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Asymmetry, Terms of Trade and the Aggregate Supply Curve in an Open Economy Model

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Abstract

We find a basic new Keynesian monetary policy DSGE model estimated for differing countries (India and the US) gives deep parameter estimates, impulse responses and forecast error variance decompositions for each in line with theory and country structure, implying similar functional forms can be estimated for different countries with estimated coefficients capturing differences in structure. Features that create excess volatility, especially in emerging markets, explain differences in policy shocks. The feature explored in this paper is external terms of trade. When this is dampened in the emerging market, using policy tools other than the policy rate, the aggregate supply curve, which was relatively steeper, becomes flatter. As a result, volatility of interest rates and their impact on output and inflation, which was relatively higher in India, becomes lower than in the US. Asymmetries between the countries are reversed. The estimated coefficient of the terms of trade is relatively higher in the US Taylor rule. It follows emerging market central banks need policy tools in addition to interest rates to affect volatility creating variables like external terms of trade.

Keywords: DSGE; India; US; Asymmetry; Open Economy Model; Terms of Trade; Aggregate Supply Curve

JEL Code: E32; F41; F44

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1 Introduction

After the initial Dynamic Stochastic General Equilibrium (DSGE) models that sought to replicate business cycles from technology and preference shocks, New Keynesian DSGEs brought in additional frictions to better explain the data series. Initial models were calibrated to replicate the data, but later models had a mix of calibration and estimation and began to be applied to study specific economies and time periods.

Ireland (2004) brought in price markup, interest rate and preference shock (shock to discount factor) in addition to technology shocks. Smets and Wouters (2007) extended the model by bringing capital and addition frictions such as wage markup shock, relative price of investment shock and government expenditure shock. Models became larger. But a model need not be large in size to capture relevant aspects. DSGE models have a modular structure and only parts necessary for the key question, friction or country studied need to be included. Calibration or estimation can capture aspects of structure in a simpler functional form. For example, the output in the new Keynesian model is demand determined and it works through real interest rate channel. The intertemporal elasticity of substitution is the important parameter and as long this is calibrated or estimate accounting for investment, a smaller model without investment is adequate, Woodford (2003, pages 243 and 352). Large models sometimes bring in realism at the cost of the theoretical clarity that is the strength of DSGE models.

New Keynesian models were also extended for open economies and two types of models emerged out of this literature. The first one is two country new Keynesian models. These models have detailed description of the two countries being considered and are usually closed using balance of payment conditions, Gregory et al. (2005). The model is estimated using data from two countries and variables from both countries are treated as endogenous. These models are applied for modeling two similar and connected countries. The second is a small open economy new Keynesian model which can be traced to Mendozaâs (1991) real business cycle model for small open economies. Gali and Monacelli (2005) is a seminal paper in this literature. The model is estimated using data from the concerned country and assuming exogenous processes for the world variables.

It is often argued that specific structural aspects and frictions relevant to a country must be included in a DSGE model that aims to study a country. Thus a number of models were built for emerging and developing economies with structural features such as credit and labour market frictions[1]. Our innovation in this paper is to show that a minimal small open DSGE, to analyze monetary policy and internal and external price shocks, gives valid coefficient estimates for both an EM and an AE. Essential structural features such as labour market dualism and credit market imperfections are included, but reduce to differences in the coefficients of the forward-looking aggregate demand and supply functions that are estimated in this paper.

Ireland (2011) estimated a simple New Keynesian (NK) DSGE model, using output, inflation and interest rate data, to investigate the dominant shocks causing the US slowdown after the global financial crisis. Goyal and Kumar (2018, 2020) estimated the same model for India also and found interesting differences in shocks and responses to shocks in the two countries. They hypothesized that this could be due to differences in country structure captured by the data.

The justification for estimating the same model in two very different countries came from Goyal (2011) who had introduced dual economy features such as distinguishing between well-off (R) and subsistence (P) households in the small open economy DSGE of Gali and Monacelli (2005) (henceforth GM). Goyal (2011) showed theoretically that as the share of the well-off approached unity the coefficients of micro-founded aggregate demand (AD) and aggregate supply (AS) curves for a small open emerging market (SOEME), derived from the underlying DSGE, converged to those for the advanced economy (SOE). This implied that the same functional forms could be estimated for structurally different countries and the differences would show up in the coefficient estimates. The NK approach reduces the optimal monetary policy problem to optimizing a Taylor Rule subject

[1]An example of an early model is Peiris and Saxegaard, 2007, a more recent one is Banerjee and Basu, 2019.

to micro-foundation based AD and AS curves that incorporate forward-looking behavior.

In this paper we have two objectives. First, to estimate the deep structural parameters for India (an emerging economy) and for the US (an advanced economy) in the AD and AS derived from GM in Goyal (2011). If differences between estimated coefficients for the two countries are consistent with structure and theory, it would imply the same model could indeed be used to make systematic comparisons between countries at different levels of development. Second, to extract insights on asymmetries in structure and policy from the comparative shocks, responses to shocks as well as estimations.

In populous emerging economies one would expect to have a flatter supply curve in comparison to advanced economies because there are a large number of subsistence workers with a high elasticity of labor supply. Their inability to save and high credit risk implies a significant number of households cannot participate in financial markets to smooth consumption. They are therefore forced to supply more labour to maintain consumption under adverse shocks. Goyal (2011) showed that despite this more elastic labour supply the theoretically derived supply curve was steeper in emerging economies. The reason was incomplete financial markets, which limited risk-sharing, made the endogenously determined real external terms of trade more volatile in the emerging economy. Therefore its aggregate supply curve (AS) was steeper despite the higher elasticity of labour supply.

If, however, the terms of trade was made exogenous and relatively fixed, through some policy process, the AS became flatter in the emerging economy. This was a theoretical prediction for asymmetry in aggregate supply curves of a SOEME in comparison to an advanced small open economy. In this paper we test it through Bayesian estimation with both endogenous and exogenous terms of trade.

A number of variants of the model are estimated for robustness and to take care of data issues. Estimated parameters are in line with theory and country structure. For example, the consumption share of the rich is always higher in the US as expected. Since habit persistence and preference shocks (shocks to inter-temporal discount factor) included in Ireland (2011) are missing in the GM model, the dominant shocks now are mark-up and interest rate[2]. The relatively higher volatility of interest rate and mark-up shocks in India compared to the US observed in Goyal and Kumar (2020) is obtained here as well. Mark-up shocks explain relatively more of inflation and interest rate shocks explain relatively less of output variance in India compared to the US. Yet the policy interest rate shock variance is higher in India.

As predicted in Goyal (2011) the AS is relatively flatter in the US when external terms of trade are endogenous, despite a higher elasticity of labour supply in India. When, however, the terms of trade are exogenously fixed as a policy target, the Indian AS becomes relatively flatter. The excessive Indian policy rate response also disappears. The response of US inflation and output to the interest rate becomes greater than that of India, especially when terms of trade enter the Taylor rule. In the latter case, the policy rate also responds to the terms of trade. The US interest rate then responds relatively more to the terms of trade compared to India. As a result, the share of output due to the interest rate rises relatively for India and the share of output and inflation variance explained by the terms of trade becomes minimal for both since its volatility reduces.

It follows additional policy instruments that reduce volatility in external terms of trade can remove excess variation in emerging market policy rates. The argument may also apply to other sources of volatility. Emerging markets face volatility from many sources and therefore especially need more instruments to moderate key sources of volatility.

The structure of the paper is as follows: Section 2 presents the models estimated. Section 3 gives data details and stylized facts. Section 4 discusses the estimation strategy before section 5 gives results and section 6 concludes.

[2]Waheed and Rashid (2021)in an optimal monetary policy DSGE find the dominant sources of changes in output, inflation and interest rate are supply shocks and credit market imperfections.

2 Model

2.1 Baseline

The AD curve as derived in Goyal (2011) after including dualism in GM is (variables in small case letters, except interest rates, are in logarithms):

$$x_t = E_t\left(x_{t+1}\right) - \frac{1}{\sigma_D}\left(r_t - E_t\pi_{H,t+1} - rr_t\right) \tag{1}$$

Where x_t is output gap, r_t is nominal interest rate, $\pi_{H,t}$ is domestic inflation and rr_t is natural rate of interest.

$$rr_t = \rho - \sigma_D(1-\rho_a)\Gamma a_t + \sigma_D(\Theta - \Psi)E_t\left(\Delta y^*_{t+1}\right) - \sigma_D(1-\eta+\Phi)E_t\Delta cp_{t+1} \tag{2}$$

Where Δy^*_{t+1} is the growth rate of the foreign economy (world economy), a_t is technology shock and Δcp_{t+1} is growth of consumption of below subsistence population. A positive technology shock increases supply and decreases the natural rate of interest. We assume an exogenous process for growth rate of world economy and growth of consumption of below subsistence population. Positive shock to world growth increases demand and natural rate of interest. An adverse shock to consumption growth of below subsistence population is a negative demand shock as well as a positive supply shock as the willingness to supply labour increases. Therefore, it decreases the natural rate of interest. The AS curve is given by:

$$\pi_{H,t} = \beta\pi_{H,t+1} + \kappa_n x_t + \epsilon_{\theta,t} \tag{3}$$

Where $\epsilon_{\theta,t}$ is a mark-up shock.

