Technology Shocks and Business Cycles in India[1]

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Abstract

A striking stylized fact of the Indian economy is the increasing predominance of the investment specific technology shocks (IST) as opposed to total factor productivity (TFP) shocks in determining the GDP fluctuations during the post liberalization era. A concurrent phenomenon is the stark increase in the relative import content in the consumption basket vis-a-vis investment. We develop an open economy dynamic stochastic general equilibrium (DSGE) model to understand the determinants of the relative importance of IST and TFP shocks. The model has standard frictions which include price stickiness, external habit formation, investment adjustment cost, and transaction cost of foreign bond holding. We find that the relative share of import content in consumption over investment and nominal friction are crucial determinants of the relative importance of these two technology shocks.

Keywords: Business cycles, IST and TFP Shocks, DSGE Modeling.

JEL Classification: E21, E22, E32, E60.

1 Introduction

In the 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 Solow neutral residual which is known as the Total Factor Productivity (TFP). From the perspective of general equilibrium models, a dominant role is attributed to this TFP shock for propagation of business cycles.

In recent years, however, there are increasing skepticisms 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 one quarter of output fluctuations. Instead, other disturbances can play a crucial role for business cycles (Justiniano et al., 2010). 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. Basu et al., 1999; Kiley, 1997; Shea, 1999; Francis, 2001) echoed the same concern. The focus in the literature gradually shifted from the TFP shock to shocks to investment technology known as the Investment Specific Technology (IST) shock as the principal driver of aggregate fluctuations. Greenwood, Hercowitz and Krussell (1997, 2000) argued that about 30% of US output fluctuations is explained by IST 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 explored for the advanced economies, evidence for the emerging economies is sparse. Some recent papers, such as Aguiar and Gopinath (2007) and Garcia-Cicco et al. (2010) have studied the role of transitory and permanent technology shocks for business cycles in emerging countries. However, none of these papers address the role of IST shock in driving emerging market business cycles. The only exception is Araujo (2012) for the Brazilian economy who found that 50% of output variations are caused by IST shocks and GDP is countercyclical in IST.

On the whole, there is still no conclusive evidence which shock is the prime driver of business cycles. The extant literature suggests that the relative importance of IST shock with respect to TFP shock depends on the structure of the economy which includes the relative importance of nominal and real frictions and the characterization of policy rule.

In this paper, we explore the determinants of the relative importance of IST to TFP shocks taking Indian economy as the test bed. We choose the Indian economy as a baseline case for the following reasons. The stylized Indian macroeconomic facts reported in the next section suggest that TFP and IST shocks have very different effects on the output growth. While output growth rate is pro-cyclical in TFP, it is countercyclical in IST as in Araujo (2012) particularly during the post liberalization period. In addition, the variance decomposition analysis of GDP suggests that IST shock plays an increasingly prominent role in determining output fluctuations in India during the post-liberalization period.

In recent years, there has been a growing interest in DSGE modeling of the Indian economy (e.g., Anand et al., 2010, Goyal, 2011, Bhattacharya and Pattnaiyk, 2012). Most notable and comprehensive modeling exercises were undertaken by Levine and Pearlman (2011) and Gabriel et al. (2010). However, none of these papers examine the relative importance of TFP and IST shocks in an open economy setting and address the research questions posed here.

Our stylized small open economy DSGE model identifies two principal frictions which determine the relative importance of IST and TFP shocks. First is the relative import content of consumption and investment goods. Second is the degree of nominal rigidity that gives rise to a staggered price adjustment of home produced traded intermediate goods. Both frictions together amplify the effect of IST shock in an open economy. The model impulse responses suggest that a positive IST shock raises the marginal efficiency of investment and consequently lowers the anticipated real marginal cost of intermediate goods production. Through this marginal cost channel it affects two crucial relative prices in the economy: (i) the relative price of investment to consumption goods, namely the internal terms of trade, declines, (ii) the external terms of trade defined as the ratio of import to export prices rises.

In contrast, a positive TFP shock impacts the internal and external terms of trade differently. Home intermediate goods producers expand output in response to a TFP boom. The real marginal cost thus rises because of rising demand for labour and capital. Through the staggered pricing adjustment, the relative price of home produced intermediate goods rises and the external terms of trade declines. The latter external terms of trade effect becomes stronger if the import content is higher in consumption than investment.

The central hypothesis that emerges from our model is that the relative importance of IST over TFP shock in determining aggregate fluctuations has increased during the post liberalization era possibly because of the interaction between nominal rigidity and a rising relative import content of consumption. Our model receives some empirical support because along with the increasing importance of IST shock during the post liberalization era, a concurrent phenomenon is a trend shift in the import content in consumption. The relative share of import content in consumption to investment more than doubled during the post liberalization era as established in the following section. This means a sharp decline in the relative home bias in consumption to investment.

Our model builds on Basu and Thoenissen (2011) and Banerjee and Basu (2015) by introducing features which pertain to a typical small open economy like India. The model has standard frictions which include (i) aggregate habit persistence (Abel, 1990), (ii) investment adjustment cost (Christiano et al., 2005), (iii) home bias in consumption and investment (Backus et al., 1994), (iv) imperfect capital mobility in terms of transaction cost of foreign asset holding (Benigno, 2009), and (v) nominal frictions in terms of staggered price setting (Calvo, 1983). Monetary policy is modelled by the forward looking inflation targeting Taylor rule. We incorporate both domestic and foreign shocks in our model. The former includes TFP, IST, monetary policy and fiscal policy shocks. The latter includes a foreign interest rate shock which is a typical feature of a *small* open emerging economy like India.

We perform a sensitivity analysis to the baseline variance decomposition with respect to changes in a few key friction parameters. This sensitivity analysis reveals that the relative import content of consumption together with nominal rigidity substantially account for the increasing role of IST shock in the Indian economy. In particular, the relative importance of IST shock significantly magnifies if the relative import content of consumption over investment and price stickiness are simultaneously higher. Intuitively, the aggregate effect of an IST shock emanates from the dynamics of relative prices of investment goods and home tradable intermediate goods, which are linked via the external terms of trade. In addition, the TFP and IST shocks also determine the fluctuations of real marginal cost. While the pass-through of TFP and IST shocks to real marginal cost is critically governed by the parameter of nominal friction, the transmission process via the external terms of trade is further strengthened if the relative import content of consumption over investment is higher. Hence, an increase in nominal friction along with the simultaneous rise in the relative import content in consumption explain the greater predominance of IST shock than TFP shock. Apart from the nominal rigidity and the relative home bias, the degree of habit formation can also contribute to the transmission channel of IST shock although its contribution is quantitatively rather small. To the best of our knowledge, our model exploring the differential propagations of IST and TFP shocks in a small open economy setting with the terms of trade channel is new in the literature.

The rest of the paper is organized in the following way. Section 2 presents the stylized facts. Section 3 lays out the model. Section 4 reports the results of the quantitative analyses. Section 5 concludes.

2 Stylized Facts

In this section, we present some stylized facts that motivate our small open economy DSGE model. We use the annual data for the period of 1971-2010 as the full sample, and the sub-sample period of 1991-2010 following economic liberalization in India. The reason for using annual data is that a consistent and reliable quarterly series dating back earlier are not available for the relevant macroeconomic variables. A reasonably long time series before 1990 is needed to examine whether the relative importance of the IST shock has changed after 1990. We use the annual series for real GDP, investment, capital stock, and labour employment to construct the TFP and IST series for India.[1]

2.1 Output Growth, TFP and IST Shocks in India

We use the standard form of Cobb-Douglas production function involving capital and labour to construct the Solow residual which is the relevant TFP series in our context. The IST series is constructed by estimating

[1]For the series of output, we take the data of GDP at factor cost with the base year of 2004-05. The data of capital stock and investment are taken with the base year of 2004-05. The time series of all these variables are in real terms, in the unit of crores, and taken from National Accounts Statistics. Finally, due to lack of reliable and systematic record of unorganized sector employment data, we use employment data in the form of working hours in the organized sector.

the following loglinear law of motion of capital stock:

$$\ln K_t = c_0 + c_1 \ln K_{t-1} + c_2 \ln I_{t-1} + \xi_{k,t} \tag{1}$$

where K_{t-1} and I_{t-1} are capital stock and investment at date $t-1$ respectively. Such loglinear specification of the law of motion of capital stock is general enough to encompass linear depreciation rule as well as nonlinear adjustment cost of changing capital stock. The estimated residual $\xi_{k,t}$ is the relevant series of IST for our purpose.[2]

<Insert Figures 1 and 2 >

Figures 1 and 2 plot the estimated TFP and IST series against GDP growth rate. TFP strongly correlates positively with output growth rate after 1990 while the relationship is reverse for the IST series. Table 1 reports the correlation for alternative sub-periods using three filtering schemes, namely, (i) without any filter, (ii) Hodrick-Prescott filter (1997), and (iii) asymmetric band pass filter as suggested by Christiano and Fitzgerald (2003).[3] The pattern, that emerges from Table 1, is that the correlation between TFP and GDP growth rate is robustly positive. On the other hand, the correlation between IST and GDP growth rate is statistically insignificant for the whole sample but is significantly negative during the post liberalization era.

