is consistent with the assumption that India is a small open economy. All the cross country data are compiled from the World Development Indicators.

[8] For the series of output, we take the data of GDP at factor cost in constant price with the base year of 2004-05. The data of capital stock are taken in constant price with the base year of 2004-05. The time series data of real GDP and capital stock are taken from National Accounts Statistics. CPI inflation is taken from Labour Bureau. The terms of trade is calculated as the ratio of unit price of foreign goods to unit price of home goods provided by the RBI. The real GDP of the US economy is taken from St. Louis FRED database. All the data series are stationarized using either HP filter suggested by Ravn and Uhlig (2002) or extracting the mean as appropriate.

[9] See Smets and Wouters (2002) for example.

level commodity-wise monthly CPI data for the industrial workers in India indicates that the Calvo probability of price stickiness would be considerably lower than the estimates used in the literature. We find that the average price duration at the aggregate level is 2.6 months, and therefore, the probability of price change within a year is even less than one-quarter.[10] In view of this, we set 0.25 as the prior mean for the parameter of nominal rigidity. The habit persistence parameter, γ_c is fixed at 0.6 as in Basu and Thoenissen (2011). The prior for investment adjustment cost parameter is set at 2 as in Christiano et al. (2005) and Gabriel et al. (2010). Assuming no cross border difference in mark up, the steady state price-marginal cost markups for both home and foreign countries are fixed at 1.2 as in Kollmann (2002) which means the priors for home market and export market elasticities are $\varepsilon = \varepsilon^* = 6$. In case of the home bias in consumption and investment goods for the Indian economy, we start off with the priors for which the relative home bias in consumption versus investment is zero. We choose priors for $\nu = \varphi = 0.8$ following Anand et al. (2010) estimates. The priors for intersectoral elasticity parameters for consumption and investment are also set in line with Anand et al. (2010) as $\theta = \tau = 2$. The priors for the shock structure, i.e. the coefficients of persistence and the standard errors of the shocks, are broadly consistent with Gabriel et al. (2010).

Our selection of the probability density functions for the priors are based on the theoretical implications of the relevant parameters in the model and the evidence from extant studies. For example, the Beta distribution is used for the fractions and probabilistic parameters, while the Inverse Gamma distribution is specified for the parameters with non-negativity constraints. Normal distributions are used in cases when more information about the priors are required. Given the dearth of the estimated DSGE models for the emerging market and developing economies, and for India in particular, we have less information regarding the standard deviations of the prior distributions. Thus, we select a higher standard deviations and allow the data to determine the location of the relevant parameters.[11]

The joint posterior distribution of the estimated parameters is obtained by standard procedure. First, the loglinearized decision rules along with the five observable variables

[10] The methodology for computing the average price duration is provided in the technical appendix available from the journal website.

[11] Choice of standard deviation of the prior's distribution is in line with Anand, et al. (2010) and Gabriel et al. (2010).

are written in a Kalman filter recursion form. Second, using this recursive equation system, the loglikelihood function of the relevant parameter vector is constructed. Third, the log posterior kernel is expressed using the prior density of the parameter. Fourth, the mode of this posterior kernel is computed using standard numerical optimization routines. Finally, a Gaussian approximation is constructed in the neighbourhood of this posterior mode using the Markov Chain Monte Carlo-Metropolis-Hastings (MCMC-MH) algorithm.[12] This algorithm simulates the smoothed histogram that approximates the posterior distributions of parameters of our interest. Two parallel chains are used in the MCMC-MH algorithm. The univariate and multivariate diagnostic statistics show convergence by comparing between and within moments of multiple chains (Brooks and Gelman, 1998).[13]

Table 2 presents the prior and posterior means of the estimated parameters for India. The posterior means of estimated parameters are reported with 90% confidence intervals subject to the posterior standard deviation. Figures 1 and 2 plot the prior versus posterior distributions. The modes of the posterior distributions are significantly different from the prior distributions which suggest that enough information is extracted from the data to compute the posterior means.[14] Combining the calibrated parameters of Table 1 and estimated parameters of Table 2, we constitute the baseline parameterization of our model for the full sample. Using the same calibrated parameters, and the same prior distributions, we also undertake a sub-sample estimation of the key structural parameters for pre- and post-liberalization periods using 1991 as the official year of liberalization.[15] This exercise is used for model validation for sub-samples and also to identify if there was any major structural shift in the economy. This is discussed in Section 4.2 later.

< Insert Table 2 >

< Insert Figure 1 to 2 >

[12] We take 100,000 replications to implement the MH algorithm (in which first 40% ‘burn-in’ observations are discarded) with an acceptance rate of 35%.

[13] For details of the computation procedure, see Dynare User Guide, 2013, Ch. 8. All the quantitative simulation and estimation of the model are done by using Dynare version 4.4.3. Codes are available from the authors upon request.

[14] Identification of the shocks and the structural parameters are examined following the criteria of asymptotic information matrix and collinearity patterns of the parameters as in Iskrev (2010a, b) and Iskrev and Rotto (2010a, b). The strength of identification is verified by visual inspection of the plots of asymptotic information matrix. The details of the identification diagnostics are available from the authors upon request.

[15] Banga and Das (2012) document 1991 as the year of new policy for deregulation of industrial licenses and opening up of the domestic market of the Indian economy.

3.2. Matching Business Cycle Facts

In Table 3, we compare cross-correlations among the key macroeconomic variables such as output, consumption, investment, labour hours, total factor productivity, and the measure of relative price of investment for the data vis-à-vis the model. Due to non-availability of Producer Price Index data in India, following Mohanty (2010) we use Wholesale Price Index (WPI) of Manufactured Goods as a proxy measure of PPI. The relative price of investment goods is computed as the ratio of WPI of Manufactured Goods to the Consumer Price Index for industrial workers (CPIIW). For both the series, 2004-05 is considered as the base year. The source of WPI Manufactured Goods series is the Handbook of Statistics on Indian Economy published by the RBI. For CPI data, the Labour Bureau is used as a source. Regarding employment series, due to lack of reliable and systematic record of unorganized sector employment data, we use working hours of the organized sector available in the database of NAS.