Deep model parameters that enter the derived AD, AS coefficents, are:

Table 1: Parameter Description

Parameter	Description
θ	Probability of price change
σ_R	Inverse of inter-temporal elasticity of substitution of rich
σ_P	Inverse of inter-temporal elasticity of substitution of poor
β	Discount factor
η	Share of rich
ϕ_P	Inverse of Frisch elasticity of labour supply of poor
ϕ_R	Inverse of Frisch elasticity of labour supply of rich
α	Openess

Other parameters derived from the above include:

$$\rho = \beta^{-1} - 1 \quad \omega = \sigma_R + (1-\alpha)(\sigma_R - 1) \quad \sigma = \frac{1}{\frac{\eta}{\sigma_R} + \frac{1-\eta}{\sigma_P}}$$

$$\Theta = \alpha(\omega - \eta) \quad d = \frac{1}{\sigma_D + \phi} \quad \Gamma = \frac{1+\phi}{\sigma_D + \phi} \quad \Psi = \eta * (\sigma - \sigma_D)d$$

$$\sigma_D = \frac{\sigma_R}{\eta(1-\alpha) + \omega\alpha} \quad \phi = \eta\phi_R + (1-\eta)\phi_P \quad \Phi = \frac{(1-\eta)(\sigma - \sigma_D)}{\sigma_D + \phi}$$

$$\lambda = (1-\beta\theta)(1-\theta)/\theta \quad \kappa_n = \lambda\left(\sigma_D + \phi\right)$$

Technological progress is exogenous and is given by:

$$a_t = \rho_a a_{t-1} + \epsilon_{at} \tag{4}$$

Foreign output growth is exogenous and is given by:

$$\Delta y_t^* = \rho_{y^*} \Delta y_{t-1}^* + \epsilon_{y^*t} \tag{5}$$

Consumption growth for below subsistence labour is exogenous and is given by:

$$\Delta cp_t = \rho_{cp} \Delta cp_{t-1} + \epsilon_{cp,t} \tag{6}$$

The steady-state natural interest rate, ρ, is the equilibrium real rate, consistent with a target rate of inflation, when prices are fully flexible. Shocks that change ρ open an output gap and affect inflation. Shocks in (2) therefore cause a deviation of the natural rate from its steady-state value. These are real disturbances that change natural output. Optimal policy requires insulating the output gap from these shocks. The central bank should, therefore, accommodate positive supply shocks that raise the natural output by lowering interest rates and offset positive demand shocks that raise output above its potential by raising interest rates. The policy rate rises for a temporary demand shock and falls for a temporary supply shock. Dualism adds a reduction in cp as an additional shock requiring reduction in the policy rate, since it increases the distance from the world consumption level.

We cannot use equations 1 and 2 alone for estimation as we do not have reliable data on domestic inflation, $\pi_{H,t}$, in India. But domestic and consumer inflation are related through the external terms of trade S_t, defined as the price of foreign goods in terms of home goods:

$$\pi_t = \pi_{H,t} + \alpha \Delta s_t \tag{7}$$

Terms of trade and real exchange rate, defined as the weighted average of the ratio of two countries' consumer price indices, both in domestic currency, are related. Assuming purchasing parity holds, the price of foreign goods equals the nominal exchange rate multiplied by the world price index. Using that we can find a relation for terms of trade as a function of the real exchange rate:

$$q_t = (1-\alpha)s_t \implies \Delta q_t = (1-\alpha)\Delta s_t$$

Substituting for Δs_t in (7) gives:

$$\pi_t = \pi_{H,t} + \frac{\alpha}{(1-\alpha)} \Delta q_t \tag{8}$$

In our estimation we use two measures of $\pi_{H,t}$. First, we use (8) to back out domestic inflation using the consumer price inflation and change in real effective exchange rate in each of the two countries. For some estimations, we assume an exogenous process for change in real exchange rate. Second, we use wholesale price index (WPI) and producer price index (PPI) inflation to measure of $\pi_{H,t}$ in case of India and US respectively. India does not have a PPI series and WPI is the closest approximation to domestic inflation.

$$\Delta q_t = \rho_s \Delta q_{t-1} + \epsilon_{q,t} \tag{9}$$

In backing out domestic inflation (9) is not required and the data on real exchange rate is used in (8).

The model is closed using a Taylor rule where the central bank responds to consumer inflation and output gap. In our benchmark case of consumer inflation targeting:

$$r_t = \rho_r r_{t-1} + \rho_\pi \pi_t + \rho_x x_t + \epsilon_{r,t} \tag{10}$$

For robustness we also have estimations where we replace π_t with $\pi_{H,t}$ in the Taylor rule. That is, the central bank responds to domestic, not consumer inflation. This can also be obtained by substituting (8) in (10). But then it would imply the restriction $\rho_q = \rho_\pi \frac{\alpha}{(1-\alpha)}$. Targeting consumer inflation implies implicitly targeting domestic inflation as well as the real exchange rate as in the rule (10') below. When we use (10'), however, we do not impose the restriction $\rho_q = \rho_\pi \frac{\alpha}{(1-\alpha)}$ and estimate ρ_q, so it implies the central bank is independently targeting both domestic inflation and the real exchange rate and decides the weight it wants to give to the change in the real exchange rate. So the rule (10') is different from (10).

$$r_t = \rho_r r_{t-1} + \rho_\pi \pi_{H,t} + \rho_x x_t + \rho_q \Delta q_t + \epsilon_{r,t} \tag{10'}$$

A third Taylor rule estimated is (10'') when the central bank responds only to domestic inflation and the output gap.

$$r_t = \rho_r r_{t-1} + \rho_\pi \pi_{H,t} + \rho_x x_t + \epsilon_{r,t} \tag{10''}$$

The lagged interest rate enters the Taylor rules to allow for interest rate persistence in setting interest rates.

2.2 Exogenous terms of trade

A second version of the model we estimate uses the AD curve as derived in Goyal (2011) under the assumption that the terms of trade is fixed exogenously by a policy process. Higher volatility of the terms of trade in thin emerging markets make macro-prudential measures or intervention in foreign exchange necessary. Such intervention is common in emerging markets. Then in deriving the deep AD, AS parameters the steady-state terms of trade are not substituted out as they are in deriving (1) and (3). The coefficients therefore differ in AD (1') and AS (3') as below:

$$x_t = E_t\left(x_{t+1}\right) - \frac{1}{\sigma'_D}\left(r_t - E_t\pi_{H,t+1} - rr_t\right) \tag{1'}$$

$$\pi_{H,t} = \beta\pi_{H,t+1} + \kappa'_n x_t + \epsilon_{\theta,t} \tag{3'}$$

The steady-state terms of trade themselves are different in a SOEME compared to a SOE. In a SOE, purchasing power parity is assumed to hold making the value unity. In a SOEME the real exchange rate is more depreciated. The terms of trade, derived from aggregate demand equal to supply market-clearing, is shown to depreciate with a rise in Y_t (or domestic supply) and appreciate with a rise in Y_t* in GM. In a SOEME, however, c_p enters the denominator and σ_D multiplies the numerator, because of constrained risk-sharing (see Goyal (2011), making the terms of trade more volatile.

The natural rate of interest now contains terms of trade and is given by:

$$rr_t = \rho - \sigma'_D(1-\rho_a)\Gamma' a_t - \sigma'_D\Psi' E_t\Delta y^*_{t+1} - \sigma'_D(1-\eta+\Phi')E_t\Delta cp_{t+1} - \sigma'_D\left(\Lambda + \$\right)E_t\Delta s_{t+1} \tag{11}$$

Which can be written using $\Delta q_t = (1-\alpha)\Delta s_t$ as:

$$rr_t = \rho - \sigma'_D(1-\rho_a)\Gamma' a_t - \sigma'_D \Psi' E_t \Delta y^*_{t+1} - \sigma'_D(1-\eta+\Phi')E_t\Delta cp_{t+1} - \frac{\sigma'_D\left(\Lambda + \$\right)}{1-\alpha} E_t \Delta q_{t+1} \tag{12}$$

Where Δy^*_{t+1} is the growth rate of the foreign economy (world economy); a_t is the technology shock Δcp_{t+1} is consumption growth of below subsistence population and Δq_{t+1} is the change in real exchange rate.

A positive technology shock decreases natural rate of interest as before. We assume exogenous processes for growth rate of the world economy (equation 5), growth of consumption of below subsistence population (equation 6) and change in real exchange rate (equation 9).

In this model, a rise in world income unambiguously lowers the natural rate, unlike in (2) where it depended on which of the effect on increased demand for domestic output or appreciation of the terms of trade induced by a rise in world income was stronger. An expected depreciation in the terms of trade raises while an expected appreciation lowers the natural rate. An expected appreciation of the real exchange rate implies that exports have become less competitive and thus policy rates should fall to raise actual output to potential output. An expected adverse shock to consumption growth of below subsistence population decreases the natural rate of interest.