< Insert Table 1>

Table 2 presents the relative volatility of these two shocks in different sample periods. The volatility of IST shock is consistently higher for all sub periods. What is noteworthy is that it has increased during the post liberalization period. This increase is particularly pronounced when one uses the Christiano-Fitzgerald filter which picks up the business cycle component of the series more adequately than the HP filter.[4]

< Insert Table 2 >

2.2 Rising Relative Importance IST Shocks

Given the difference in volatilities of these two technology shocks, a natural question arises which shock may contribute more to output fluctuations. In order to answer this question, we need a measure of the relative importance of IST shock to TFP shock. To this end, based on the variance decomposition analysis of aggregate output, we construct the ratio of contributions of IST to TFP to the total variance of GDP. In other words, we define,

[2] We use GMM technique to estimate the production and investment functions to circumvent the problem of endogeneity. Details of the estimation and instrument choices are omitted for brevity but available from the authors upon request.

[3] In Table 1, we use the symbols ‘ * ’, ‘ ** ’, and ‘ *** ’ to denote statistical significance levels of 10%, 5%, and 1% respectively for the correlation coefficients.

[4] Cogley and Nason (1995) pointed out that HP filter sometimes picks up spurious trend by not eliminating high frequency fluctuations.

$$\omega^{IST} = \left(\frac{\pi_Y^{IST}}{\pi_Y^{TFP}} \right) \tag{2}$$

where π_Y^j is the percent of forecast error variance of output explained by the j^{th} shock and $j = IST$, TFP, Y. Note that, by construction $\sum_j \pi_Y^j$ equals 100% of forecast error variance of output.

Table 3 reports the values of ω^{IST} obtained from the variance decomposition of GDP based on our unrestricted VAR model that considers cyclical components of the GDP series and two shocks at levels. The relative importance of IST shock in driving GDP fluctuation has increased after 1991 and it holds regardless of Cholesky ordering of the shocks and forecast horizons. In Table 4, we repeat the same exercise using first differenced series of output and the cyclical components of two shocks, and arrive at similar conclusion.

< Insert Tables 3 and 4 >

Further robustness checks are carried out by running a Vector Error Correction Model (VECM) which considers logarithm of the raw series of real GDP, TFP series and IST series. All three series are integrated of order one according to the Augmented Dickey Fuller Unit root test. Johansen test of cointegration confirms that these three series are cointegrated with at least one cointegrating vector. Given the evidence of cointegration, one can conclude that there exists a long run relationship between these three variables which justifies the use of VECM. Table 5 reports the results which reflect the same property of ω^{IST} as in the VAR analysis reported in Tables 3 and 4.

< Insert Table 5 >

2.3 Rising Relative Import Content for Consumption over Investment in Post Liberalization Period

Along with the increasing importance of IST shock over TFP shock, one concurrent phenomenon in the post liberalization period is the rising import content in consumption and investment. The OECD Science, Technology, and Industry Scoreboard (2011) reports that the import content in aggregate consumption in India has nearly doubled during the period of liberalization. According to the report, the import content in household's consumption has gone up from 5.7% to 11.7% during the period of 1993-94 to 2006-07.

We investigate further the robustness of this rising trend in the relative import content of consumption by using more disaggregated data for imported commodities.[5] We compute the five year time average of shares of import content in aggregate consumption and investment for the period of 1991-2010 by segmenting into four sub-periods (See Table 6). The results show a gradual rise of import content between 1991-2005 followed by a significant upward shift between 2006-2010 in aggregate consumption as well as in investment.

[5] The data of principal imported commodities came from the Handbook of Statistics on Indian Economy (2013) published by the Reserve Bank of India. Data on private consumption and investment are available from the National Accounts of Statistics (2013), MOSPI. Computational details of the shares are provided in Appendix A.

What is striking is the stark increase in the relative import content of consumption relative to investment computed by the ratio of import share of consumption to investment as seen in the last column of Table 6.

< Insert Table 6 >

2.4 Summarizing Empirical Observations

In sum, three salient observations emerge from our analysis. First, TFP is positively correlated with the GDP growth rate at different episodes of the Indian economy. On the other hand, IST correlates negatively with the GDP growth, particularly after 1990 when the Indian economy underwent major structural reforms.[6] Second, the IST shock shows greater contribution to aggregate fluctuations than TFP during the post liberalization era. Third, the relative share of import content of consumption to investment has significantly gone up during the post liberalization period. In the next section, we develop a calibrated small open economy DSGE model to reconcile these three stylized facts.

3 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 tradable 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.

3.1 Description of the Economy

Two kinds of firms exist in this economy, namely final goods and intermediate goods. Competitive 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. The Central Bank follows a Taylor type interest rate rule to target inflation and business cycle conditions.

[6] This is in line with Araujo (2012) who finds similar negative relationship between IST shock and output growth rate for the Brazilian economy.

3.2 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.

$$E_0 \sum_{t=0}^{\infty} \beta^t V \left[(C_t^j - \gamma_c C_{t-1}), L_t^j) \right] \tag{3}$$

where E_0 denotes the conditional expectation at date 0, 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}. The household 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):

$$V\left(C_t^j, L_t^j\right) = \left[\frac{1}{1-\sigma_c} \left(C_t^j - \gamma_c C_{t-1} \right)^{1-\sigma_c} - \frac{1}{1+\sigma_l} \left(L_t^j \right)^{1+\sigma_l} \right] \tag{4}$$

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

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:

$$K_{t+1}^j = (1-\delta)K_t^j + [1 - S(X_t^j / X_{t-1}^j)]X_t^j \tag{5}$$

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 flow budget constraint summarizes the choice set facing the representative home consumer:

$$P_tC_t^j + P_{x,t}X_t^j + \frac{B_{H,t}^j}{(1+i_t)} + \frac{\xi_t B_{F,t}^j}{(1+i_t^*)\,\Theta\left(\frac{\xi_t B_{F,t}^j}{P_t}\right)} = W_tL_t^j + R_{k,t}K_t^j + B_{H,t-1}^j + \xi_t B_{F,t-1}^j + \Omega_t^{d,j} - T_t^j \quad (6)$$

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 (6). In addition, $\Omega_t^{d,j}$ is the monopoly profit of the domestic intermediate goods firms which are evenly distributed between 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 lump sum taxes net of transfer from the government. The flow budget constraints are subject to the usual solvency condition that $\lim_{T->\infty} E_t B_{H,t+T}^j \geq 0$ and $\lim_{T->\infty} E_t B_{F,t+T}^j \geq 0$ for all t.

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

$$C_t^j : V_{1t} - \lambda_t P_t = 0 \quad (7)$$

$$L_t^j : -V_{2t} + \lambda_t P_t (W_t/P_t) = 0 \quad (8)$$

$$K_{t+1}^j : -\mu_t + E_t\mu_{t+1}(1-\delta) + E_t\lambda_{t+1}P_{t+1}(R_{k,t+1}/P_{t+1}) = 0 \quad (9)$$

$$X_t^j : \mu_t \left[(1 - s(X_t^j/X_{t-1}^j)) - s'(X_t^j/X_{t-1}^j)(X_t^j/X_{t-1}^j)\right] + E_t\mu_{t+1}s'(X_{t+1}^j/X_t^j)(X_{t+1}^j/X_t^j)^2 - \lambda_t P_t (P_{x,t}/P_t) = 0 \quad (10)$$

$$B_{H,t+1}^j : -\lambda_t \frac{1}{1+i_t} + E_t\lambda_{t+1} = 0 \quad (11)$$

$$B^j_{Ft+1}: \frac{-\xi_t\lambda_t}{(1+i^*_t)\,\Theta\left(\frac{\xi_t B^j_{F,t}}{P_t}\right)} + E_t\xi_{t+1}\lambda_{t+1} = 0 \tag{12}$$

where λ_t and μ_t are the Lagrangian multipliers associated with the nominal flow budget constraint (6) and the capital accumulation technology (5) 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 (10) as:

$$q_t\left[(1-s(X^j_t/X^j_{t-1})) - s'(X^j_t/X^j_{t-1})(X^j_t/X^j_{t-1})\right] + E_t q_{t+1} s'(X^j_{t+1}/X^j_t)(X^j_{t+1}/X^j_t)^2 m_{t+1} = P_{x,t}/P_t \tag{13}$$

where m_{t+1} is the stochastic discount factor and expressed as: $m_{t+1} = \beta V_{1t+1}/V_{1t}$

The equation (9) can be written as:

$$q_t = E_t q_{t+1}(1-\delta)m_{t+1} + E_t m_{t+1}(R_{k,t+1}/P_{t+1}) \tag{14}$$

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.