The business cycle components are constructed by passing the growth rates of all the relevant series through the Ravn-Uhlig HP filter except the relative price of investment goods as it appears stationary at the growth rate. The TFP shock is the standard Solow residual from a loglinear regression of output on capital stock and hours of employment. The IST shock is backed out from our estimated DSGE model in a similar spirit as in Justiniano, et al. (2011). The model performs well in predicting the signs of all key correlations except a few correlations involving relative price of investment and employment. The official hours of employment data for India should be interpreted with caution because it only includes the organized sector while a vast unorganized sector is left out. All the statistically significant cross-correlations observed in the data are well in line with our model's prediction.

The correlations between y and TFP is positive and y and IST is negative for the whole sample period for both the data and model. The split sample results show that correlation between y and TFP becomes weaker during the period of liberalization compared to the pre-liberalization period. However, an opposite result is observed for correlation between y and IST. The negative correlation between y and IST becomes stronger during the period of liberalization. Given that TFP and IST account for the brunt of the variance decompositions of output, these contrasting correlations are in accord with our model's predictions.

< Insert Table 3 >

3.3. Forecast Variance Decomposition of Key Aggregates

Table 4 reports the unconditional forecast variance decomposition of major macroeconomic aggregates with respect to five shocks for the baseline model.[16] Technology shocks are the principal drivers of economic fluctuations. While shock to TFP is the primary driver, IST shock is the second most important contributor to business cycle fluctuations. In particular, the IST disturbance takes a prominent role in driving the real marginal cost, inflation, nominal interest rate and the depreciation of nominal exchange rate.

< Insert Table 4 >

Fiscal spending shock explains some variation in the cyclical movement for the macroeconomic indicators. However, the effects of home and foreign monetary policy shocks are substantially low. Overall, the demand side shocks such as fiscal spending shock, home and foreign interest rates shocks play very limited role in contributing to aggregate fluctuations, which is in line with a few existing studies on Indian economy (RBI, 2013; Mishra, et al., 2016). Robustness checks are conducted with respect to alternative parameterization of various structural parameters. The importance of the shocks in absolute terms continue to hold.[17]

Given the predominance of technology shocks for business cycle variations in India, hereafter our impulse response analysis focuses only on the propagation mechanisms of the TFP and IST shocks. This is also in line with the principal scope of this paper.

3.4. Impulse Response Analysis

3.4.1. Effects of Total Factor Productivity Shock

In Figures 3 and 4, we report the Bayesian impulse response functions (IRFs) and its confidence bands with respect to a one standard deviation TFP shock.[18] We focus on the impact effects of such shock only. Prior to the shock, the baseline is the flexible price steady state where the real marginal cost (mc_t) is proportional to the inverse of the markup, i.e. $(\varepsilon - 1)/\varepsilon$. It is straightforward to verify that the real wage, w_t and the real rental price, $r_{k,t}$ are proportional to $\{(\varepsilon - 1)/\varepsilon\}MPL_t$ and $\{(\varepsilon - 1)/\varepsilon\}MPK_t$ respectively.

[16] Conditional forecast variance decompositions were also computed at a few low order lags which do not differ much from their unconditional counterparts.

[17] Details of robustness checks are available from the authors upon request.

[18] New notations in IRF plots Figures 3 through 6 are as follows: php=$P_{H,t}/P_t$, pfph= $P_{F,t}/P_{H,t}$, pxp= $P_{x,t}/P_t$, del_xi=ξ_t/ξ_{t-1}.

A higher TFP shock raises both w_t and $r_{k,t}$. Higher real wage boosts labour supply making employment procyclical. On the other hand, higher factor prices raise the real marginal cost of production through (33) which translates into a higher relative price of home goods $(P_{H,t}/P_t)$ via the staggered price setting rule (43). Given that the real GDP in this open economy is $(P_{H,t}/P_t)Y_t$, GDP rises not only because $P_{H,t}/P_t$ rises but also employment (L_t) rises which boosts Y_t through the production function (30). Since the estimated home bias in consumption (ν) is higher than that in investment (φ), the relative price of investment goods $(P_{x,t}/P_t)$ drops.[19] Higher real wages and rental prices also give rise to a positive wealth effect which makes agents consume and invest more. Because of the presence of investment adjustment cost, Tobin's q rises following this investment boom. Nothing happens to the government spending (G_t) because it is exogenously specified. The overall effect is a rise in domestic absorption on the demand side.

On the external front, a higher relative price of home goods means a decline in the terms of trade, $P_{F,t}/P_{H,t}$ via (27). The impact effect of TFP on CPI inflation is positive which reflects the higher real marginal cost. The policy rates also mimic the same pattern because it depends positively on inflation and output growth. The nominal exchange rate response mirrors the inflation rate due to the UIP condition.

< Insert Figures 3 and 4 >

3.4.2. Effects of Investment Specific Technology Shock

Figures 5 and 6 plot the Bayesian IRFs with respect to a positive IST shock. The effects sharply contrast with the IRFs with respect to TFP shock. As in any standard dynamic model of q and investment (e.g. Basu and Thoenissen, 2011), the impact effect of a positive IST shock on Tobin's q is negative because $q = 1/\bar{Z}_x$. From the Euler equation (12), the steady state rental price of capital is given by:

$$r_k = \frac{\{1 - \beta(1 - \delta)\}q}{\beta} \tag{57}$$

which means that the impact effect of a higher $Z_{x,t}$ is a lower $r_{k,t}$. Given the cost minimization condition (31), a lower $r_{k,t}$ also translates into a lower w_t for a given capital:labour

[19] To see it clearly, loglinearize eq (29) and plug the loglinearized (27) to get $\widehat{\frac{P_{x,t}}{P_t}} = \frac{(\nu-\varphi)}{(\nu-1)}\widehat{\frac{P_{H,t}}{P_t}} - \widehat{Z_{x,t}}$. If $\nu - \varphi > 0$, higher $\widehat{\frac{P_{H,t}}{P_t}}$ lowers $\widehat{\frac{P_{x,t}}{P_t}}$.

ratio. Thus, both real wage and real rental price of capital fall via the Tobin's q channel. Household supplies less hours in response to a lower wage. The fall in $r_{k,t}$ and w_t lower the real marginal cost via (32) which lowers the relative price of home goods $P_{H,t}/P_t$. Falling relative price of home goods coupled with a decline in labour supply lowers GDP, $(P_{H,t}/P_t)Y_t$.[20]

< Insert Figures 5 and 6>

On the demand side, lower real wage and rental price of capital lower household's income. An adverse income effect makes households cut back consumption and investment. On the external front, the terms of trade, $P_{F,t}/P_{H,t}$ rises because of a falling relative price of home goods, $P_{H,t}/P_t$. The impact effect on the relative price of investment goods $(P_{x,t}/P_t)$ is negative as in any standard q theory of investment. On the inflation front, the impact effect of a positive IST shock is negative due to drop in the real marginal cost. The policy rate also mirrors output and inflation responses and the exchange rate follows the same pattern via UIP.