Other deep model parameters are given by:

$$\frac{1}{\sigma'_D} = \frac{\eta}{\sigma_R} \quad \Lambda = \frac{\alpha\left(\omega - \eta\right)}{\sigma_R} \quad \$ = \frac{\left(\sigma\eta(1-\alpha) + \alpha\sigma_R\right)}{\sigma_R \phi}$$

$$\Gamma' = \frac{1+\phi}{\phi} \quad \Psi' = \frac{\sigma\eta}{\phi} \quad \Phi' = \frac{\sigma(1-\eta)}{\phi}$$

Other model equations remain as in the section above.

2.3 Estimated Models

To establish robustness in estimation of deep parameters and examine issues related to the terms of trade 3 models are estimated.

The benchmark model with consumer inflation in the Taylor rule is estimated using (1), (2), (3),(4), (5), (6), (8), (9) and (10). Since the model is estimated with demeaned inflation, interest rate ρ does not appear in the natural rate expression and the Taylor rule is in deviation form without any constant.

In this model,the real exchange rate shock in equation (9) is calibrated to zero. This effectively implies that terms of trade remain constant so that domestic inflation and consumer inflation differ by a constant. We need equation (9) for estimation as the real exchange rate, which converts consumer price inflation into the domestic inflation required in equations (1) and (3). Equation (8) gives the conversion.

A second model is estimated using (1), (2), (3), (4), (5), (6) and (10'') with domestic inflation in the Taylor rule. This model does not contain a terms of trade shock. To compensate for poor data, estimations are done with two measures of domestic inflation. One with wholesale and producer price index in India and US respectively and another one with domestic inflation obtained using equation (8). Since we know consumer inflation (π_t), change of exchange rate (Δq_t) and openness (α), we can obtain domestic inflation using equation (8). We call this backed out domestic inflation.

The third model with exogenous terms of trade is estimated with (1'), (12), (3'), (4), (5), (6), (9) and (10').

3 Data

We use quarterly gross domestic product, consumer price inflation, wholesale price inflation, real effective exchange rate and 15-91 days treasury bill rate for India. In case of

US we use gross domestic product, consumer price inflation, producer price inflation, real effective exchange rate and 3 month treasury bill rate. The data covers the period 1996 Q3 to 2018 Q2. The output gap is estimated using a one sided HP filter. This optimises the trend at the given time point and does not use the entire sample as in the HP filter. It is better suited for New Keynesian models, because it realistically calculates the trend at a point in time using information available till then only. In real time this is what is available for decision making.