3.3 Final Goods Producing Firms

3.3.1 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.

$$C_t = \left[v^{\frac{1}{\theta}} C_{H,t}^{\frac{\theta-1}{\theta}} + (1-v)^{\frac{1}{\theta}} C_{F,t}^{\frac{\theta-1}{\theta}}\right]^{\frac{\theta}{\theta-1}} \tag{15}$$

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:

$$C_{H,t} = \left[\int_0^1 C_{H,t}^{\frac{\varepsilon-1}{\varepsilon}}(i)di\right]^{\frac{\varepsilon}{\varepsilon-1}} \tag{16}$$

$$C_{F,t} = \left[\int_0^1 C_{F,t}^{\frac{\varepsilon-1}{\varepsilon}}(i)di \right]^{\frac{\varepsilon}{\varepsilon-1}} \tag{17}$$

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

$$C_{H,t}(i) = v \left(\frac{P_{H,t}(i)}{P_{H,t}} \right)^{-\varepsilon} \left(\frac{P_{H,t}}{P_t} \right)^{-\theta} C_t \tag{18}$$

$$C_{Ft}(i) = (1-v) \left(\frac{P_{F,t}(i)}{P_{F,t}} \right)^{-\varepsilon} \left(\frac{P_{F,t}}{P_t} \right)^{-\theta} C_t \tag{19}$$

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

$$P_t = [vP_{H,t}^{1-\theta} + (1-v)P_{F,t}^{1-\theta}]^{1/(1-\theta)} \tag{20}$$

while

$$P_{H,t} = \left[\int_0^1 P_{H,t}^{1-\varepsilon}(i)di \right]^{\frac{1}{1-\varepsilon}} \tag{21}$$

and

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

The ratio of $P_{F,t}$ to $P_{H,t}$ is the external 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.

3.3.2 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:

$$X_t = Z_{x,t} \left[\varphi^{\frac{1}{\tau}} X_{H,t}^{\frac{\tau-1}{\tau}} + (1-\varphi)^{\frac{1}{\tau}} X_{F,t}^{\frac{\tau-1}{\tau}} \right]^{\frac{\tau}{\tau-1}} \tag{23}$$

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).

$$X_{H,t} = \left[\int_0^1 X_{H,t}^{\frac{\varepsilon-1}{\varepsilon}}(i)di \right]^{\frac{\varepsilon}{\varepsilon-1}} \tag{24}$$

$$X_{F,t} = \left[\int_0^1 X_{F,t}^{\frac{\varepsilon-1}{\varepsilon}}(i)di \right]^{\frac{\varepsilon}{\varepsilon-1}} \tag{25}$$

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

$$X_{H,t}(i) = \varphi \left(\frac{P_{H,t}(i)}{P_{H,t}} \right)^{-\varepsilon} \left(\frac{P_{H,t}}{P_{x,t}} \right)^{-\tau} X_t \tag{26}$$

$$X_{F,t}(i) = (1-\varphi) \left(\frac{P_{F,t}(i)}{P_{F,t}} \right)^{-\varepsilon} \left(\frac{P_{F,t}}{P_{x,t}} \right)^{-\tau} X_t \tag{27}$$

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

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

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 and different degrees of home biases in consumption and investment.

3.3.3 Completing the Price Nexus

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

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

$$P_{x,t} = P_{H,t} \left[\varphi + (1-\varphi)(P_{F,t}/P_{H,t})^{1-\tau} \right]^{1/(1-\tau)} (1/Z_{x,t}) \tag{30}$$

Thus, the relative price of investment is:

$$\frac{P_{x,t}}{P_t} = \frac{\left[\varphi + (1-\varphi)(P_{F,t}/P_{H,t})^{1-\tau} \right]^{1/(1-\tau)}}{\left[\nu + (1-\nu)(P_{F,t}/P_{H,t})^{1-\theta} \right]^{1/(1-\theta)}} . \frac{1}{Z_{x,t}} \tag{31}$$

As in Basu and Thoenissen (2011), the terms of trade $P_{F,t}/P_{H,t}$ can create a wedge between the relative price of investment ($P_{x,t}/P_t$) 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 makes it a major driver in business cycle fluctuation to be seen later.

3.4 Intermediate Goods Producing Firms

As in Kollmann (2002), intermediate goods firms produce tradable 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,

$$Y_t(i) = A_t K_t(i)^{\alpha} L_t(i)^{1-\alpha} \tag{32}$$

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

$$\frac{K_t(i)}{L_t(i)} = (1-\alpha)\alpha^{-1}\frac{W_t}{R_{k,t}} \tag{33}$$

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:

$$MC_t = \frac{1}{A_t} R_{k,t}^{\alpha} W_t^{1-\alpha} \alpha^{-\alpha}(1-\alpha)^{\alpha-1} \tag{34}$$

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

$$mc_t = \frac{1}{A_t} r_{k,t}^{\alpha} w_t^{1-\alpha} \alpha^{-\alpha}(1-\alpha)^{\alpha-1} \tag{35}$$

where $r_{k,t} = R_{k,t}/P_t$ and $w_t = W_t/P_t$. It is noteworthy that a positive TFP shock could raise or lower mc depending on general equilibrium effect of such a shock on the real wage and real rental prices of capital in an imperfectly competitive intermediate goods market while in a perfectly competitive scenario the above marginal cost is always unity.

3.5 Home and Foreign Demands

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

$$Y_{H,t} = C_{H,t} + X_{H,t} \tag{36}$$

$$Y_{H,t}^{*} = C_{H,t}^{*} + X_{H,t}^{*} \tag{37}$$

Using (18), (26) 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:

$$Y_{H,t} = v\left(\frac{P_{H,t}}{P_t}\right)^{-\theta} C_t + \varphi\left(\frac{P_{H,t}}{P_{x,t}}\right)^{-\tau} X_t \tag{38}$$

To get the aggregate foreign demand for home intermediate goods (37), following Kollmann (2002) we assume that the home country charges the price of its exportables 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:

$$Y_{H,t}^{*} = \lambda_1 \nu^{*} \left(\frac{\xi_t P_{H,t}^{*}}{P_t} .rx_t^{-1} \right)^{-\theta^{*}} + \lambda_2 \varphi^{*} \left(\frac{\xi_t P_{H,t}^{*}}{P_t} .rx_t^{-1} \frac{1}{Z_{xt}^{*}} \right)^{-\tau^{*}} \tag{39}$$

where rx_t is the real exchange rate defined as $\xi_t P_t^{*}/P_t$. We normalize the aggregate foreign demand Y_t^{*} to unity which means that λ_1 and λ_2 are fractions of foreign GDP devoted to consumption and investment respectively.[7]

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

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

$$P_{H,t}^{*} = \left[\gamma_p \left(P_{H,t-1}^{*} \Pi^{*} \right)^{1-\varepsilon^{*}} + \left(1 - \gamma_p\right) \left(\widetilde{P}_{H,t}^{*} \right)^{1-\varepsilon^{*}} \right]^{\frac{1}{1-\varepsilon^{*}}} \tag{41}$$

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 :

$$\widetilde{P}_{H,t} = \arg\max_{\varrho_t} \sum_{k=0}^{\infty} \beta^k \gamma_p^k D_{t,t+k} E_t \left[\Pi^k \varrho_t \left(\frac{\Pi^k \varrho_t}{P_{H,t+k}} \right)^{-\varepsilon} Y_{H,t+k} - \Psi(Y_{t+k}) \right] \tag{42}$$

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

Since prices are non-stationary, we deflate the domestic price by CPI deflator. By doing this, one can

[7] To see how one gets (39), 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 $\frac{P_{x,t}^{*}}{P_t^{*}} = \frac{\left[\varphi^{*}+(1-\varphi^{*})(P_{F,t}^{*}/P_{H,t}^{*})^{1-\tau^{*}}\right]^{1/(1-\tau^{*})}}{\left[\nu^{*}+(1-\nu^{*})(P_{F,t}^{*}/P_{H,t}^{*})^{1-\theta^{*}}\right]^{1/(1-\theta^{*})}} \cdot \frac{1}{Z_{x,t}^{*}}$. 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.

write the optimal price in a standard form as follows:

$$\frac{\widetilde{P}_{H,t}}{P_t} = \frac{(\varepsilon/(\varepsilon-1))E_t \sum\limits_{k=0}^{\infty} \beta^k \gamma_p^k D_{t,t+k} mc_{t+k} Y_{H,t+k}}{E_t \sum\limits_{k=0}^{\infty} \beta^k \gamma_p^k D_{t,t+k} Y_{H,t+k}} \tag{43}$$

which can be written in the following recursive form at the steady state where Y_{Ht} is time invariant [8]:

$$\frac{\widetilde{P}_{H,t}}{P_t} = \frac{\varepsilon}{\varepsilon-1}(1-\beta\gamma_p)mc_t + \beta\gamma_p E_t \frac{\widetilde{P}_{H,t+1}}{P_{t+1}} \tag{44}$$