4. Discussion

4.1. Procyclical TFP and Countercyclical IST

The stochastic simulation of the model reveals that the correlation of output is positive with the TFP shocks (0.36) and negative with the IST shocks (-0.31) at the baseline parameter values which are consistent with the impulse response properties of GDP with respect to TFP and IST shocks. The procyclical and countercyclical correlations of GDP with TFP and IST are remarkably robust with respect to the alternative parameter values which we have reported in the technical appendix (available from the journal website) accompanying this paper.

The contrasting responses of GDP to TFP vis-à-vis IST is the central feature of our DSGE model fitted to the Indian data. Particularly striking is that the impact effect of the IST shock is countercyclical for output, hours, and investment. These results are different

[20] The negative effect of IST on output arises along the short run path assuming that the IST shock is purely transitory. On the other hand, if the positive IST shock is permanent, the long run output rises. It is straightforward to check from the steady state property of model that the steady state GDP is rising in $\bar{Z}_x$. The long run property of the model is described in the technical appendix available from the journal website.

from the extant literature (e.g. Fisher, 2006, Justiniano, et al. 2011) that analyzes the macroeconomic effects of a positive IST shock in a closed economy. In our open economy DSGE model, the negative output effect of an IST shock comes primarily from the terms of trade channel. To see it clearly, recall from the right hand side of the national income identity (53) that the GDP is $(P_{H,t}/P_t)Y_t$. Using the Cobb-Douglas production function (30) and loglinearizing, one gets:

$$\widehat{GDP_t} = \widehat{A_t} \ + \alpha\widehat{K_t} \ + (1-\alpha)\widehat{L_t} \ + (\nu - 1)\widehat{\frac{P_{F,t}}{P_{H,t}}} \tag{58}$$

where '^' represents the log-deviation from the steady state. The impact effect of any technology shock has no effect on the existing capital stock which means $\widehat{K_t}$ is equal to zero. A positive TFP shock ($\widehat{A_t} > 0$) leads to a positive $\widehat{L_t}$ and a negative $\widehat{\frac{P_{F,t}}{P_{H,t}}}$ for reasons explained earlier. The overall effect is that $\widehat{GDP_t}$ is positive. On the other hand, as already explained in the preceding section, a positive IST shock ($\widehat{Z_{x,t}} > 0$) means a negative $\widehat{L_t}$ and a positive $\widehat{\frac{P_{F,t}}{P_{H,t}}}$ which means a negative $\widehat{GDP_t}$. The extant literature that analyzes the macroeconomic effects of a positive IST shock in a closed economy does not take into account this terms of trade transmission channel via the relative price of home produced goods.[21]

4.2. Rising importance of IST Shocks

A striking feature of our estimated DSGE model is that the relative importance of IST shock has increased during the post liberalization period based on our estimation for the pre- and post-liberalization periods (1971-1990 and 1991-2010). This increasing prominence of the IST shock vis-à-vis TFP shock emerges from several indicators.

First, Table 3 shows that the correlation between output and IST became stronger during the post-liberalization period. In the data, correlation between y_t and $Z_{x,t}$ is statistically insignificant during the pre-liberalization period. However, it turns to -0.51 and statistically significant at the 5% level during the post-liberalization period. In contrast, the correlation between y_t and A_t declines from 0.61 to 0.42 after liberalization policy

[21] In fact, in the context of emerging economies, the terms of trade transmission channel is potentially important (see for example, Mendoza (1995), Basu and McLeod (1992)). In the context of India, the external terms of trade showed major swings during our sample period. Banerjee and Basu (2016) document the volatility of terms of trade during the pre- and post- quantitative easing (QE) era in India and find that an external QE shock could potentially impact the Indian economy via this terms of trade channel.

introduced in the economy.

Second, we compare the IRF plots across split samples and present the same in Figures 7 and 8 for the TFP and IST shocks respectively. In general, the figures display more pronounced propagation mechanism for each shock in the post liberalization era. However, the plots show that IST shock leads to relatively larger swings for the macroeconomic variables compared to TFP shock. Our visual impression gains further support from the comparison of impact and accumulated effects of the TFP and IST shocks on output and other variables such as consumption, investment, hours, and relative price of investment across the sub-samples which we present in Table 5.[22] Comparing the magnitude of changes of the macroeconomic variables across sub-samples in response to respective shocks, one notices that the effect of IST shock intensified during the period of 1991-2010 and became more relevant for economic fluctuations compared to the TFP shock.

Finally, the variance decomposition results for the pre and post liberalization periods, presented in Table 6, highlights the increasing role of the IST shock. The absolute contribution of TFP shocks to total output variance declined from 72.60% to 63.19% (a decline of 13%) while the absolute contribution of IST shocks increased from 18.61% to 27.15% (a rise of nearly by 46%). To get a further grip on the rising relative importance of IST versus TFP shock, we compute the ratio of cells in column 2 and column 1 in Table 6 which we call ω^{IST} hereafter. Note that ω^{IST} increased by 65%. from pre- to post-liberalization period.

< Insert Figures 7 and 8 >

< Insert Tables 5 and 6 >

To probe deeper into the possible causes of the increasing prominence of the IST shock for output fluctuations, we next investigate whether there are any noticeable shifts in the structural parameters of the Indian economy between pre and post liberalization periods. Table 7 reports the posterior means of the key structural parameters of the model for these two periods using the same priors as in Table 2. A few observations are in order. First, as far as the second moments are concerned, both the serial correlation and the volatility of IST increased substantially during the post liberalization era.[23] Second, the structural

[22] We consider a time horizon of twenty periods to compute the accumulated response of each shock on the macroeconomic variables.