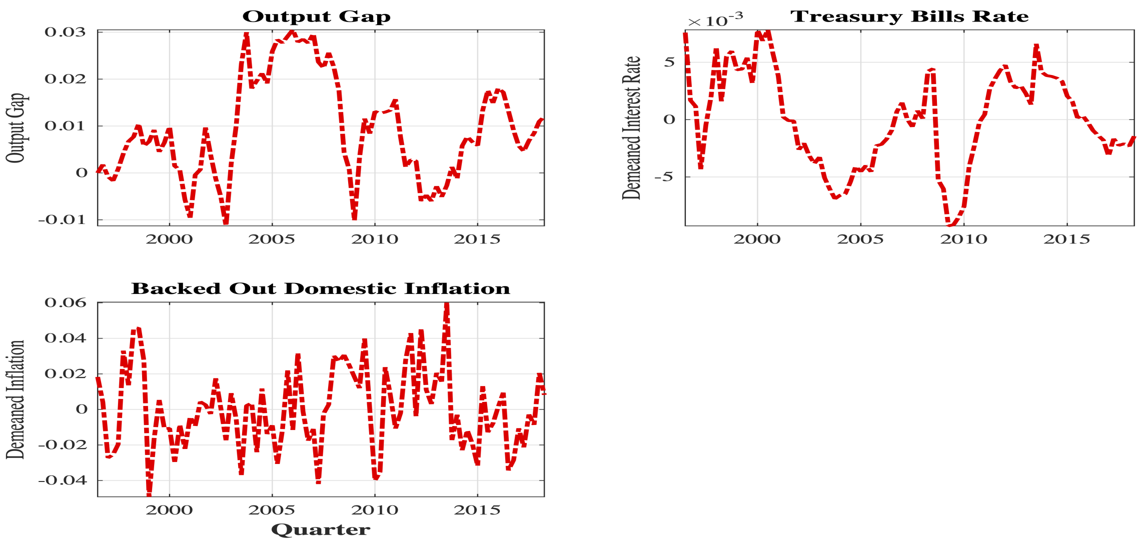

Figure 1: Data Series Used in Estimation: India

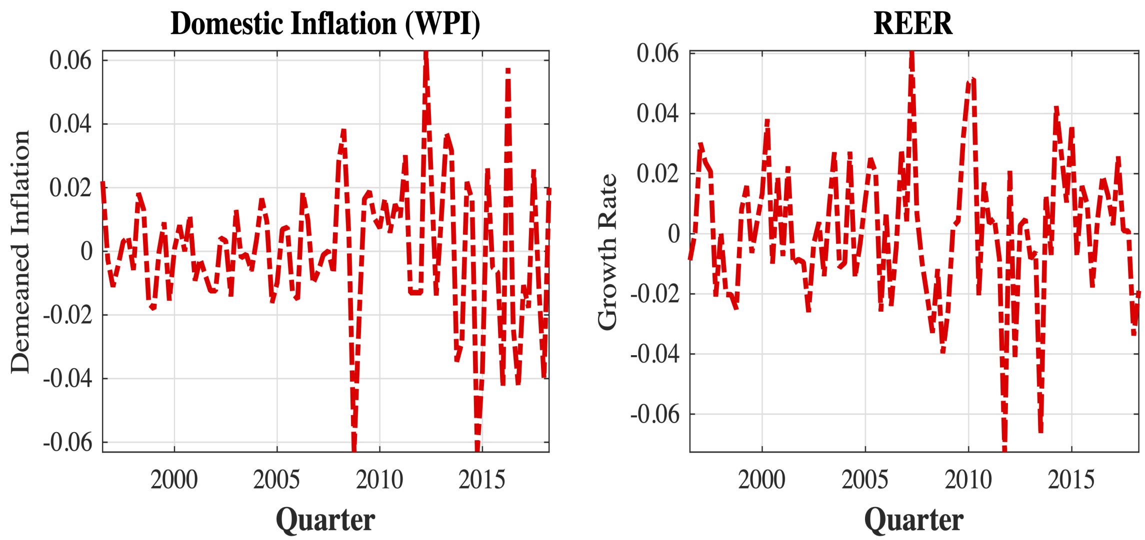

Figure 2: Data Series Used in Estimation: India

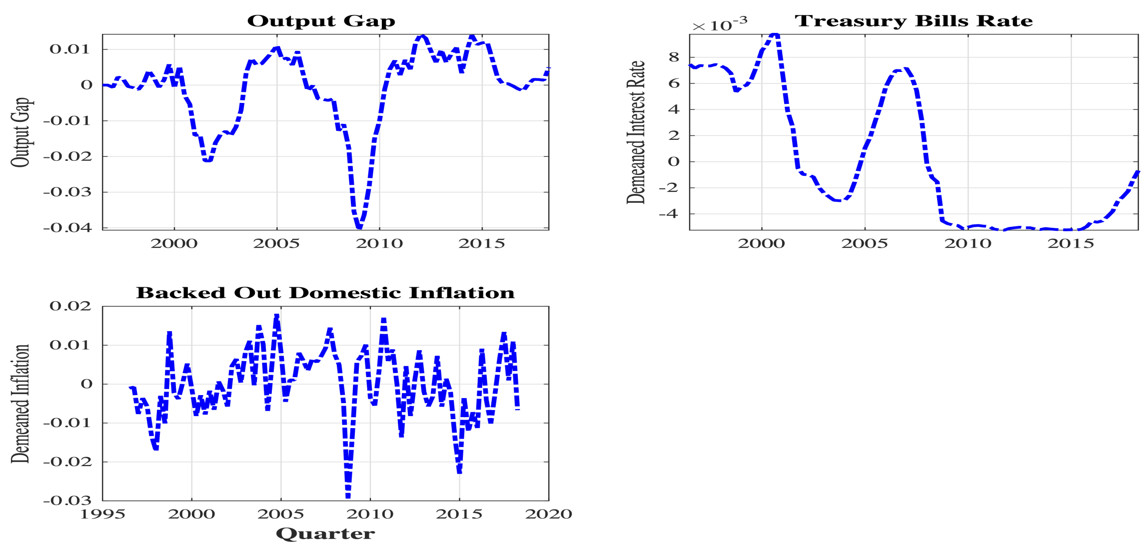

Figure 3: Data Series Used in Estimation: US

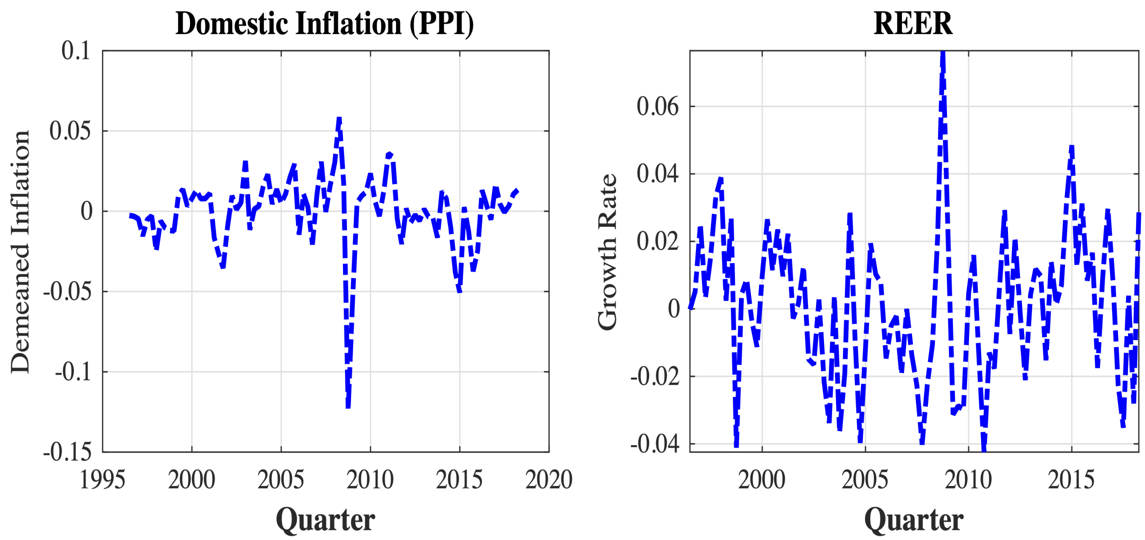

Figure 4: Data Series Used in Estimation: US

4 Empirical strategy

We calibrate some parameters: openness α is calibrated using the trade GDP ratio obtained from the World Bank. The discount factor β is inverse of the average nominal interest rate in the two countries; we also calibrate θ as explained in Table 1. The calibrated value of θ is consistent with an average period of one year between price adjustments. In one set of estimations we also calibrate η (share of rich in the two countries), as 1 - poverty rate in each country.

Table 2: Calibrated Parameters

Parameter	Description	Value
θ	Probability of price change	0.75
α	Openness in US	0.27
α	Openness in India	0.43
β	Discount factor in India	0.9829
β	Discount factor in US	0.9946
$1/\sigma_P$	inter-temporal elasticity of substitution of the poor	$\tilde{}0$
η	Share of rich in India	0.8
η	Share of rich in US	0.882.

Notes: Above values of α and η are used when they are not estimated. α is trade GDP ratio in 2018 as per World Bank. η is 1- poverty rate. Poverty rate for India is from World Bank and for US is from US census. The World Bank poverty estimates are from 2011 and therefore we use a slightly lower value.

Three exogenous processes in the model, Δcp_t, Δy_t^* and Δq_t are estimated externally. Δy_t^* is the same for both US and India and its parameters are estimated using growth of OECD countries quarterly GDP. Δq_t is estimated separately for India and US using real effective exchange rate (REER). REER has been taken from Federal Reserve Bank of Saint Louis (RBUSBIS for US and RBINBIS for India), for comparability. In the BIS data used for REER an increase in the index indicates an appreciation, but in the theoretical terms of trade it is the reverse. So signs have to be reversed in interpretation. For example, a rise in REER requires a fall in the natural rate to compensate for the fall in world demand.

Seasonally adjusted food inflation is used to proxy Δcp_t for India. This shock is absent in US. A rise in food prices is a fall in Δcp_t and requires a fall in the natural rate. The parameters estimates for these exogenous process are given in Table 3. Since the auto regressive term of Δq_t for India is not significant, while doing model estimation we assign a very low value for this.

Table 3: Estimation of Exogenous Process

	(1) Growth OECD	(2) Change in REER India	(3) Food Inflation India	(4) Change in REER US
L.Growth OECD	0.839***			
	(14.31)			
L.Change in REER India		0.137		
		(1.27)		
L.Food Inflation India			0.29***	
			(2.83)	
L.Change in REER US				0.307**
				(2.95)
Constant	0.00253	0.00118	0.0129***	0.000808
	(1.63)	(0.47)	(4.54)	(0.35)
N	87	87	87	87
$Std.Dev.of Shock$	0.0120	0.0234	0.0176	0.0215
R^2	0.704	0.019	0.086	0.093

t statistics in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

We feed estimates of these exogenous parameters in the models and estimate the remaining parameters using Bayesian likelihood.

5 Results

The models are estimated with differing Taylor Rules. The central banks target either consumer inflation or domestic inflation with and without a weight on external terms of trade. This follows a literature that assesses different types of targeting[3]. In this paper, however, the focus is on robustness of parameters estimated in different models and to analyze the relative terms of trade volatility.

In the benchmark model with consumer inflation the terms of trade enter the Taylor

[3]GM find full domestic inflation targeting optimally corrects for domestic frictions, while a exchange rate peg leads to too much volatility. In Svensson (2000) since full consumer inflation targeting uses the direct exchange rate channel at short-horizons to stabilize CPI inflation, it leads to too large a variation in exchange rates. Flexible consumer inflation targeting performs best, since it stabilizes the real exchange rate also. Goyal (2011) finds flexible domestic and consumer inflation targeting perform equally when terms of trade are exogenous. Otherwise volatility is highest in the SOEME with consumer inflation targeting.

Rule implicitly with fixed weights. This model is estimated with consumer inflation as the observable. In the second model domestic inflation is used as the observable. Under domestic inflation targeting in this model there is no weight on terms of trade. In the third model terms of trade is exogenous and is an independent argument in the Taylor Rule. All the models give similar consistent parameter estimates. The impulse responses are also in the expected direction.

The benchmark shows higher responses in India to most shocks. The interest shock and its response to the mark-up shock is higher in India. The FEVDs show the dominant share of output gap variance is explained by the interest rate and of inflation by the mark-up shock in both countries, but the output share of the interest rate is lower and the inflation share of the mark-up is higher in India.

When wholesale and producer prices are used instead of domestic inflation, backed out from consumer inflation using the real exchange rate, the contribution of mark-up shocks to output and inflation variance rises in both countries as volatility in producer prices is higher compared to backed out domestic inflation.

When the model is estimated with terms of trade fixed by an exogenous policy process the variance of interest rate shocks falls and mark-up shocks rises. The Indian interest rate response is now less than that of the US and it has a relatively lower impact on output and inflation. The asymmetry in interest rate response is reversed. The reason is the slope of the Indian AS is now less than that of the US. Since the share of output and inflation explained by the interest rate falls, the share due to mark-up rises, suggesting a flat AS subject to volatile shifts. In the US the interest rate remains the dominant factor for output, but its share falls to accommodate a sharp rise in the share of the terms of trade.

When terms of trade enter the Taylor rule so central banks vary interest rates also in response to terms of trade, the variance of the interest rate rises compared to the estimation without terms of trade in the Taylor Rule. It becomes almost double in US of that for India. The estimated weight of the real exchange rate change in the US Taylor rule is more than double that in India. US interest rate shocks as well as terms of trade shocks now exceed those for India and the share of interest rate explained by terms of trade is highest in this case. The Indian central bank intervenes more in other ways while in an advanced economy with more interest sensitive capital flows the interest rate has more impact on the nominal exchange rate and terms of trade.

5.1 Baseline with Consumer Inflation in the Taylor Rule

The model is estimated using (1), (2), (3), (4), (5), (6), (8), (9) and (10). In equation (9) the variance of $\epsilon_{q,t}$ is calibrated to 0 implying that terms of trade is constant. Therefore domestic inflation and consumer inflation differ by a constant and deviation from steady state, which is used for estimating the model, would be the same for both of them.

Comparing the estimated parameters in tables 4 and 5 (Appendix A) for India and the US respectively shows the share of the rich is relatively lower in India, labour elasticity is higher, the inter-temporal elasticity of substitution is lower and the variance of the mark-up shock is higher as expected.

The impulse responses are also in the expected directions. Figures 5 and 6 show higher responses in India to most shocks. The interest shock and its response to the mark-up shock is higher in India. The Indian AS curve (Figure 7) is steeper than that for the US, despite higher labour elasticities, in line with the theoretical derivations. The FEVDs in tables 6 and 7, show the dominant share of output gap variance is explained by the interest rate and of inflation by the mark-up shock in both countries, but the output share of the interest rate is lower and the inflation share of the mark-up is higher in India.

To check for robustness of the deep parameters, we estimate the model with domestic inflation in the Taylor rule, replacing (10) with (10''). The estimated parameters are similar[4]. One interesting difference worth reporting is that when wholesale and producer prices are used instead of domestic inflation, backed out from consumer inflation using the real exchange rate, the contribution of mark-up shocks to output and inflation variance rises in both countries (tables 6 and 7). This is intuitive, as figures 1-4 that map the data series show much higher volatility in producer prices compared to backed out domestic inflation.