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:

$$\widetilde{P}^*_{H,t} = \arg\max_{\varkappa_t} \sum_{k=0}^{\infty} \beta^k \gamma_p^k D_{t,t+k} E_t \left[\xi_{t+k} {\Pi^*}^k \varkappa_t \left(\frac{\varkappa_t {\Pi^*}^k}{P_{t+k}} \right)^{-\varepsilon^*} Y^*_{H,t+k} - \Psi(Y_{t+k}) \right] \tag{45}$$

The optimal export price can be written analogously as:[9]

$$\frac{\xi_t \widetilde{P}^*_{H,t}}{P_t} = \frac{(\varepsilon^*/(\varepsilon^*-1))E_t \sum_{k=0}^{\infty} \beta^k \gamma_p^k D_{t,t+k} mc_{t+k} Y^*_{H,t+k} \Pi_{t+k}}{E_t \sum_{k=0}^{\infty} (\gamma_p \Pi^{*-\varepsilon^*})^k D_{t,t+k} Y^*_{H,t+k} \Pi_{t+k}} \tag{46}$$

which gives rise to the following recursive representation of the relative export price with respect to the home CPI:

$$\frac{\widetilde{P}^*_{H,t}\xi_t}{P_t} = \frac{\varepsilon^*}{\varepsilon^*-1}(1-\beta\gamma_p {\Pi^*}^{-\varepsilon^*})mc_t + \beta\gamma_p E_t \frac{\widetilde{P}^*_{H,t+1}\xi_{t+1}}{P_{t+1}} \tag{47}$$

Not surprisingly, the relative domestic and export prices (44) and (47) depend positively on the current and anticipated real marginal cost via the staggered price setting rules. A higher steady state foreign inflation (Π^*) is passed through to the export price via the first term in (47) because the export price is set in foreign currency indexed for foreign steady state inflation.

3.7 Fiscal and Monetary Policy

The home government spends a stream of final consumption goods, G_t financed 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:

$$\widehat{i_t} = \phi_i \widehat{i_{t-1}} + (1-\phi_i)\left[\phi_\pi E_t\left\{\widehat{\pi}_{t+1}\right\} + \phi_y \widehat{y}_{H,t}\right] + \xi_t^m \tag{48}$$

[8] Details of the derivation of (44) are available from the authors upon request.

[9] The details of the derivation of (47) are available upon request from the authors.

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

3.8 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:

$$Y_t = Y_{H,t} + Y^*_{H,t} \tag{49}$$

2. Foreign-produced intermediate goods market clears:

$$Y^*_t = Y_{F,t} + Y^*_{F,t} \tag{50}$$

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

$$\frac{\xi_t B_{F,t}}{P_t(1+i^*_t)\Theta\left(\frac{\xi_t B_{F,t}}{P_t}\right)} - \frac{\xi_t B_{F,t-1}}{P_t} = \frac{\xi_t P^*_{H,t}}{P_t} Y^*_{H,t} - \frac{P_{F,t}}{P_t} Y_{F,t} \tag{51}$$

Note that the right hand side of (51) is the home country's net export.

3.9 Aggregation

It is straightforward to verify that the Walras law holds for the aggregate economy. Aggregation of the flow budget constraints (6) of all home households and the use of the bond market clearing conditions in (51) yields:

$$P_t C_t + P_{x,t} X_t + P^*_{H,t} \xi_t Y^*_{H,t} - P_{F,t} Y_{F,t} = W_t L_t + R_{k,t} K_t + \Omega^d_t \tag{52}$$

However the aggregate profit is given by (using the market clearing condition (49)):

$$\Omega^d_t = P_{H,t} Y_t - W_t L_t - R_{k,t} K_t \tag{53}$$

which after plugging into (52) together with the government budget constraint yields the usual national income identity:

$$P_t C_t + P_{x,t} X_t + P_t G_t + P^*_{H,t} \xi_t Y^*_{H,t} - P_{F,t} Y_{F,t} = P_{H,t} Y_t \tag{54}$$

3.10 Modified Uncovered Interest Parity Condition

Using (11) and (12), it is easy to verify that a modified uncovered interest parity (UIP) condition holds as follows:

$$\frac{1+i_t}{1+i^*_t} = E_t\left(\frac{\xi_{t+1}}{\xi_t}\right)\Theta\left(\frac{\xi_t B_{F,t}}{P_t}\right) \tag{55}$$

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 set out by the current account equation (51) pin down the expected nominal rate of depreciation via the modified UIP condition (55).

3.11 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:

$$\widehat{RX}_t = \widehat{\frac{\xi_t}{\xi_{t-1}}} - \widehat{\frac{P_t}{P_{t-1}}} + \widehat{RX_{t-1}} \tag{56}$$

Thus, the real exchange rate fluctuates around its PPP level following the relationship (56).

3.12 Forcing Processes

There are seven exogenous variables, namely, (i) TFP (A_t), (ii) IST ($Z_{x,t}$), (iii) monetary policy shock (ξ^m_t), (iv) fiscal policy shock (G_t), (v) Foreign interest rate (i^*_t), (vi) Foreign IST shock ($Z^*_{x,t}$), (vii) Foreign inflation rate Π^*_t. 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 IST ($Z^*_{x,t}$) and the foreign inflation, $\frac{P^*_{t+1}}{P^*_t}$ (denoted as Π^*) are assumed to be a constant.[10] We assume that all these five shocks are independently and identically distributed (iid) shocks around their respective steady state values with a standard deviation of unity. The underlying rationale for making this simplifying iid assumption is that our

[10] Shocking these two processes have minimal change in the variance decomposition analysis.

principal goal is to see the relative contribution of each of these shocks to the aggregate fluctuations. Thus, the assumption of iid distribution underlying each shock does not presuppose any initial structure for the distribution of these shocks. If all shocks are of equal importance apriori, it is easier to gauge which shock contributes more to the propagation of business cycles based on our calibrated baseline model.

4 Quantitative Analysis

For the quantitative analysis, as in Kollmann (2002), we specialize to the following utility function:

$$V\left[(C_t^j - \gamma_c C_{t-1}), L_t^j\right] = \ln(C_t^j - \gamma_c C_{t-1}) - L_t^j \tag{57}$$

Since the purpose of this quantitative analysis is predominantly illustrative, we do not formally estimate the structural parameters. We fall back on the existing studies to set the parameter values except the parameters of price setting behaviour (γ_p), share of consumption to foreign GDP (λ_1), and share of investment to foreign GDP (λ_2).

4.1 Baseline Parameterization

We take the subjective discount factor β equal to 0.98 from Gabriel, et al. (2010). The habit persistence parameter γ_c is fixed at 0.6 as in Basu and Thoenissen (2011). The adjustment cost parameter $s''(1)$ is fixed at 2.5 as in Christiano et al. (2005). The bond holding cost $-\Theta'(b_f)\bar{c} = 0.001$ as in Basu and Thoenissen (2011) where $\bar{c}$ is the steady state consumption. 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 $\varepsilon = \varepsilon^* = 6$. 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. Regarding the home bias in consumption and investment goods for the Indian economy, we start off with a baseline scenario where the relative home bias in consumption is zero meaning $\nu = \varphi$. We set $\nu = \varphi = 0.85$ as in Basu and Thoenissen (2011) estimates. The Taylor 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 foreign consumption and investment share parameters, λ_1 and λ_2 are computed as 0.67 and 0.24 respectively. The details of calculation are provided in Appendix B.

We calculate the value of price stickiness index γ_p for India based on the micro-level commodity-wise monthly CPI data for industrial workers. The average price duration at the aggregate level is 2.64 months (i.e., approximately a quarter), which implies that the probability of price change within a year is 0.22. This estimate of nominal rigidity is considerably lower than the estimates used in the literature.[11] Further details on the methodology are provided in Appendix C. The long run foreign inflation rate is set at popular 2% target inflation rate for major industrial countries. The home inflation target is set at 4% according to the

[11] See Kollmann (2002) for example.

recent Patel commission report.[12] This means a 2% steady state rate of nominal depreciation according to the relative purchasing power parity condition.

Table 7 reports the baseline parameter values. The short run equations are loglinearized around the steady state.[13]

< Insert Table 7>

4.2 Impulse Response Analysis

Figure 4 plots the effects of a one standard deviation shock to TFP.[14] For the calibrated model, a positive TFP shock raises real wage and rental price of capital in (34) more than proportionately than the TFP. This means a rise in the real marginal cost of production which translates into a higher relative price of home goods (P_{Ht}/P_t) through the staggered price setting rule (44). Higher real wages and rental prices give rise to a positive wealth effect which makes agents consume and invest more. The substitution effect of a higher real wage induces households to supply more labour. Because of the presence of investment adjustment cost, Tobin's q rises following this investment boom.

On the external front, the terms of trade, P_{Ft}/P_{Ht} declines because a higher real marginal cost makes the home tradable good dearer. The net export, NX_t consequently falls. Since the home bias in consumption and investment are the same in this baseline economy, the relative price of investment goods (P_{xt}/P_t) shows near zero change (see (31)). The overall effect is a higher GDP, consumption and investment. The CPI inflation momentarily rises reflecting the rise in real marginal cost but then it falls in conformity with a rising relative price of tradable intermediate goods with respect to final good (P_{Ht}/P_t). Nominal interest rate declines which reflects the Central Bank's response to lower expected CPI inflation.