[23] Volatilities of other shocks except the foreign interest rate also increased but these changes do not seem to have any first order effects on business cycle fluctuations.

parameters remained reasonably stable over the two periods. The only exception is the nominal rigidity parameter γ_p which showed an increase of 30.4%. Third, although individually ν and φ seem stable, the relative consumption to investment home bias measured by $(\nu - \varphi)$ declined by 6.25% which is rather nontrivial.

< Insert Table 7>

To see the joint role of nominal rigidity and the relative consumption home bias more clearly, we perform two separate sensitivity experiments. Table 8 reports the sensitivity of ω^{IST} to changes in γ_p, ν, and φ. Given ν or φ, the sensitivity of ω^{IST} is more pronounced for a higher value of γ_p. On the other hand, for a given γ_p, a minute two basis point decline in ν or an increase in φ makes ω^{IST} increase substantially. A higher nominal rigidity (higher γ_p) governs the transmission of a shock to mc_t to the relative price of home goods through the usual new Keynesian channel. To see it, note that the forward looking term F_t in the price setting equation (43) amplifies the effect of a shock to the real marginal cost (mc_t) if γ_p is higher. In other words, the price stickiness governs the transmission of a shock to mc_t to the relative price of home goods. On the other hand, a lower ν or higher φ makes investment goods less import intensive relative to consumption. Given that the home bias in consumption is higher than investment, if the relative import intensity of consumption to investment increases, an IST shock heightens the volatility of terms of trade. Through this channel, it raises the relative importance of the IST shock.

<Insert Table 8>

5. Conclusion

In this paper, we examine the role of technology shocks in the forms of TFP and IST in driving the aggregate fluctuations using the Indian economy as the testing ground. The paper presents a small open economy DSGE model which is estimated using the annual macroeconomic data for India. Our empirical investigation reveals the following: (i) TFP shock correlates positively and IST shock correlates negatively with the business cycle component of GDP, and (ii) the relative contribution of IST shock compared to TFP shock for output variations has risen during the post-liberalization period. In our model, a positive TFP shock promotes GDP through the usual supply side channel via an upward shift of the value of the marginal products of labour and capital. The counterintuitive negative short run effect of an IST shock on GDP arises due to an adverse shift in the external terms of trade and a higher relative home bias in consumption goods. Our estimated DSGE model shows that the relative home bias in consumption to investment has decreased while the nominal rigidity increased after economic liberalization in India. These two factors together determine the rising prominence of the IST shocks in contributing to aggregate fluctuations during the post liberalization period.

Our study has implications for designing fiscal and monetary policies in emerging market economies. Since TFP and IST have opposing effects on output, the fiscal authority may need to think of an optimal mix of production and investment subsidies to stabilize output fluctuations. Since short run inflation is directly related to real marginal cost, a Central Bank of an emerging market economy such as India may like to take into consideration the countervailing effects of these two shocks on real marginal cost while designing an optimal monetary policy to control inflation. These issues could be addressed in a future extension of our work. Our model can be extended in a number of directions. First, one can introduce financial frictions by adding rule of thumb consumers who do not participate in financial markets. Second, we can add an unorganized labour market and informal credit market along the line of Kletzer (2012) to bring the model closer to the Indian economy. Third, a banking moral hazard friction along the line of Gertler and Karadi (2011) can be brought into the model although we are not sure whether this kind of banking friction is very relevant for the Indian economy where the banking sector is heavily regulated. These additional engines can strengthen the model validation against the data and provide further insights about the relative importance of IST and TFP shocks in driving aggregate fluctuations in India.

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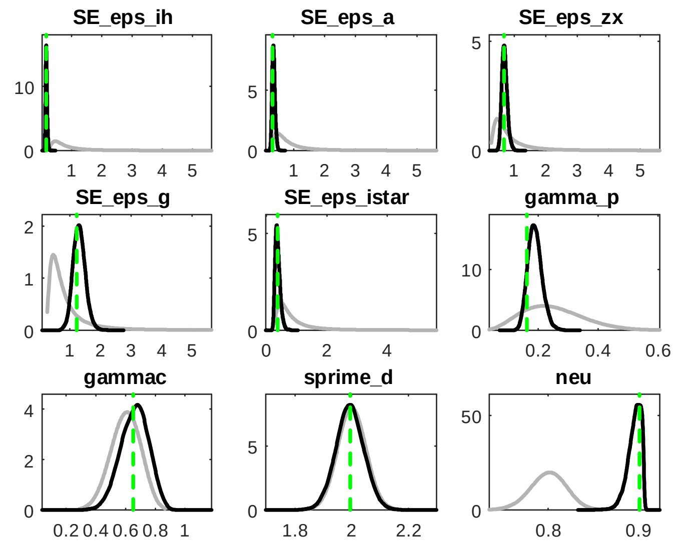