5.2 Exogenous Terms of Trade with Consumer Inflation

The model is estimated using (1'), (12), (3'), (4), (5), (6), (7), (8), (9) and (10). The pattern of parameter estimates (table 8, Appendix B) is similar. Only the variance of mark-up shocks, σ_θ, is now 3 times larger in India and that of the interest rate is lower both compared to its value in the benchmark estimation and with the US. With the terms of trade not able to respond endogenously, the volatility in the EM now goes to the mark-up. In the impulse responses (figures 8) also, most patterns are similar, but now the Indian interest rate response is less than the US. It has a lower impact on output and inflation. Figure 9 shows the reason why–the slope of the Indian AS is now less than that of the US. Therefore, Indian monetary policy can be more accommodating. The Indian FEVDs (Table 9) now show a sharp fall in the share of output explained by the interest rate. The inflation variance explained by the interest rate is only 0.6. The mark-up now has a dominant share and that of the terms of trade also rises. In the US the interest rate remains the dominant factor for output, but its share falls to accommodate a sharp rise in the share of the terms of trade, especially in explaining inflation. The terms of trade is now an added exogenous shock, affecting the natural rate (equation 12).

The results imply that as in Goyal (2011) the AS for an EM can be characterized as relatively flat, but subject to more shocks. Policy interventions that reduce some types of bottlenecks and sources of volatility can actually flatten the supply curve. This is a better policy option in such countries than excessive use of interest rates in response to structural bottlenecks.

[4]They are not reported to save space but are available on request.

5.3 Exogenous Terms of Trade With Domestic Inflation

In view of the volatility due to the terms of trade, we now allow the central bank to respond to terms of trade shocks also with the policy rate. Therefore the terms of trade enters the Taylor rule. The model is estimated using (1'), (12), (3'), (4), (5),(6), (9) and (10''). The estimation for each country is done with both backed out domestic inflation as well as with WPI for India and PPI for the US.

The pattern of parameters (table 10, Appendix C) is in line with theory as earlier, supporting the robustness of the approach, where structural differences can be captured in coefficient estimates of similar functional forms. But now the variance of the interest rate rises compared to the last estimation and is almost double in US of that for India. Mark-up variance also rises for both and is actually higher in the US compared to India. The estimated weight of the real exchange rate change in the US Taylor rule is more than double that in India, since capital flows are more sensitive to the interest rate in a country like the US.

The impulse responses (figures 10-11) consistently show US interest rate shocks as well as terms of trade shocks now exceed those for India or becomes very similar. The Indian AS is flatter again at 0.6 compared to 0.74 for the US with backed out domestic inflation and 0.6 (India WPI) compared with 0.7 (US PPI). The FEVDs (table 11) show the share of terms of trade shocks is damped for both countries and goes to interest rate for output and mark-up for inflation. But the share of mark-up in explaining output remains relatively high at 22 for US PPI and the share of interest rate explained by terms of trade is highest in this case. One explanation is the Indian CB intervenes more in other ways such as reserve accumulation to reduce terms of trade volatility. As this damps volatility of the supply curve, it needs to use the interest rate less. US volatility is probably highest in PPI and targeting that makes it look like an emerging market in the high share of mark-up volatility. In an advanced economy, since interest sensitive flows are large, the interest rate affects the nominal exchange rate and terms of trade.

6 Conclusion

In emerging economies one would expect to have a flatter supply curve in comparison to advanced economies because there are a large number of workers with very high labor supply elasticity. Goyal (2011) showed theoretically that excessive volatility in terms of trade can make the supply curve steeper in emerging economies despite their higher elasticity of labour supply. But when terms of trade is exogenous, thus dampening excessive volatility, then aggregate supply curve is flatter in comparison to the advanced economy. Our estimations corroborate these results.

The results give a number of other insights. First, a similar basic NKE model can be estimated for differing countries. Structural differences result in different coefficient estimations in similar functional forms. Deep parameter estimations, impulse responses and FEVDs are in line with expectations from theory as well as the structural differences between the countries.

Second, larger policy rate shocks in emerging markets can be explained by features that create excess volatility. The feature explored in this paper is volatile external terms of trade. When this is dampened, using other policy tools, the AS flattens, volatility of interest rates and their impact on output is reduced. Asymmetries between the countries are reversed. Therefore, emerging markets need to use tools such as foreign exchange market intervention, reserve accumulation, macro prudential regulation and other capital flow management measures, apart from interest rates to reduce volatility in the external terms of trade. Goyal and Kumar (2018) find another factor that steepens the AS for an EM is relatively higher habit persistence. This could be capturing imperfections in financial markets or fiscal interventions that need to be removed.

The estimated parameters across all the simulations show the share of the rich is relatively lower in India compared to the US, labour elasticity is higher, the inter-temporal elasticity of substitution is lower and the variance of the mark-up shock is higher as expected. The impulse responses and FEVDs are all consistent and give useful insights.

As in Goyal (2011) the AS for an emerging market can be characterized as relatively flat, but subject to more shocks. Policy interventions that reduce some types of bottlenecks and sources of volatility can actually flatten the supply curve. This is a better policy option in such countries than excessive use of interest rates in response to structural bottlenecks. The latter impacts output more than inflation.

Finally, the US and India, have many asymmetries but some stylized facts such as the share of the rich, the degree of openness and even volatility due to mark-up shocks are not very different.

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A Baseline with Consumer Inflation in the Taylor Rule

Table 4: Parameters Estimate for India: Consumer Inflation

Parameters	Prior Mean	Posterior Mean	90% HPD interval		Prior	Post Dev.
η	0.7	0.7783	0.717	0.8361	beta	0.05
ϕ_P	0.01	0.031	0.01	0.0621	beta	0.05
ϕ_R	0.4	0.6658	0.4335	0.9234	beta	0.2
σ_R	0.4	0.1304	0.1	0.1722	beta	0.2
ρ_π	0.6	0.7695	0.5472	0.9691	beta	0.2
ρ_r	0.5	0.817	0.6839	0.9608	beta	0.2
ρ_x	0.6	0.963	0.9277	0.9975	beta	0.2
ρ_a	0.6	0.865	0.8045	0.9252	beta	0.2
σ_a	0.05	0.0297	0.0175	0.042	invg	0.08
σ_θ	0.05	0.0135	0.0119	0.0152	invg	0.08
σ_r	0.05	0.1012	0.1	0.1027	invg	0.08

Notes: η is share of rich, ϕ_P and ϕ_R are inverse of Frisch elasticity of labour supply for poor and rich. σ_P and σ_R are inverse of intertemporal elasticity of substitution for poor and rich. σ_P has been calibrated as a very large value. ρ_π, ρ_x, and ρ_r are weight of inflation, output gap, and past rate in Taylor rule. ρ_a is AR term of technology shock. σ_a, σ_θ and σ_r are variance of technology, mark-up and interest rate shock respectively.

Table 5: Parameters Estimate for US: Consumer Inflation

Parameters	Prior Mean	Posterior Mean	90% HPD interval		Prior	Post Dev.
η	0.8	0.8846	0.8253	0.9497	beta	0.05
ϕ_P	0.01	0.0499	0.01	0.1028	beta	0.05
ϕ_R	0.4	0.8209	0.6645	0.9469	beta	0.2
σ_R	0.4	0.1067	0.1	0.1153	beta	0.2
ρ_π	0.6	0.8778	0.76	0.9759	beta	0.2
ρ_r	0.5	0.7476	0.6594	0.8493	beta	0.2
ρ_x	0.6	0.975	0.9546	0.9989	beta	0.2
ρ_a	0.6	0.9369	0.9028	0.9706	beta	0.2
σ_a	0.05	0.0601	0.0298	0.0972	invg	0.08
σ_θ	0.05	0.0102	0.01	0.0104	invg	0.08
σ_r	0.05	0.1011	0.1	0.1026	invg	0.08

Notes: η is share of rich, ϕ_P and ϕ_R are inverse of Frisch elasticity of labour supply for poor and rich. σ_P and σ_R are inverse of intertemporal elasticity of substitution for poor and rich. σ_P has been calibrated as a very large value. ρ_π, ρ_x, and ρ_r are weight of inflation, output gap, and past rate in Taylor rule. ρ_a is AR term of technology shock. σ_a, σ_θ and σ_r are variance of technology, mark-up and interest rate shock respectively.