< Insert Figure 3>

A positive IST shock sharply contrasts with the effect of a positive TFP shock as seen in Figure 4. Given that the home bias in consumption and investment are the same ($\nu = \varphi$) for our baseline model, the relative price of investment (P_{xt}/P_t) falls as seen from (31). This negatively impacts the Tobin's q through the Euler equation (13). This lower q translates into a lower anticipated rental price of capital via the Euler equation (14) which lowers investment and also drives down the real marginal cost (34) of production. The real wage falls as a general equilibrium response which is associated with a decline in labour supply through the substitution effect. The lower real marginal cost impacts negatively the relative price of home goods (P_{Ht}/P_t) via the staggered price setting rule (44). The CPI inflation momentarily falls in response to a

[12] According to the Patel commission report (2014, available on Reserve Bank of India website), the inflation rate is targeted to be brought down to 4% from the current 10% gradually over approximately in three years.

[13] The details of the steady state calculations are relegated to the Appendix D. The short run loglinearized equation system of the model are omitted for brevity but available from the authors upon request.

[14] The quantitative simulation of the short run equation system is done by using dynare version 4.2. Codes are available from the authors upon request.

decline in real marginal cost but then it rises to reflect the fall in the relative price of home intermediate goods (P_{Ht}/P_t). The Central Bank responds by changing the nominal interest rate accordingly. Given that the nominal interest rate is set by a monetary policy based on expected inflation, real interest rate rises which explains why the household consumes less and save more.

On the external front, drives up the terms of trade (P_F/P_H) by making the home traded goods cheaper which boosts home country's net export. The overall effect is a decline in GDP accompanied by a fall in consumption, investment, employment and a rise in trade balance.

<Insert Figure 4>

In a nutshell, this impulse response analysis helps us understand why there is a positive correlation between TFP and GDP growth while the correlation is negative between IST and GDP growth as seen in the data.

4.3 Variance Decomposition of Output and Sensitivity Analysis

Table 8 reports the variance decomposition of GDP with respect to five shocks driving the economy. For the baseline model with identical home bias in consumption and investment, TFP and IST shocks account for 63.54% and 30.13% of output variability respectively. Next to TFP and IST, monetary policy shock occupies 4.48% share in the output variability. In contrast, government spending shock and foreign shocks play negligible roles.

< Insert Table 8 >

Given our baseline result of variance decomposition, we investigate the structural factors which can potentially explain the increasing importance of the IST shock for output fluctuations in the post liberalization period. We undertake a sensitivity analysis with respect to the key structural parameters of the model such as home bias in consumption and investment, price stickiness, habit formation, adjustment cost, and transaction cost for foreign bond holding. Tables 9 through 14 report the results of these sensitivity analysis when each of these friction parameters is gradually changed within a plausible range from its baseline value. A cursory glance at the numbers in the tables suggest the following. First, a lower home bias in consumption magnifies the contribution of IST relative to TFP shocks to aggregate output fluctuation while a lower home bias in investment does exactly the opposite. Second, a greater nominal rigidity also magnifies the relative contribution of IST to output fluctuations. Third, a greater habit persistence has a similar effect but its intensity is significantly less than the nominal rigidity or home bias in consumption. Finally, adjustment cost and bond holding costs have negligible effects on the relative contribution of IST vis-a-vis TFP.

<Insert Tables 9 to 14>

To get a further grip on the roles of the two parameters, ν and γ_p in determining the relative contributions of IST and TFP shocks to GDP fluctuations, we compute the model based relative importance of IST to TFP shock, ω^{IST}. Table 15 reports how the model generated ω^{IST} responds to alternative values of ν and γ_p. A lower consumption bias (ν) and/or a higher nominal rigidity (γ_p) raise ω^{IST}. However, what is noteworthy is that both ν and γ_p together remarkably amplify ω^{IST}. For example, ω^{IST} rises from 0.51 to 5.64 when the consumption home bias, ν is lowest and the nominal rigidity, γ_p is highest. When ν ranges from 0.65 to 0.75 and γ_p is in the range of 0.27 and 0.37, the model comes close to the value of ω^{IST} as seen in the data of post liberalization period (see column 3 in Table 3 - 5).

<Insert Table 15 >

4.4 Relative Importance of IST to TFP Shocks in Determining Aggregate Fluctuations: Some Intuitions

Why is the relative import content of consumption coupled with nominal rigidity so powerful in determining the course of aggregate fluctuations? In our open economy model, the aggregate effect of an IST shock comes primarily from the fluctuations of two key relative prices namely, relative price of investment goods (P_{xt}/P_t) and the relative price of home tradable intermediate goods (P_{Ht}/P_t).[15] The external terms of trade (P_{Ft}/P_{Ht}) forms the bridge between these two key relative prices. To see this clearly, as in Basu and Thoenissen (2011) loglinearize (31) to write as:

$$\widehat{\frac{P_{xt}}{P_t}} = (\nu - \varphi)\widehat{\frac{P_{Ft}}{P_{Ht}}} - \widehat{Z_{xt}} \tag{58}$$

where '^' represents the log deviation from the steady state.

Loglinearizing the CPI aggregator (20) one can write:

$$\widehat{\frac{P_{Ht}}{P_t}} = (\nu - 1)\widehat{\frac{P_{Ft}}{P_{Ht}}} \tag{59}$$

Using (58) and (59), one gets,

$$\widehat{\frac{P_{xt}}{P_t}} = \frac{(\nu - \varphi)}{(\nu - 1)}\widehat{\frac{P_{Ht}}{P_t}} - \widehat{Z_{xt}}$$

[15] To see it clearly, note from (38) that the demand function for home tradable goods is: $Y_{H,t} = v\left(\frac{P_{H,t}}{P_t}\right)^{-\theta} C_t + \varphi\left(\frac{P_{H,t}}{P_{x,t}}\right)^{-\tau} X_t$. Thus fluctuations of $\frac{P_{H,t}}{P_t}$ and $\frac{P_{x,t}}{P_t}$ are crucial determinants of the aggregate fluctuations.

Taking the variance transform of (58) one gets:

$$var\left(\widehat{\frac{P_{xt}}{P_t}}\right) = \left(\frac{\nu-\varphi}{\nu-1}\right)^2 var\left(\widehat{\frac{P_{Ht}}{P_t}}\right) + var\left(\widehat{Z_{xt}}\right) - 2\frac{(\nu-\varphi)}{(\nu-1)}cov\left(\widehat{\frac{P_{Ht}}{P_t}}, \widehat{Z_{xt}}\right) \tag{60}$$

If $\nu < \varphi$, the effect of a change in home IST shock is magnified as long as the last covariance term is negative. Our impulse response analysis reported in Figure 4 suggests that $\partial\widehat{\frac{P_{Ht}}{P_t}}/\partial\widehat{Z_{xt}}$ is indeed negative.

Let us now turn to the role of nominal rigidity in contributing to aggregate fluctuations. First note that TFP and IST are the two primitive shocks that determine the real marginal cost.[16] This real marginal cost feeds then into the relative price of home tradeable intermediate goods, $\widehat{\frac{P_{Ht}}{P_t}}$ via the staggered price setting equation (44). A close look at the price reoptimization equation (44) reveals that a shock to the current real marginal cost (mc_t) impacts $\widehat{\frac{P_{Ht}}{P_t}}$ more via the forward looking component ($\widehat{\frac{P_{Ht+1}}{P_{t+1}}}$) if γ_p is higher. In other words, the price stickiness governs the transmission of a shock to mc to future relative price of home goods. Since the same real marginal cost determines the evolution of the export prices, a similar argument holds for the relative price of exports, $\xi_t P^*_{Ht}/P_t$ in the export price setting equation (47). Hence, for a given relative home bias in consumption ($\nu - \varphi$), the relative contribution of IST vis-a-vis TFP shock increases with respect to nominal rigidity rises as seen in Table 15.

In a nutshell, the results of quantitative analysis can be summarized as follows. First, our baseline model explains why the TFP and IST shocks have differential output effects as seen in the data. Second, the sensitivity analysis with respect to the key structural parameters suggests that the increase in the relative importance of IST shock is possibly due to a combination of rising import content in consumption goods basket and greater nominal rigidity.