Figure 1: Prior and Posterior Distributions

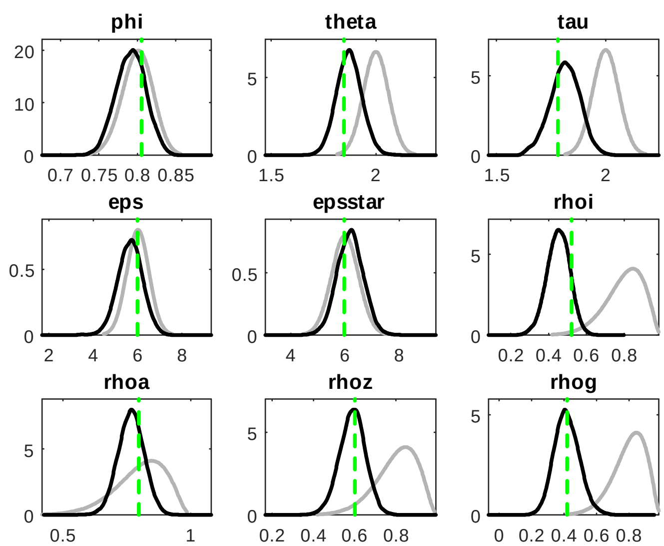


Figure 2: Prior and Posterior Distributions

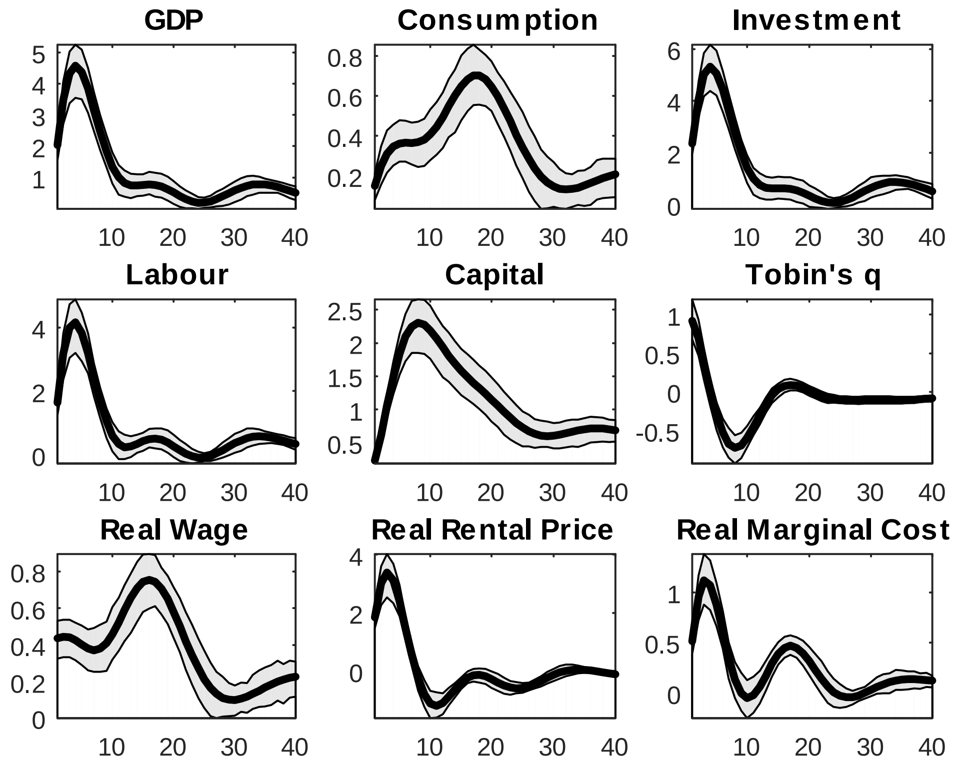
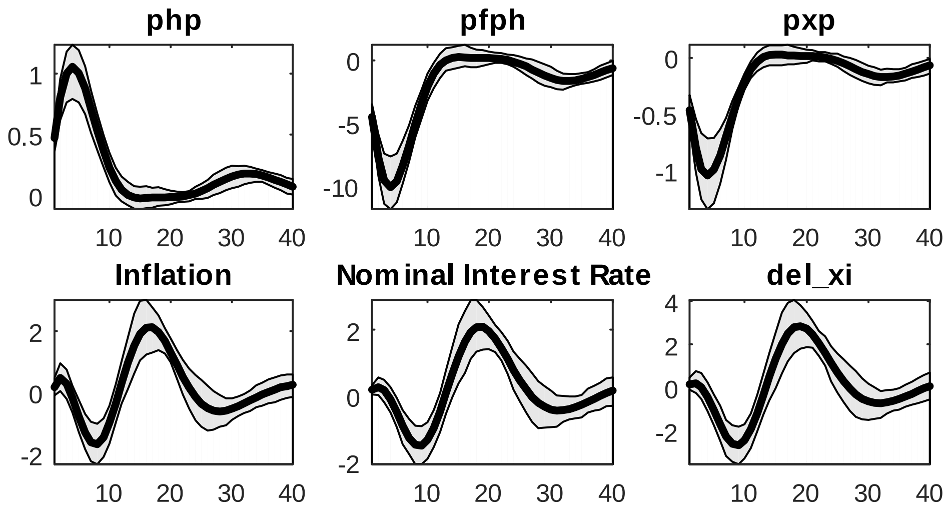


Figure 3: Effects of a TFP Shock



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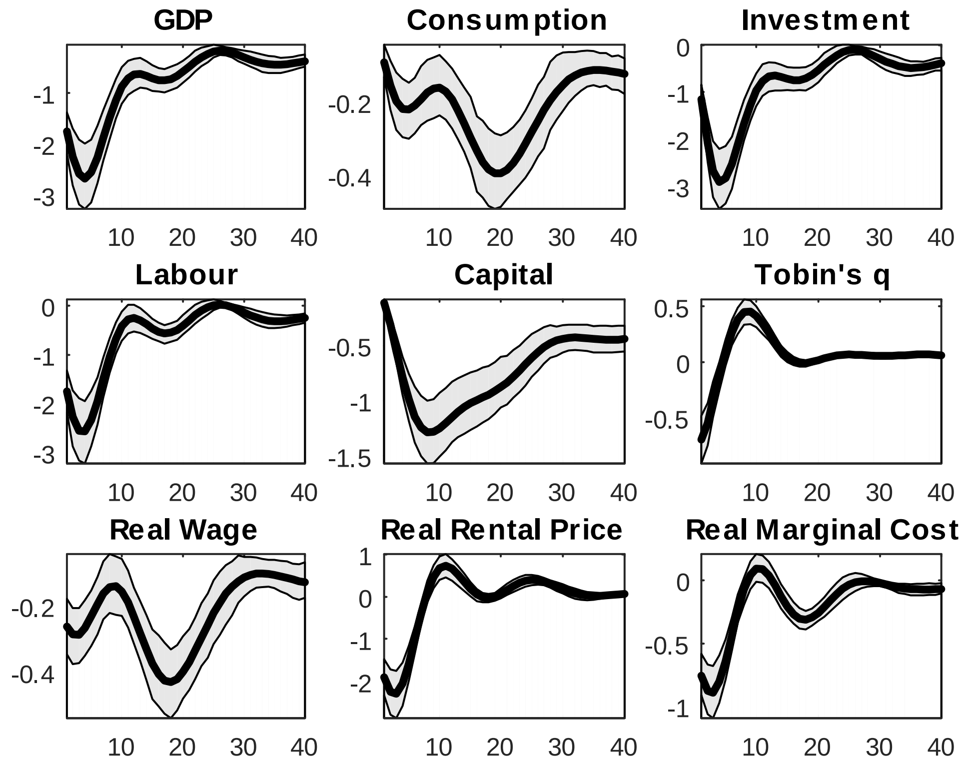