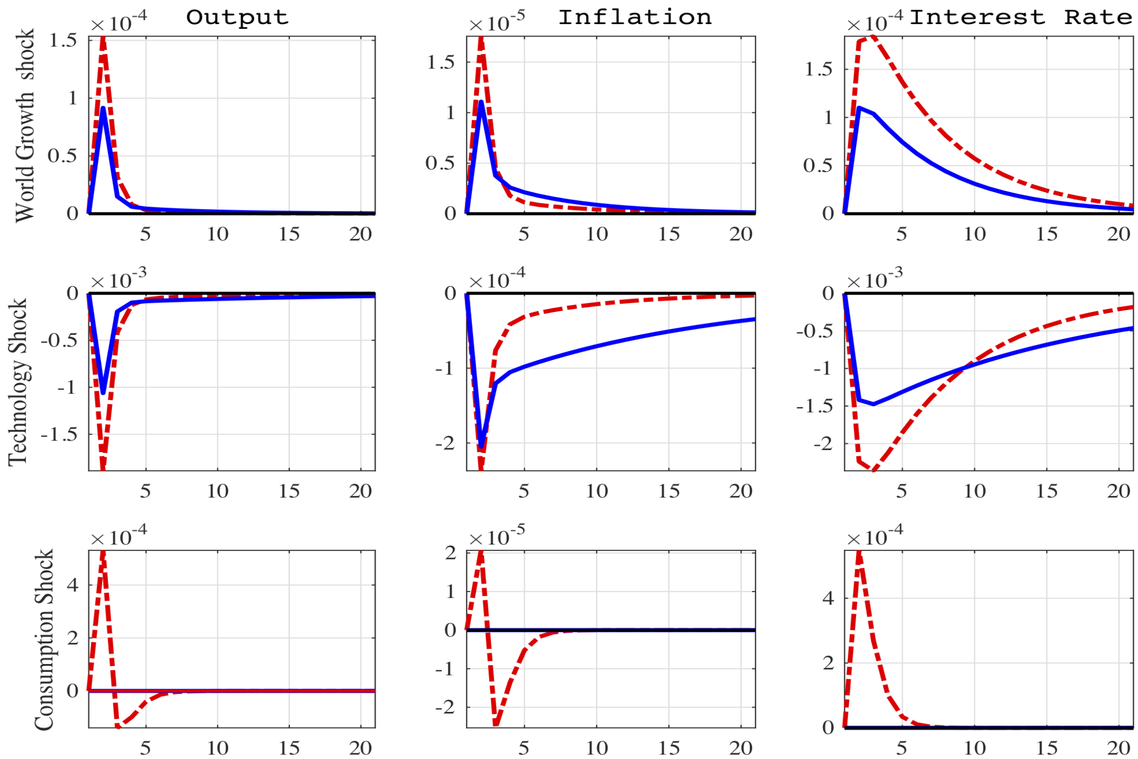

Figure 5: Blue Line for US: Red dashed line for India; Consumer Inflation

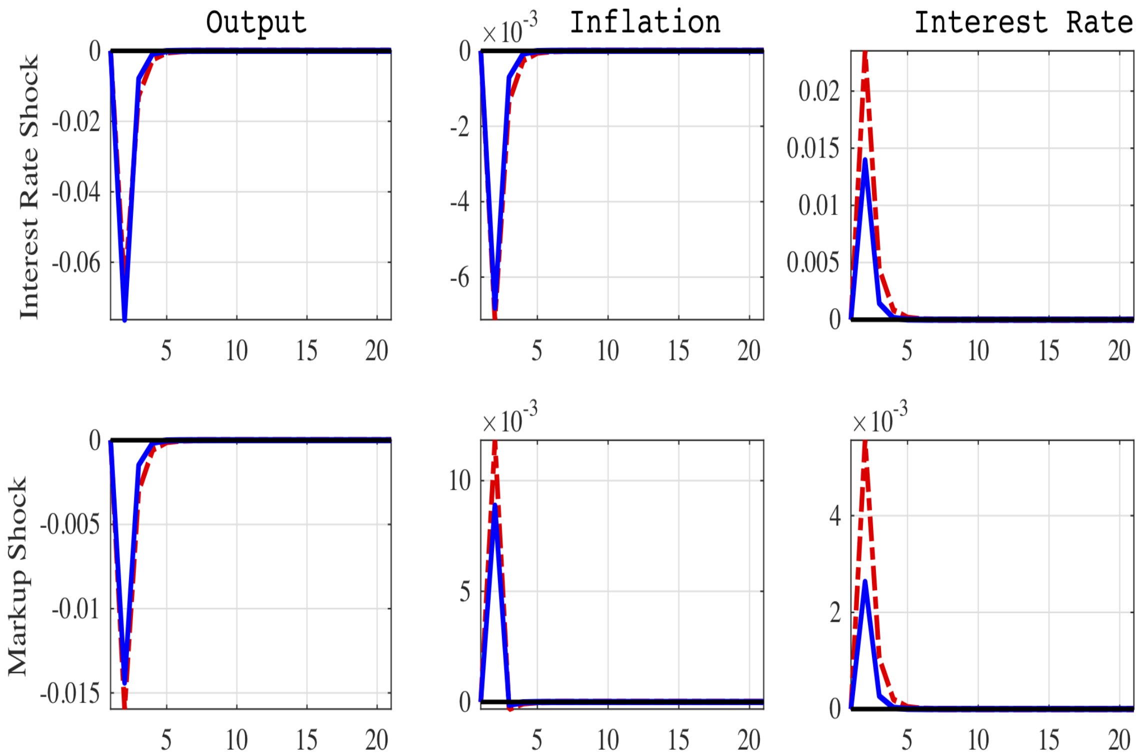

Figure 6: Blue Line for US: Red dashed line for India; Consumer Inflation

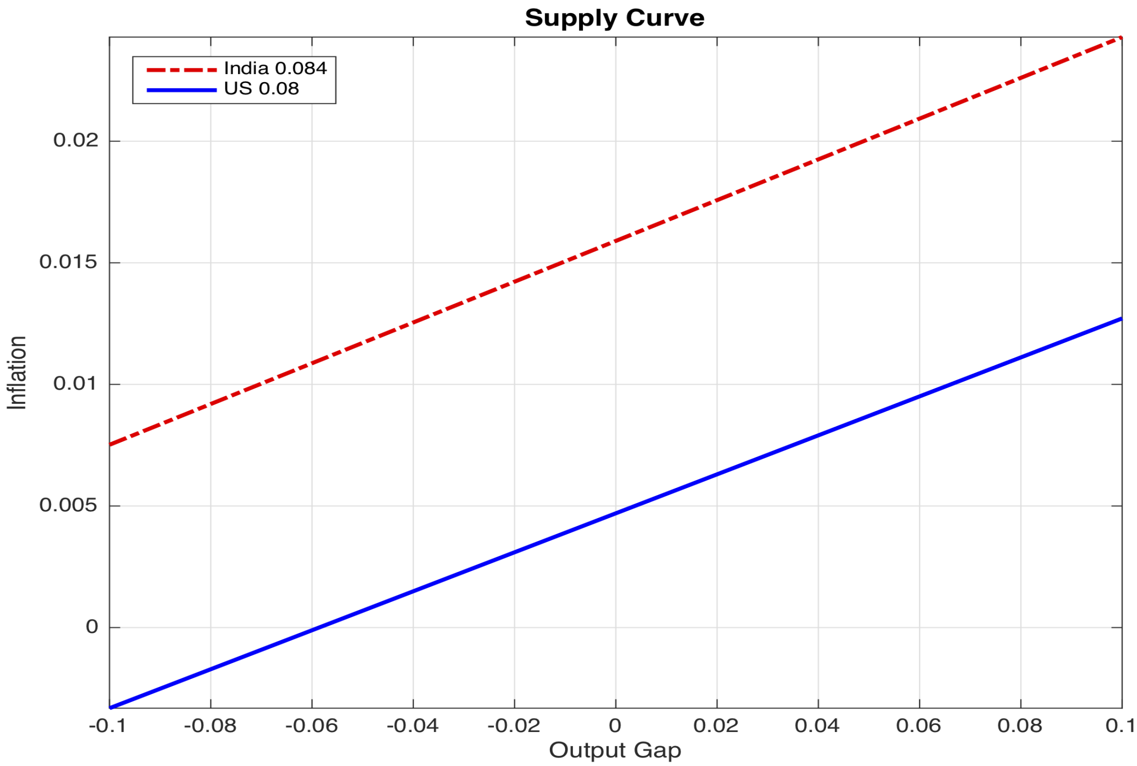

Figure 7: Blue Line for US: Red dashed line for India; Consumer Inflation

Table 6: Forecast Error Variance Decomposition for India and US: Benchmark Consumer Inflation

Period	India		US	
Quarter	Interest Rate	Markup	Interest Rate	Markup
		Output		
1	94.6	5.3	96.5	3.4
4	94.6	5.3	96.5	3.4
8	94.6	5.3	96.5	3.4
12	94.6	5.3	96.5	3.4
20	94.6	5.3	96.5	3.4
		Inflation		
1	26.6	73.3	37.1	62.9
4	27.3	72.6	37.3	62.6
8	27.3	72.6	37.3	62.6
12	27.3	72.6	37.3	62.6
20	27.3	72.6	37.3	62.6
		Interest Rate		
1	93.9	5.2	95.6	3.4
4	91.8	5.1	93.0	3.3
8	90.8	5.1	90.8	3.2
12	90.5	5.1	89.6	3.2
20	90.4	5.0	88.4	3.1

Table 7: Forecast Error Variance Decomposition for India and US: WPI and PPI as Domestic Inflation