5 Conclusion

In this paper, we examine the role of two types of technology shocks, namely TFP and IST in driving the business cycle fluctuations taking Indian economy as the test bed. Our study is motivated by three stylized facts based on the annual macroeconomic data for India: (i) TFP and IST shocks positively and negatively correlate with GDP growth rate respectively; (ii) the relative contribution of IST shocks to aggregate output fluctuations has risen during the post-liberalization era, and (iii) during the same post-reform period, the relative import content of consumption to investment goods underwent an upward shift. In light of these empirical regularities, the paper presents a small open economy DSGE model for India to connect these three empirical regularities. Regarding (i), the impulse response analysis based on our calibrated model explains the differential effects of TFP and IST shocks in driving the cyclical variation in output. It illustrates that a positive TFP shock promotes GDP by altering the external terms of trade in home country's favour while the opposite happens when a positive IST shock hits the economy. The differential effect arises fundamentally

[16] See equation of the real marginal cost (35). TFP (A_t) directly influences mc_t . The effect of IST comes via the rental price of capital r_{Kt} and the two Tobin's q equations (13) and (14).

due to the opposing effects of these two shocks on the real marginal cost of production. Regarding the stylized facts (ii) and (iii), the model sensitivity analysis predicts that the rising importance of IST shock in driving GDP fluctuations could be due to a combination of a rising import content in consumption and a greater nominal rigidity. Both these factors open up the terms of trade channel in magnifying the effect of IST shock on output. In addition, our model predicts that greater habit formation could also contribute to the effect of IST shock on output variation through the standard channel of real marginal cost although its effect is weak.

Our model can be extended in a number of directions. First, one can add 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 frictions along the lines of Gertler and Karadi (2011) can be added although we are not sure whether this kind of banking friction is too relevant for the Indian economy where the banking sector is heavily regulated. Fourth, distortionary taxation and public debt can be added to the model. These additional engines can strengthen the model validation against the data but it is unlikely to alter the main conclusion regarding the relative importance of IST and TFP shocks in driving the aggregate fluctuations.

Appendix

A Computing Shares of Import Content in Consumption and Investment

The import content in the aggregate consumption and investment are computed using the data of:

1. Imports of Principal Commodities provided by the RBI (Table 132 in Handbook of Statistics on the Indian Economy, 2013).

2. Private Consumption Expenditure and Gross Fixed Capital Formation provided by the National Accounts of Statistics.

All data are assembled in Rupees in Crores. We disaggregate the imported commodities between consumption goods and capital goods. Originally, the import data are provided into two major categories namely, bulk and non-bulk imports. Bulk imports incorporate petroleum products and consumption goods. Non-bulk imports consist of capital goods consisting of mainly export related items and other non-bulk items. We lump the bulk imports and other non-bulk items together to measure the aggregate imported consumption goods. Capital goods of the non-bulk imports proxy the imported investment goods.

Next, we take the ratio of nominal values of imported consumption goods to private consumption expenditure and imported investment goods to gross fixed capital formation for the period of 1991-2010. These ratios represent the shares of import content in consumption and investment respectively.

B Computing Values of λ_1 and λ_2

In our model, λ_1 and λ_2 denote the share of consumption and investment in GDP of the foreign economy respectively. For the purpose of calibration, we compute the values of these two parameters. We consider the household's consumption expenditure and gross capital formation as the percentage of GDP for almost all countries provided in the World Development Indicator data except India. The rest of the world comprising countries except India is considered as a closed economy which is consistent with the assumption that India is a small open economy vis-a-vis the rest of the world.

In sum, our sample includes 189 countries and we take the average of the percentage of household's consumption expenditure to GDP and gross capital formation to GDP. We find that on an average household's consumption occupies 67% and gross capital formation takes 24% of the GDP of the foreign economies. $\lambda_1$and λ_2 are thus fixed at 0.67 and 0.24 respectively in the baseline model.

C Measuring Price Stickiness for Indian Economy

We use the method of Indirect Estimation of Price Duration under Frequency Approach as in Kovanen (2006) and Lavín and Tejada (2008). The data are taken from the Office of Economic Adviser for the period of 2006M01 to 2010M12. The duration of price spell for each commodity is computed. We use unweighted average of price duration for the entire set of 389 commodities due to unavailability of weights of the respective commodities in the consumption basket. The method of Indirect Estimation of Price Duration under Frequency Approach is used to evaluate the probability of price change at the aggregate level for the Indian economy. The key advantage to use this methodology is that, it allows to estimate the stickiness of aggregate price even if the sample period is very short as long as the behavioral assumptions of stationary and homogeneity for the price changes in the cross section dimension are in place (Lavín and Tejada, 2008). We have described below the methodology in brief following Kovanen (2006) and Lavín and Tejada (2008).

Let us define an indicator function of price change $I_{i,t}$ such that: $I_{i,t} = 0$ if $P_t(i) = P_{t-1}(i)$ and $I_{i,t} = 1$ if $P_t(i) \neq P_{t-1}(i)$ for all $i = 1, ..., N$ and $t = 1, ..., T$.

We assume that all the firms, producing commodity i, are homogeneously distributed. Note that, in our sample, $N = 389$ and t traces through the period of 2006: M1 to 2010: M12.

Using indicator function, the average frequency of the price changes of commodity i $(F(i))$ is defined as:

$$F(i) = \frac{1}{T}\sum_{t=0}^{T}(I_{i,t}) \qquad \forall i = 1, ..., N \tag{C.1}$$

Next, the measure of the duration of the interval $(D(i))$, during which the aggregate price of the commodity basket remains unchanged (which is implicit in the evaluation of $F(i)$) is calculated as:

$$D(i) = -\left[\frac{1}{\ln\{1 - F(i)\}}\right] \qquad \forall i = 1, ..., N \tag{C.2}$$

In the third step, we compute the aggregate price duration by taking the unweighted average of $T(i)$ across all commodities included in the consumption basket. Due to unavailability of respective weights of 389 commodities included in the consumption basket, we have no other choice than to take the unweighted average.

$$D = \frac{1}{N}\sum_{i=1}^{N} D(i) \qquad \forall i = 1, ..., N \tag{C.3}$$

According to our sample, we obtain the duration of price spell for the aggregate commodity basket (T) as 2.64 months.

The value of D, within a year's time span one can expect to see the change of a particular price spell at the aggregate level with the probability of: $\left(\frac{2.64}{12}\right) = 0.22$.

Thus, in calibration we use the value of $\gamma_p = 0.22$.

D Steady State System

In this section all variables except nominal prices are without subscript. Note that all nominal prices are non-stationary which means ratio of two such prices is stationary. Note that the steady state system has a partial recursiveness property as far as relative prices are concerned if we invoke the long run Law of One Price (LOOP).[17]

$$\frac{P_{F,t}}{P_{H,t}} = 1 \tag{D.4}$$

Next, using (28) solve the relative price of investment as follows

$$\frac{P_{x,t}}{P_t} = 1 \tag{D.5}$$

which also implies

$$\frac{P_{H,t}}{P_t} = 1 \tag{D.6}$$

Using (D.5) and (13)

$$q = 1$$

which after substitution in (14) pins down the steady state real rental price of capital.

$$r_k = \frac{R_{k,t}}{P_t} = \left[\frac{1-\beta}{\beta} + \delta\right] \tag{D.7}$$

From (44),

$$MC = \frac{\varepsilon - 1}{\varepsilon}$$

and likewise from (47),

$$\frac{P^*_{H,t}\xi_t}{P_t} = \frac{\varepsilon^*}{\varepsilon^* - 1}\frac{\varepsilon - 1}{\varepsilon}.\frac{(1 - \beta\gamma_p \Pi^{*^{-\varepsilon^*}})}{((1 - \beta\gamma_p)} \tag{D.8}$$

Next note from (35) that

$$\frac{\varepsilon - 1}{\varepsilon} = \frac{1}{A}(R_{k,t}/P_t)^\alpha (W_t/P_t)^{1-\alpha}\alpha^{-\alpha}(1-\alpha)^{\alpha-1} \tag{D.9}$$

Given r_k from (D.7), one can solve w,

$$w = W_t/P_t = \left[\frac{\frac{\varepsilon-1}{\varepsilon}A\alpha^\alpha(1-\alpha)^{1-\alpha}}{r_k^\alpha}\right]^{1/(1-\alpha)} \tag{D.10}$$

Once w and r_k are determined, using the cost minimization condition (33), the optimal $K : L$ ratio can

[17] As in Benigno (2009), to invoke the LOOP we need to assume that both home and foreign countries consume the same commodity basket. which means $\nu = 1 - \nu^*$.

be determined as follows:

$$L = BK \tag{D.11}$$

where $B = [(\alpha/(1-\alpha))(w/r_k)]^{-1}$.

Next, we use (5) to determine the steady state investment,

$$X = \delta K \tag{D.12}$$

Further, using (7) and (8) we can get the following static efficiency condition,

$$L^{\sigma_L} C^{\sigma_c} = w(1-\gamma_c)^{-\sigma_c}$$

Since $\sigma_L = 0$ and $\sigma_c = 1$ in our utility function, we can derive the following consumption function in the steady state:

$$C = \frac{w}{(1-\gamma_c)} \tag{D.13}$$

Next, note from the market clearing condition (49) and the production function (32), we get,

$$Y_H + Y_H^* = AK^{\alpha} L^{1-\alpha}$$

Plugging (D.11)) into above

$$\begin{aligned} Y_H + Y_H^* &= A^* K \\ \text{where } A^* &= AB^{1-\alpha} \end{aligned}$$

From (39) and noting that in the steady state the real exchange rate, $rx = 1$, one gets the following steady state foreign demand:

$$Y_H^* = \lambda_1 \nu^* \left(\frac{\xi_t P_{H,t}^*}{P_t} \right)^{-\theta^*} + \lambda_2 \varphi^* \left(\frac{\xi_t P_{H,t}^*}{P_t} \right)^{-\tau^*} \tag{D.14}$$

where $\frac{\xi_t P_{H,t}^*}{P_t}$ is given by (D.8).