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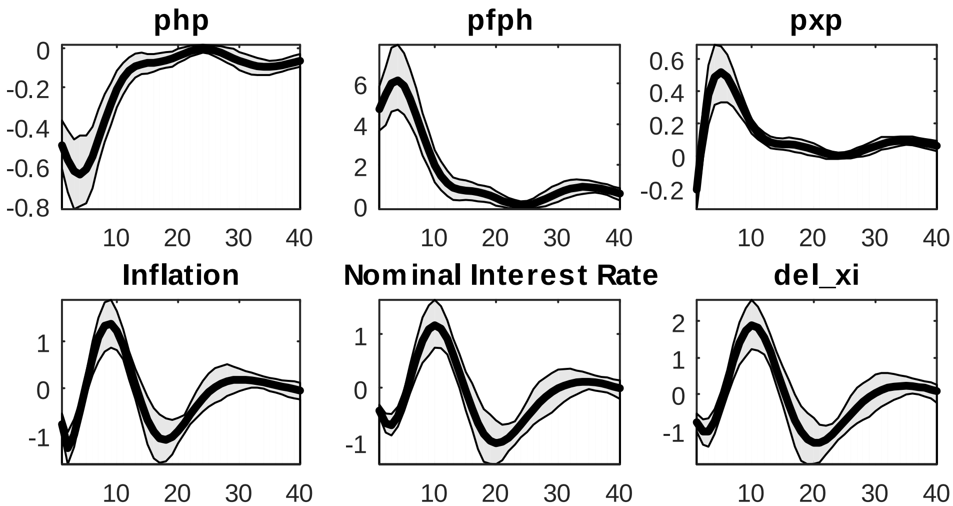