	India		US	
Quarter	Interest Rate	Markup	Interest Rate	Markup
		Output		
1	89.1	10.8	89.0	11.0
4	89.1	10.8	89.0	11.0
8	89.1	10.8	89.0	11.0
12	89.1	10.8	89.0	11.0
20	89.1	10.8	89.0	11.0
		Inflation		
1	11.4	88.6	10.3	89.7
4	11.6	88.3	10.4	89.6
8	11.6	88.3	10.4	89.6
12	11.6	88.3	10.4	89.6
20	11.6	88.3	10.4	89.6
		Interest Rate		
1	88.4	10.7	88.3	11.0
4	86.7	10.5	86.6	10.7
8	85.9	10.4	85.1	10.6
12	85.6	10.4	84.3	10.5
20	85.5	10.4	83.6	10.4

B Exogenous Terms of Trade with Consumer Inflation

Table 8: Parameters Estimate for India and US: Consumer Inflation

	India		US	
Parameters	Prior Mean	Posterior Mean	Prior Mean	Posterior Mean
η	0.7	0.8275	0.8	0.8392
ϕ_P	0.01	0.0549	0.01	0.0656
ϕ_R	0.4	0.7616	0.4	0.8992
σ_R	0.4	0.4463	0.4	0.3022
ρ_π	0.6	0.7429	0.6	0.8604
ρ_r	0.5	0.7455	0.5	0.8758
ρ_x	0.6	0.9698	0.6	0.9494
ρ_a	0.6	0.7164	0.6	0.9556
σ_a	0.05	0.0205	0.05	0.0815
σ_θ	0.05	0.0345	0.05	0.0103
σ_r	0.05	0.0603	0.05	0.1011

Notes: η is share of rich, ϕ_P and ϕ_R are inverse of frisch elasticity of labour supply for poor and rich. σ_P and σ_R are inverse of intertemporal elasticity of substitution for poor and rich. σ_P has been calibrated as very large value. ρ_π, ρ_x, ρ_q and ρ_r weight of inflation, output gap, real exchange rate and past rate in Taylor rule. ρ_a is AR term of technologogy shock. σ_a, σ_θandσ_r are variance of technology, markup and interest rate shock.

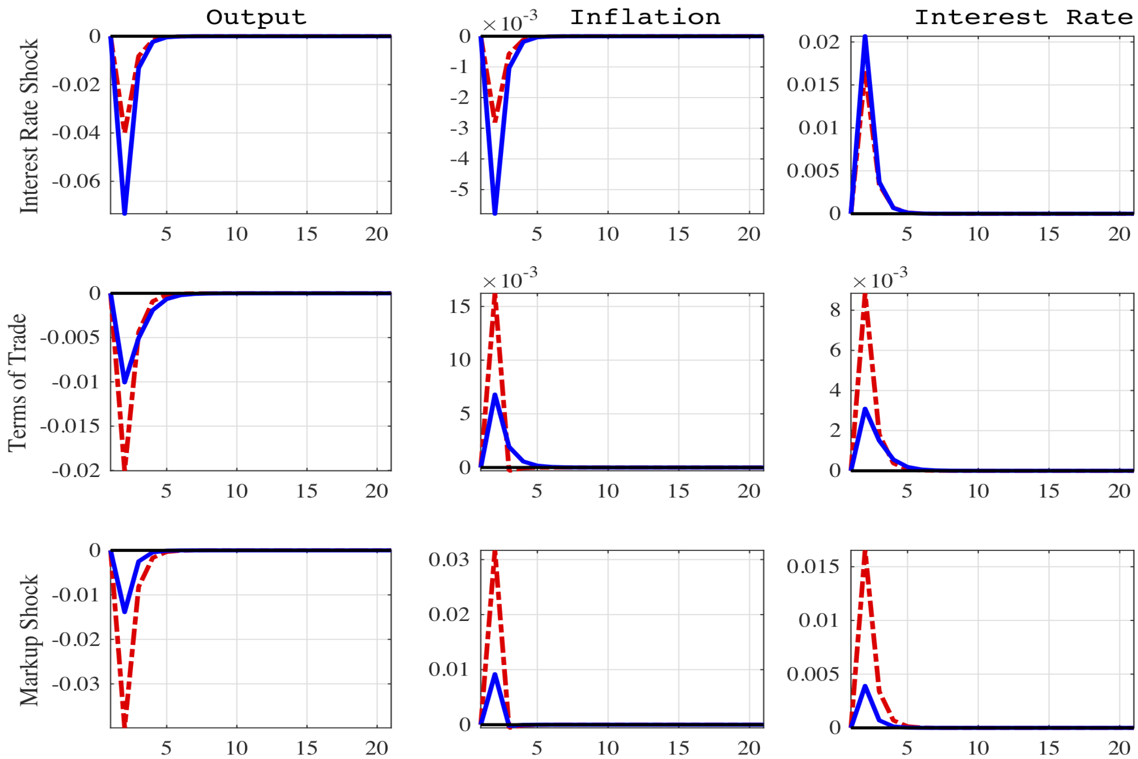

Figure 8: Blue Line for US: Red dashed line for India; Consumer Inflation

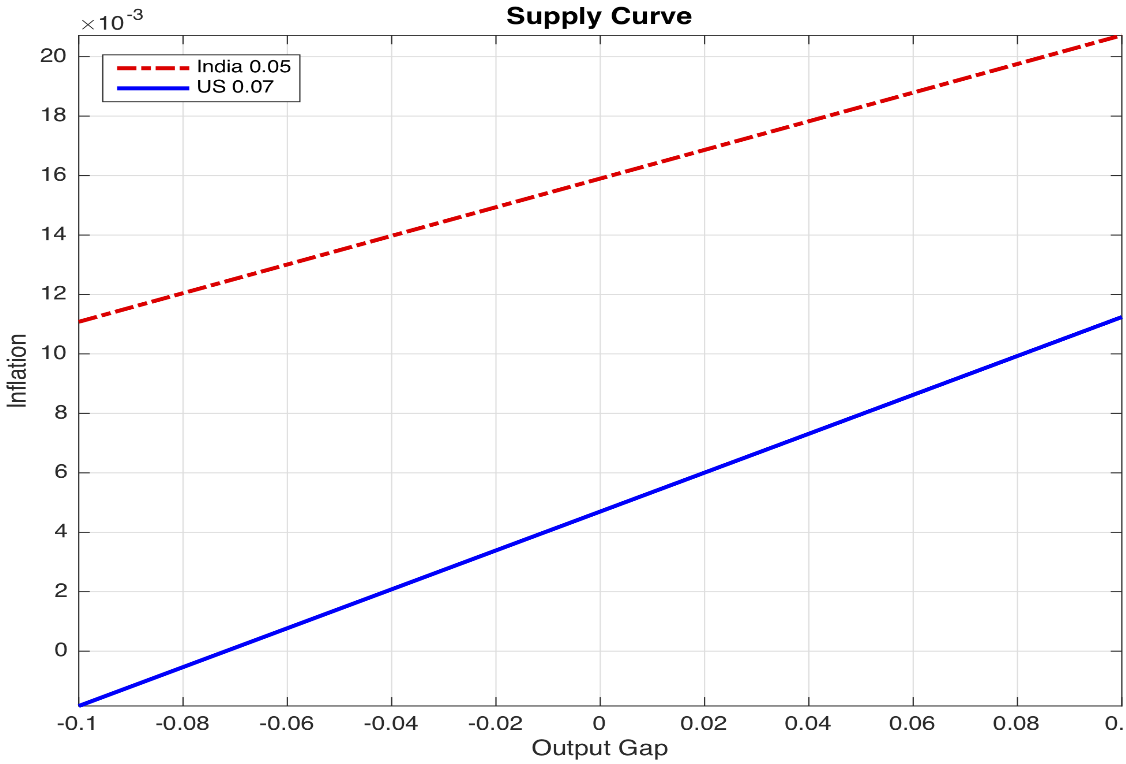

Figure 9: Blue Line for US: Red dashed line for India; Consumer Inflation

Table 9: Forecast Error Variance Decomposition for India and US: Consumer Inflation

	India			US		
Quarter	Interest Rate	Terms of Trade	Markup	Interest Rate	Terms of Trade	Markup
			Output			
1	44.2	11.1	43.9	94.8	1.8	3.4
4	44.2	11.1	43.8	94.3	2.2	3.4
8	44.2	11.1	43.8	94.3	2.2	3.4
12	44.2	11.1	43.8	94.3	2.2	3.4
20	44.2	11.1	43.8	94.3	2.2	3.4
			Inflation			
1	0.6	20.7	78.7	20.4	28.2	51.4
4	0.6	20.7	78.7	20.5	29.7	49.8
8	0.6	20.7	78.7	20.5	29.7	49.8
12	0.6	20.7	78.7	20.5	29.7	49.8
20	0.6	20.7	78.7	20.5	29.7	49.8
			Interest Rate			
1	41.6	11.8	41.3	93.2	2.1	3.3
4	38.7	11.0	38.4	88.4	2.4	3.2
8	38.2	10.9	37.9	84.4	2.3	3.0
12	38.2	10.9	37.9	81.9	2.3	2.9
20	38.2	10.8	37.9	79.1	2.2	2.8