Given (D.6) and (D.12), note from (38) that

$$Y_H = vC + \varphi \delta K \tag{D.15}$$

=>

$$vC + \varphi \delta K = A^* K - Y_H^*$$

Plugging (D.13), into above solves

$$K = \frac{v\frac{w}{(1-\gamma_c)} + Y_H^*}{[A^* - \varphi\delta]} \tag{D.16}$$

which after plugging into (D.11) yields L.

Next, we need to solve G. From the national income identity (54), we obtain:

$$C + X + G + (\xi_t P_{H,t}^* / P_{H,t}) Y_H^* - Y_F = AK^\alpha L^{1-\alpha} \tag{D.17}$$

Using (D.8) as the steady state solution for $\frac{\xi_t P_{H,t}^*}{P_t}$, we rewrite (54) as:

$$C + X + G + \left(\frac{\xi_t P_{H,t}^*}{P_t}\right) Y_H^* - Y_F = A^* K \tag{D.18}$$

Plugging the steady state import demand function, $Y_F = (1-\nu)C + (1-\varphi)X$, the steady state export demand function (D.14), the steady state replacement investment (D.12) , the steady state capital stock (D.16) and consumption (D.13) into (D.18), one could solve for the steady state government spending (G).

Finally, we solve the steady state foreign bond holding. Since B_{Ft} is denominated in foreign currency, the real bond holding b_{ft} is defined as $\xi_t B_{Ft}/P_t$. Using (51) and the fact that the steady state bond holding spread $\Theta(b_f) = 1$, to get:

$$b_f \left[\frac{1}{1+i^*} - \frac{\triangle\xi}{1+\pi}\right] = \left(\frac{\xi_t P_{H,t}^*}{P_t}\right) Y_H^* - Y_F \tag{D.19}$$

where $\triangle\xi = \xi_t/\xi_{t-1}$

Using steady state UIP condition, $(1+i) = (1+i^*)\triangle\xi$ and the Fisher's relation based on (11) that $1+i = (1+\pi^{t\arg et})/\beta$,

$$b_f = \frac{1+\pi^*}{(1-\beta)}\left[Y_F - \left(\frac{\xi_t P_{H,t}^*}{P_t}\right) Y_H^*\right] \tag{D.20}$$

Finally, the foreign inflation and interest rate are given by,

$$\pi^* = \pi^{*target} \tag{D.21}$$

$$i_t^* = i^* \tag{D.22}$$

The long run relative PPP means

$$\triangle\xi_t = \pi^{target} - \pi^{*target}$$

The remaining two technology shocks are fixed at the respective steady states,

$$A_t = A,\ Z_t^x = Z^x. \tag{D.23}$$

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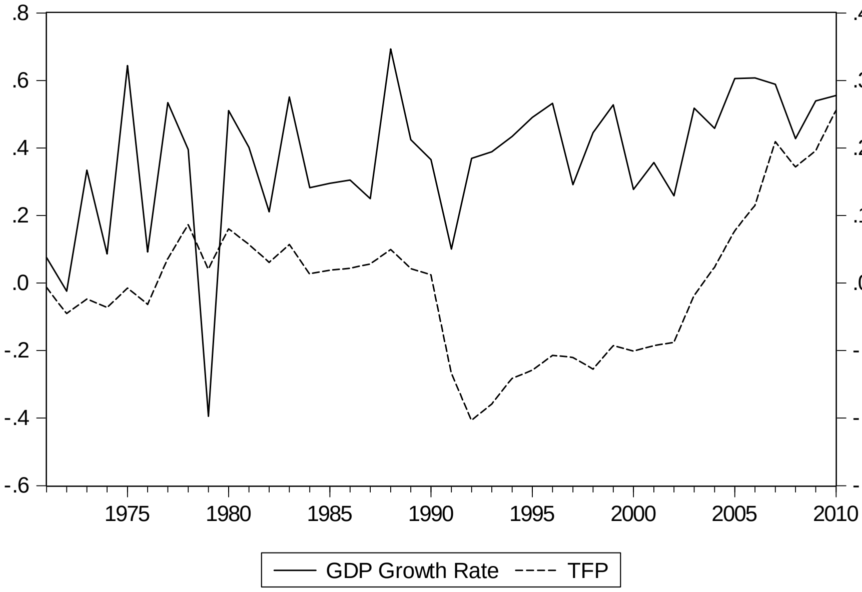