Figure 6: Effects of an IST Shock

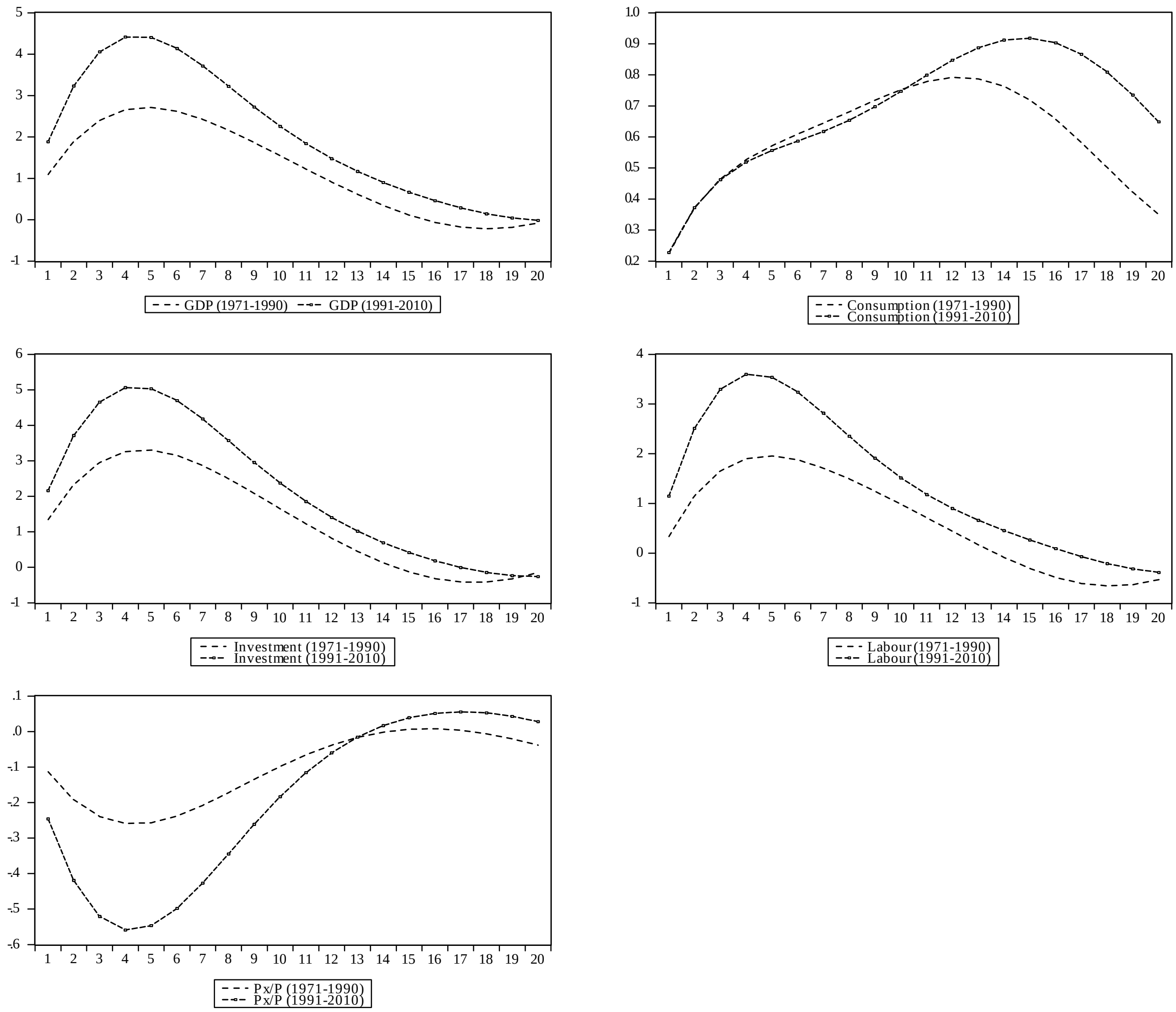

Figure 7: Comparing Effects of TFP Shock across Sub-samples

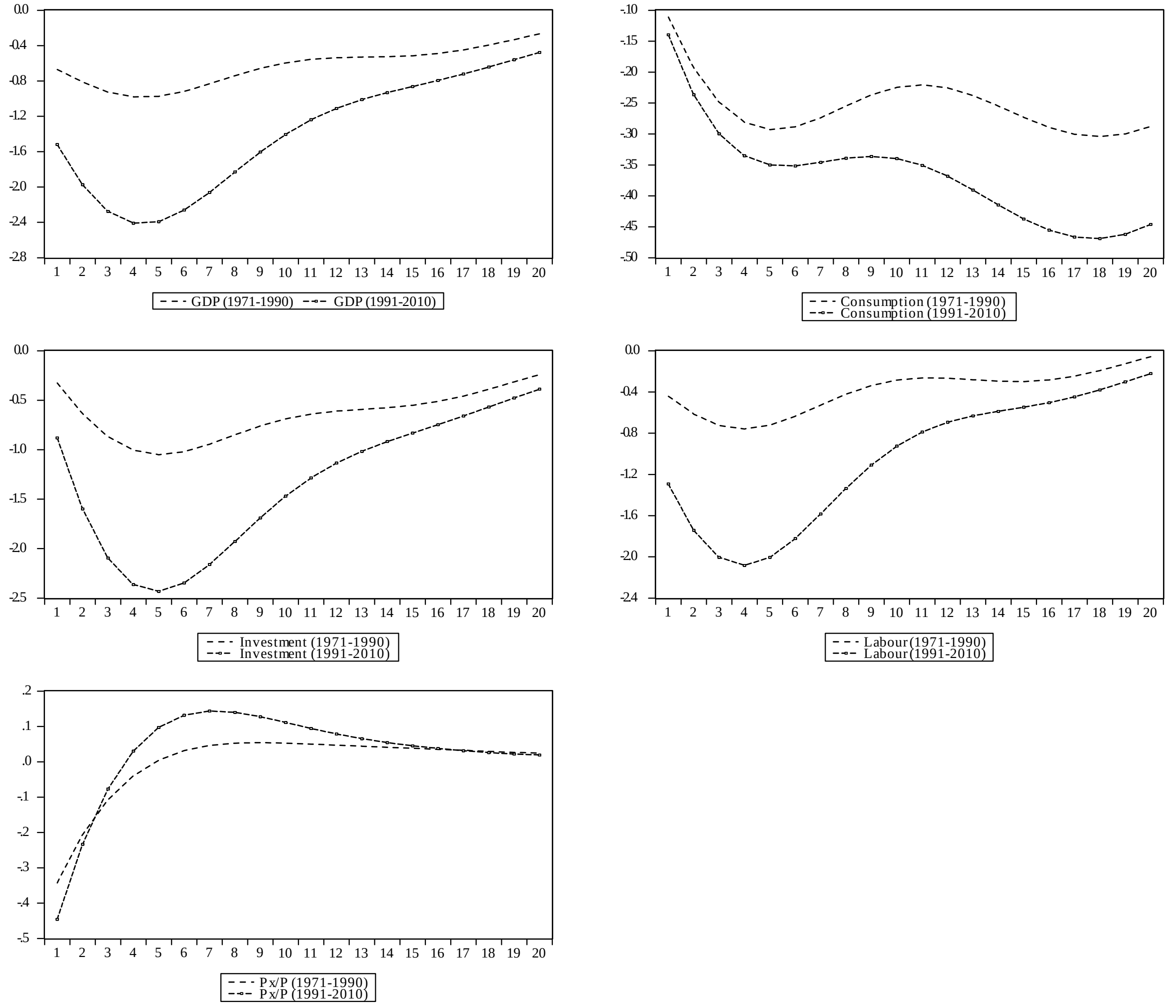

Figure 8: Comparing Effects of IST Shock across Sub-samples

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Table 1: Calibrated Parameters of Baseline Model

β	α	δ	Π	Π^*	$-\Theta'(\bar{b}_f).\bar{c}$	ϕ_i	ϕ_π	ϕ_y	λ_1	λ_2
0.98	0.3	0.1	1.04	1.02	0.01	0.81	1.64	0.5	0.67	0.24

Table 2: Prior Densities and Posterior Estimates for Baseline Model

Estimated	Prior			Posterior	
Parameters	Prior Density	Mean	Std. Dev	Mean	90% HPD Intervals
γ_p	Beta	0.25	0.10	0.189	[0.151, 0.227]
γ_c	Beta	0.60	0.10	0.659	[0.515, 0.819]
ν	Beta	0.80	0.02	0.895	[0.885, 0.906]
φ	Beta	0.80	0.02	0.791	[0.761, 0.824]
θ	Normal	2.00	0.06	1.872	[1.774, 1.971]
τ	Normal	2.00	0.06	1.813	[1.699, 1.922]
ε	Normal	6.00	0.50	5.645	[4.723, 6.528]
ε^*	Normal	6.00	0.50	6.179	[5.384, 6.945]
$\varkappa$	Normal	2.00	0.05	1.993	[1.911, 2.073]
ρ_a	Beta	0.80	0.10	0.765	[0.684, 0.849]
ρ_z	Beta	0.80	0.10	0.588	[0.483, 0.690]
ρ_g	Beta	0.80	0.10	0.417	[0.289, 0.539]
ρ_i	Beta	0.80	0.10	0.451	[0.356, 0.550]
σ_a	Inv. Gamma	1	∞	0.346	[0.267, 0.417]
σ_z	Inv. Gamma	1	∞	0.699	[0.559, 0.833]
σ_g	Inv. Gamma	1	∞	1.305	[0.975, 1.618]
σ_i	Inv. Gamma	1	∞	0.175	[0.133, 0.216]
σ_{i^*}	Inv. Gamma	1	∞	0.368	[0.239, 0.491]