C Exogenous Terms of Trade With Domestic Inflation

Table 10: Parameters Estimate for India and US: Backed Out Domestic Inflation, WPI and PPI

	India			US		
Par-meters	Prior Mean	Posterior Mean	Posterior Mean	Prior Mean	Posterior Mean	Posterior Mean
η	0.7	0.8009	0.7969	0.8	0.8844	0.8863
ϕ_P	0.01	0.0204	0.033	0.01	0.0889	0.0349
ϕ_R	0.4	0.8878	0.8847	0.4	0.9125	0.9206
σ_R	0.4	0.3649	0.3651	0.4	0.1791	0.1166
ρ_π	0.6	0.6589	0.6825	0.6	0.7354	0.6081
ρ_r	0.5	0.7477	0.7781	0.5	0.8017	0.6851
ρ_x	0.6	0.9237	0.9253	0.6	0.9169	0.8773
ρ_q	0.6	0.3615	0.3284	0.6	0.6788	0.7495
ρ_a	0.6	0.7915	0.7946	0.6	0.8744	0.7586
σ_a	0.05	0.0281	0.029	0.05	0.0734	0.0794
σ_θ	0.05	0.0436	0.0426	0.05	0.0367	0.0695
σ_r	0.05	0.1111	0.1111	0.05	0.201	0.2108

Notes: Column 3 and 4 are estimates for India using backed out domestic inflation and WPI as domestic inflation. Column 6 and 7 are estimates for US using backed out domestic inflation and PPI as domestic inflation. η is share of rich, ϕ_P and ϕ_R are inverse of frisch elasticity of labour supply for poor and rich. σ_P and σ_R are inverse of intertemporal elasticity of substitution for poor and rich. σ_P has been calibrated as very large value. ρ_π, ρ_x, ρ_q and ρ_r weight of inflation, output gap, real exchange rate and past rate in Taylor rule. ρ_a is AR term of technologogy shock. σ_a, σ_θandσ_r are variance of technology, markup and interest rate shock.

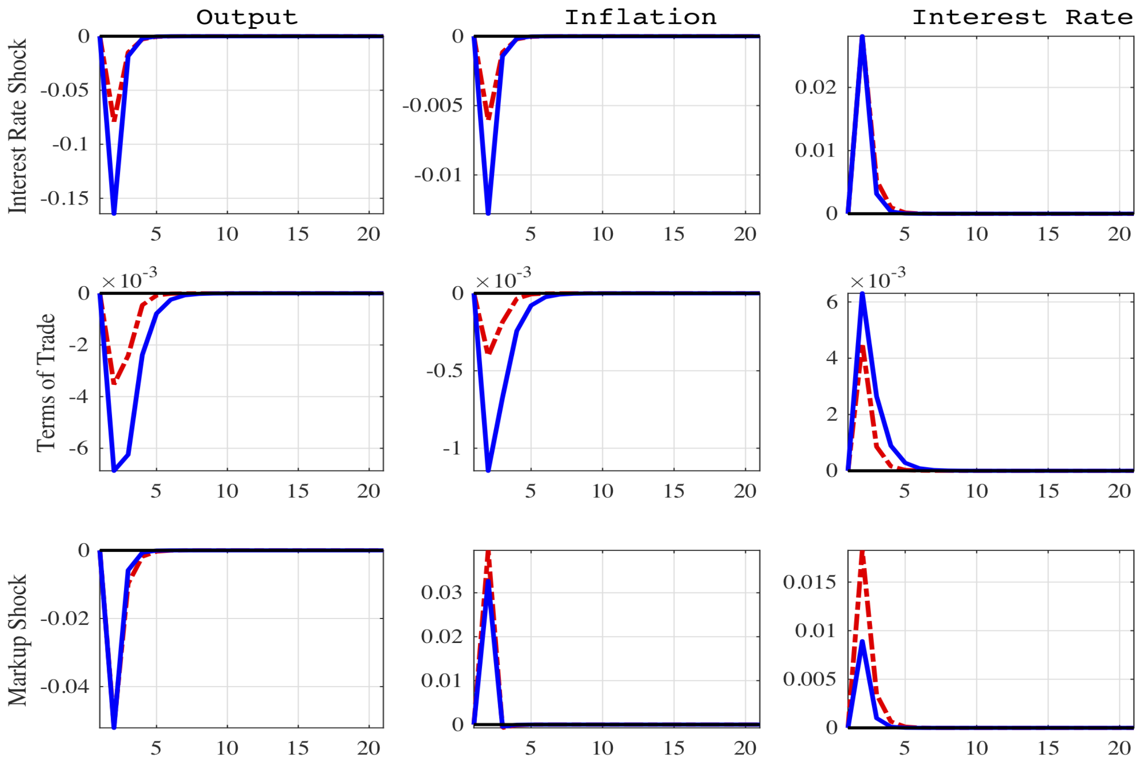

Figure 10: Blue Line for US: Red dashed line for India, Backed out Domestic Inflation

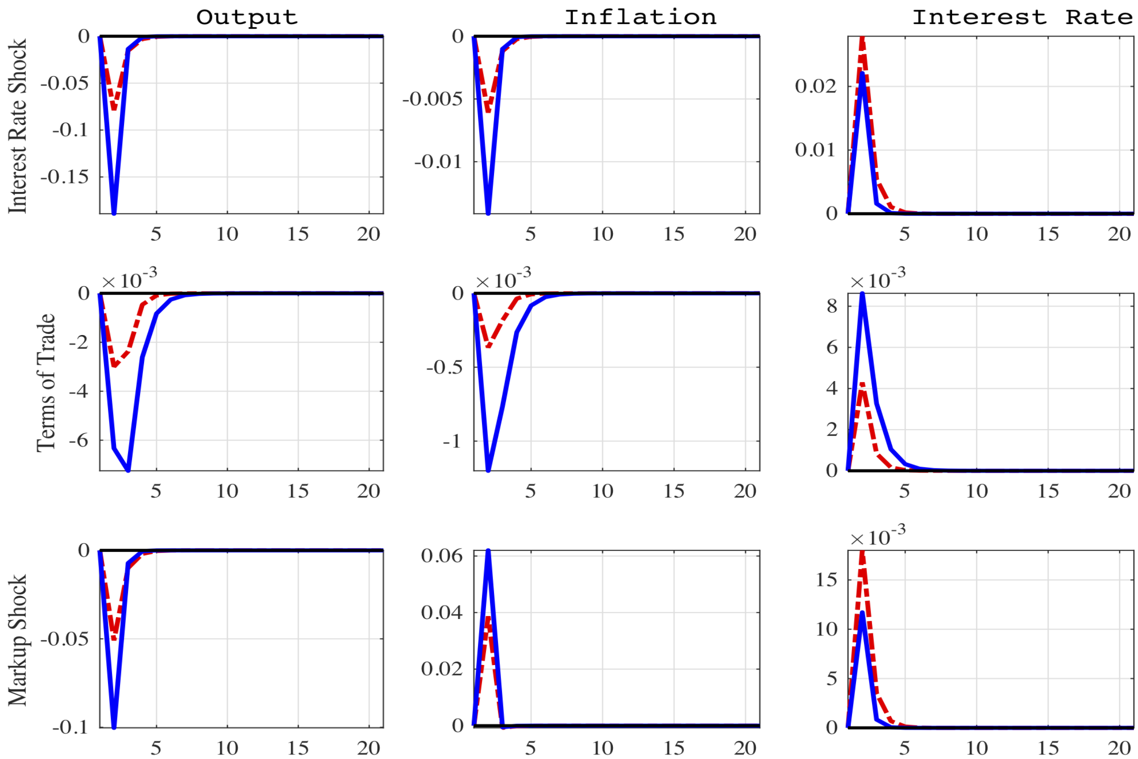

Figure 11: Blue Line for US: Red line for India, Domestic Inflation, WPI for India and PPI for US

Table 11: Forecast Error Variance Decomposition for India and US: WPI and PPI for India and US respectively as Domestic Inflation

	India			US		
Quarter	Interest Rate	Terms of Trade	Markup	Interest Rate	Terms of Trade	Markup
			Output			
1	70.3	0.1	29.3	77.9	0.1	21.9
4	70.3	0.2	29.3	77.8	0.2	21.9
8	70.3	0.2	29.3	77.8	0.2	21.9
12	70.3	0.2	29.3	77.8	0.2	21.9
20	70.3	0.2	29.3	77.8	0.2	21.9
			Inflation			
1	2.4	0.0	97.6	4.9	0.0	95.0
4	2.5	0.0	97.5	5.0	0.1	95.0
8	2.5	0.0	97.5	5.0	0.1	95.0
12	2.5	0.0	97.5	5.0	0.1	95.0
20	2.5	0.0	97.5	5.0	0.1	95.0
			Interest Rate			
1	67.8	1.6	28.3	67.2	10.3	18.9
4	65.0	1.5	27.1	63.2	11.1	17.8
8	64.2	1.5	26.8	62.6	11.0	17.6
12	64.1	1.5	26.7	62.5	11.0	17.6
20	64.1	1.5	26.7	62.5	11.0	17.6