Figure 1: Estimated TFP against GDP Growth rate

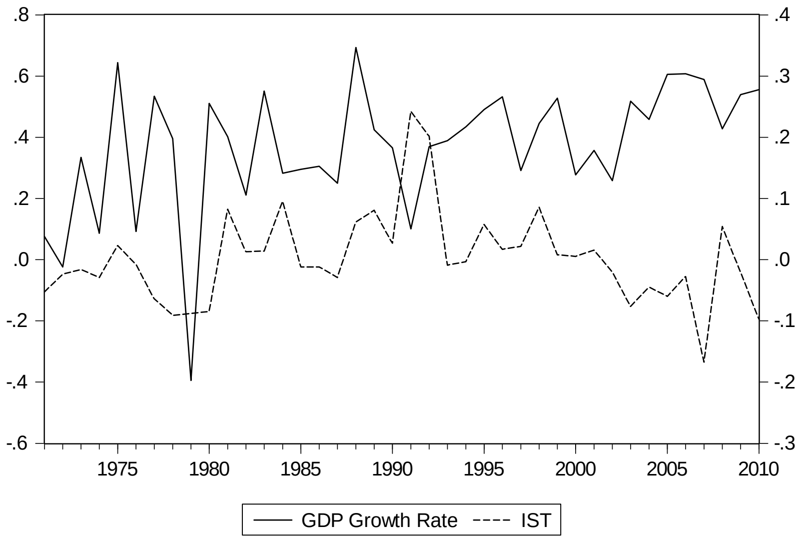

Figure 2: Estimated IST against GDP Growth rate

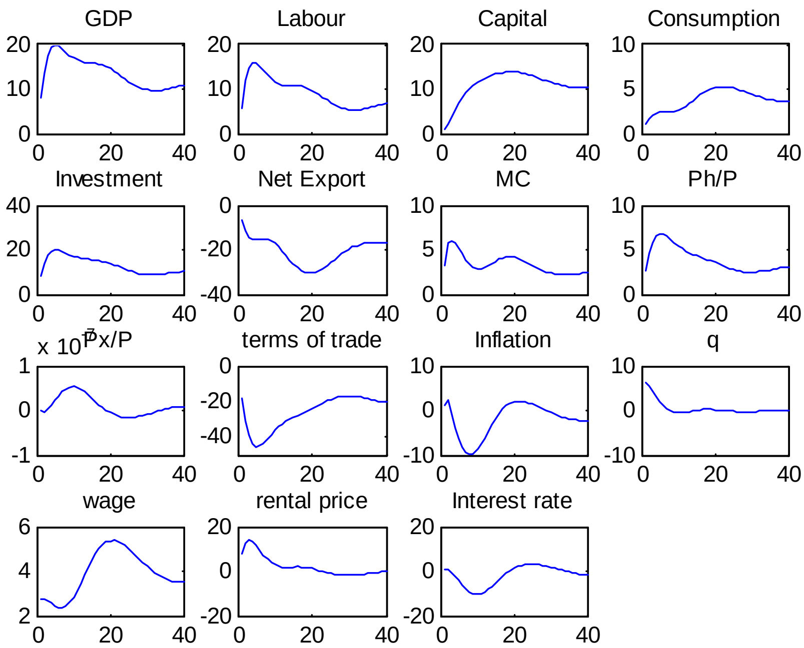

Figure 3: Impulse response to 1% std shock to TFP

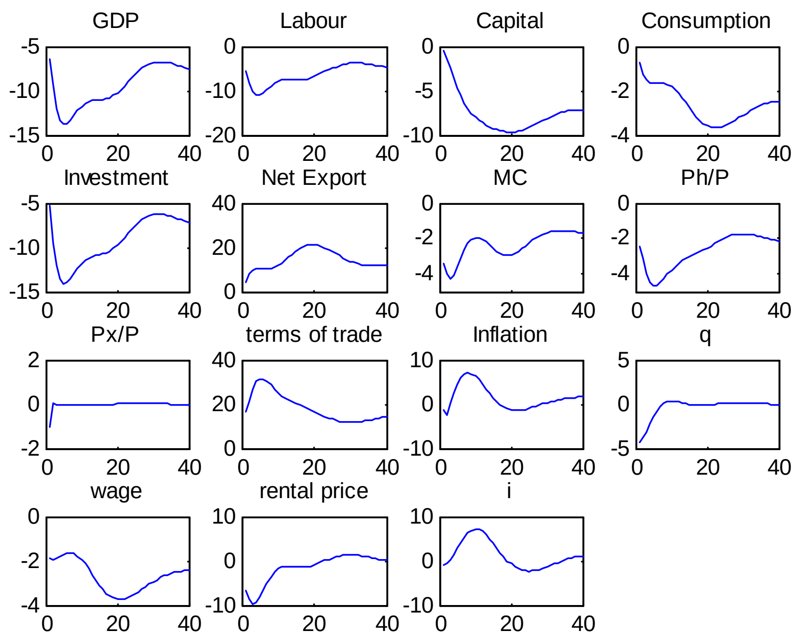

Figure 4: Impulse response to 1% std shock to IST

Table 1: Correlations of GDP growth with TFP and IST

Without Any Filter		
Sample Period	TFP	IST
1971-2010	0.27*	-0.04
1991-2010	0.57***	-0.64***
HP Filtered Series		
Sample Period	TFP	IST
1971-2010	0.40***	-0.064
1991-2010	0.46**	-0.51**
Asymmetric CF Filtered Series		
Sample Period	TFP	IST
1971-2010	0.59***	-0.05
1991-2010	0.37	-0.39*

Table 2: Relative Volatility of IST Shock over TFP Shock

Relative Volatility	1970-2010	1970-1990	1991-2010
(*std.dev* of IST / *std.dev* of TFP) - HP Filtered	1.59	1.35	1.81
(*std.dev* of IST / *std.dev* of TFP) - CF Filtered	2	1.5	3

Table 3: Relative Importance of IST to TFP Shock: Using Variance Decomposition Results with Cyclical GDP

	Cholesky Ordering is: TFP IST Y		Cholesky Ordering is: IST TFP Y	
Periods	1971-2010	1991-2010	1971-2010	1991-2010
1	0.905	2.515	0.001	0.076
2	0.897	2.595	0.003	0.127
3	0.928	3.151	0.006	0.123
4	0.929	3.148	0.054	0.128
5	0.937	3.156	0.059	0.129
6	0.916	3.145	0.080	0.130
7	0.924	3.127	0.087	0.133
8	0.922	3.105	0.087	0.134
9	0.921	3.094	0.087	0.135
10	0.923	3.093	0.088	0.135

Table 4: Relative Importance of IST to TFP Shock: Using Variance Decomposition Results with First Differenced GDP

	Cholesky Ordering is: TFP IST Y		Cholesky Ordering is: IST TFP Y	
Periods	1971-2010	1991-2010	1971-2010	1991-2010
1	0.681	2.335	0.034	0.000
2	0.479	1.504	0.031	0.339
3	0.480	1.547	0.032	0.345
4	0.477	1.719	0.032	0.349
5	0.473	1.778	0.032	0.350
6	0.473	1.762	0.032	0.352
7	0.474	1.785	0.032	0.353
8	0.474	1.773	0.032	0.363
9	0.473	1.773	0.033	0.363
10	0.473	1.773	0.033	0.361

Table 5: Relative Importance of IST to TFP Shock: Using Variance Decomposition Results from VECM Analysis

	Cholesky Ordering is: TFP IST Y		Cholesky Ordering is: IST TFP Y	
Periods	1971-2010	1991-2010	1971-2010	1991-2010
1	0.953	1.382	0.010	0.048
2	0.955	2.487	0.010	0.014
3	1.027	1.956	0.007	0.024
4	0.960	1.594	0.011	0.042
5	0.878	1.325	0.017	0.064
6	0.808	1.197	0.024	0.078
7	0.752	1.072	0.031	0.098
8	0.707	0.992	0.037	0.113
9	0.675	0.937	0.042	0.124
10	0.650	0.902	0.045	0.131

Table 6: Rising Trend of Relative Share of Import Content in Consumption to Investment

Year	Share of Import Content		Relative Share of Import Content
	Consumption	Investment	in Consumption to Investment
1991-1995	0.041	0.083	0.49
1996-2000	0.078	0.104	0.75
2001-2005	0.136	0.142	0.96
2006-2010	0.302	0.253	1.19

Table 7: Baseline Parameterization

β	γ_p	ε	ε^*	θ	ν	φ	τ	γ_c	α
0.98	0.22	6	6	2	0.85	0.85	2	0.6	0.3
Π	Π^*	δ	$S"(1)$	ϕ_i	ϕ_π	ϕ_y	$\Theta'(\bar{b}_f).\bar{c}$	λ_1	λ_2
1.04	1.02	0.1	2.5	0.81	1.64	0.5	0.001	0.67	0.24

Table 8: Baseline Result of Variance Decomposition of GDP (in percent)

Baseline Result	A	Z_x	i	g	i^*
Y_t	63.54	30.13	4.80	0.62	0.91

Table 9: Variance Decomposition of GDP with respect to Home Bias in Consumption (in percent)

Home Bias in Consumption	A	Z_x	i	g	i^*
$\nu = 0.85$	63.54	30.13	4.80	0.62	0.91
$\nu = 0.80$	53.58	42.04	3.07	0.58	0.73
$\nu = 0.75$	45.98	50.84	2.06	0.52	0.60
$\nu = 0.70$	40.29	57.34	1.43	0.46	0.49
$\nu = 0.65$	35.89	62.30	1.02	0.38	0.41

Table 10: Variance Decomposition of GDP with respect to Home Bias in Investment (in percent)

Home Bias in Investment	A	Z_x	i	g	i^*
$\varphi = 0.85$	63.54	30.13	4.80	0.62	0.91
$\varphi = 0.80$	71.15	22.28	4.88	0.68	1.01
$\varphi = 0.75$	76.52	16.94	4.72	0.75	1.07
$\varphi = 0.70$	80.35	13.28	4.43	0.83	1.11
$\varphi = 0.65$	82.74	10.87	4.32	0.95	1.12

Table 11: Variance Decomposition of GDP with respect to Price Stickiness (in percent)

Nominal Friction	A	Z_x	i	g	i^*
$\gamma_p = 0.22$	63.54	30.13	4.80	0.62	0.91
$\gamma_p = 0.27$	53.57	35.55	8.82	0.56	1.49
$\gamma_p = 0.32$	42.84	40.34	14.12	0.48	2.21
$\gamma_p = 0.37$	32.33	43.92	20.36	0.40	3.00
$\gamma_p = 0.42$	22.96	45.95	26.99	0.31	3.78

Table 12: Variance Decomposition of GDP with respect to Habit Formation (in percent)

Habit Formation	A	Z_x	i	g	i^*
$\gamma_c = 0.60$	63.54	30.13	4.80	0.62	0.91
$\gamma_c = 0.65$	62.23	31.72	4.44	0.72	0.89
$\gamma_c = 0.70$	60.33	34.01	3.92	0.87	0.87
$\gamma_c = 0.75$	57.11	37.25	3.68	1.13	0.83

Table 13: Variance Decomposition of GDP with respect to Adjustment Cost (in percent)

Adjustment Cost	A	Z_x	i	g	i^*
$s''(1) = 2.5$	63.54	30.13	4.80	0.62	0.91
$s''(1) = 3.0$	63.23	30.52	4.72	0.63	0.90
$s''(1) = 3.5$	63.00	30.79	4.67	0.64	0.90
$s''(1) = 4.0$	62.84	30.98	4.63	0.65	0.90
$s''(1) = 4.5$	62.70	31.14	4.61	0.66	0.90

Table 14: Variance Decomposition of GDP with respect to Transaction Cost of Bond Holding (in percent)

Bond holding cost $(\Theta'(\bar{b}_f)\bar{c})$	A	Z_x	i	g	i^*
0.001	63.54	30.13	4.80	0.62	0.91
0.002	63.46	30.28	4.74	0.62	0.90
0.003	63.36	30.42	4.71	0.63	0.88
0.004	63.24	30.56	4.70	0.63	0.87
0.005	63.12	30.70	4.70	0.63	0.85

Table 15: Relative Importance of IST Shock to TFP Shock for Alternative Values of Consumption Home Bias and Price Stickiness

ω^{IST} ↘	$\nu = 0.85$	$\nu = 0.80$	$\nu = 0.75$	$\nu = 0.70$	$\nu = 0.65$
$\gamma_p = 0.22$	0.47	0.78	1.10	1.42	1.75
$\gamma_p = 0.27$	0.66	1.06	1.46	1.84	2.19
$\gamma_p = 0.32$	0.94	1.47	1.99	2.46	2.89
$\gamma_p = 0.37$	1.35	2.08	2.77	3.39	3.92
$\gamma_p = 0.42$	2.00	3.01	4.01	4.78	5.46