Table 3: Comparing Cross-correlations between Model and Data

Correlation Coefficients	1971-2010		1971-1990		1991-2010	
	Model	Data	Model	Data	Model	Data
$(y,\ c)$	0.96	0.90***	0.87	0.92***	0.94	0.82***
$(y,\ x)$	0.98	0.22	0.93	0.19	0.95	0.32
$(y,\ l)$	0.99	-0.03	0.89	-0.08	0.96	0.19
$(y,\ P_x/P)$	-0.76	-0.37**	-0.17	-0.48**	-0.21	-0.02
$(y,\ a)$	0.36	0.51***	0.39	0.61***	0.39	0.42*
$(y,\ Z_x)$	-0.31	-0.08	-0.34	0.25	-0.38	-0.51**
$(c,\ x)$	0.97	0.05	0.87	0.10	0.94	-0.03
$(c,\ l)$	0.95	0.04	0.68	-0.01	0.85	0.23
$(c,\ P_x/P)$	-0.83	-0.25	-0.25	-0.29	-0.28	-0.17
$(c,\ a)$	0.42	0.57***	0.49	0.64***	0.50	0.53**
$(c,\ Z_x)$	-0.18	-0.01	-0.22	0.13	-0.31	-0.17
$(x,\ l)$	0.96	0.13	0.80	0.29	0.90	-0.15
$(x,\ P_x/P)$	-0.88	-0.21	-0.45	-0.49**	-0.46	0.16
$(x,\ a)$	0.37	0.22	0.41	0.30	0.41	0.16
$(x,\ Z_x)$	-0.12	-0.15	-0.07	0.16	-0.15	-0.31
$(l,\ P_x/P)$	-0.75	0.16	-0.17	0.28	-0.21	-0.31
$(l,\ a)$	0.27	0.15	-0.03	0.11	0.14	0.27
$(l,\ Z_x)$	-0.31	-0.12	-0.25	-0.13	-0.35	-0.16
$(P_x/P,\ a)$	-0.12	-0.05	-0.22	-0.13	-0.24	-0.07
$(P_x/P,\ Z_x)$	-0.16	-0.04	-0.86	-0.22	-0.81	0.11

Table 4: Baseline Result of Variance Decomposition of Key Aggregates (in percent)

	A	Z_x	G	ξ^m	i^*
Y	57.80	28.20	11.07	1.89	1.05
C	54.43	29.04	12.21	3.17	1.15
X	63.02	21.43	12.38	2.03	1.14
L	54.58	29.64	12.51	2.10	1.17
K	62.27	22.35	12.30	1.96	1.13
q	54.43	31.54	10.65	2.29	1.10
w	56.81	27.34	11.73	3.07	1.05
R_k	52.33	33.12	11.07	2.28	1.20
mc	41.94	41.02	12.50	3.07	1.47
$\frac{P_H}{P}$	53.30	33.51	10.54	1.70	0.95
$\frac{P_x}{P}$	55.51	30.75	10.98	1.77	0.99
$\frac{P_F}{P_H}$	53.30	33.51	10.54	1.70	0.95
π	26.82	46.35	15.53	8.14	3.16
i	35.49	38.47	14.18	10.07	1.79
NX	53.25	30.96	12.33	2.28	1.18
$\Delta\xi$	33.75	39.49	12.53	10.46	3.76

Table 5: Comparing Impact and Accumulated Effects (in percentage) of TFP and IST Shocks over Full Sample and Sub-samples

Effects of TFP Shock						
Macroeconomic Variables	Impact Effect			Accumulated Effect		
	1971-2010	1971-1990	1991-2010	1971-2010	1971-1990	1991-2010
y	2.08	1.09	1.88	38.18	23.80	40.96
c	0.13	0.22	0.23	8.81	11.92	13.76
x	2.30	1.35	2.16	39.95	26.26	43.29
l	1.77	0.34	1.15	29.85	12.27	28.47
P_x/P	-0.45	-0.11	-0.25	-6.48	-2.08	-3.91
Effects of IST Shock						
y	-1.78	-0.67	-1.52	-25.24	-12.71	-28.09
c	-0.07	-0.11	-0.14	-4.17	-5.10	-7.34
x	-1.08	-0.33	-0.88	-24.71	-13.05	-27.00
l	-1.82	-0.44	-1.29	-21.14	-7.79	-21.01
P_x/P	-0.22	-0.34	-0.45	3.30	-0.09	0.49

Table 6: Variance Decomposition of GDP across Sub-samples

Sample Periods	A	Z_x	G	ξ^m	i^*
1971-1990	72.60	18.61	7.41	0.75	0.62
1991-2010	63.19	27.15	7.02	1.89	0.75

Table 7: Model Estimation for Pre and Post Lliberalization Periods

Parameters	1971-1990	1991-2010	% Change
γ_p	0.148	0.193	30.4
γ_c	0.656	0.645	-1.7
ν	0.845	0.856	1.3
φ	0.777	0.792	1.9
θ	1.956	1.930	-1.3
τ	1.952	1.926	-1.3
ε	5.727	5.758	0.5
ε^*	6.152	6.111	-0.7
$\varkappa$	1.994	1.992	-0.1
ρ_a	0.750	0.765	2.0
ρ_z	0.687	0.762	10.9
ρ_g	0.556	0.518	-6.8
ρ_i	0.533	0.659	23.6
σ_a	0.395	0.506	28.1
σ_z	0.476	0.733	53.9
σ_g	1.168	1.678	43.7
σ_i	0.258	0.304	17.8
σ_{i^*}	0.546	0.531	-2.8

Table 8: Relative Importance of IST Shock to TFP Shock for Alternative Values of Home Bias and Price Stickiness

Home Bias in Consumption (ν) and Price Stickiness (γ_p)					
$\omega^{IST} \searrow$	γ_p= 0.20	γ_p= 0.25	γ_p= 0.30	γ_p= 0.35	γ_p= 0.40
$\nu = 0.92$	0.27	0.44	0.69	1.06	1.62
$\nu = 0.90$	0.46	0.67	0.96	1.38	2.00
$\nu = 0.88$	0.68	0.91	1.24	1.71	2.38
$\nu = 0.86$	0.91	1.17	1.53	2.04	2.76
Home Bias in Investment (φ) and Price Stickiness (γ_p)					
$\varphi = 0.80$	0.56	0.80	1.12	1.59	2.27
$\varphi = 0.82$	0.67	0.93	1.30	1.83	2.60
$\varphi = 0.84$	0.80	1.10	1.53	2.14	3.01
$\varphi = 0.86$	0.96	1.32	1.82	2.53	3.54