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Exploring Correlations between Aggregate Demand and Supply Shocks in India

Ashima Goyal and Sritama Ray

Indira Gandhi Institute of Development Research, Mumbai
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Email(corresponding author): ashima@igidr.ac.in

Abstract

We explore the relative contributions of demand and supply shocks on inflation and output in India when correlation is allowed between shocks. Our SVAR model is estimated with quarterly GDP, WPI and CPI data covering the period between 1997Q2 and 2020Q1. The Keynesian case is of demand leading to a shift in supply as firms with excess capacity respond, while the case of supply affecting demand could be due to policy reactions to supply shocks. We estimate the correlations and slopes under different identifying assumptions. We find a positive correlation between shocks in all cases. Overall, a Horizontal Supply Curve (HSC) identification is supported, an asymmetry expected for a populous emerging market in transition. The short-run output cost of disinflationary policy is, therefore, large. Moreover, a policy demand contraction following a negative supply shock turns out to have perverse effects when the HSC holds, further aggravated when headline CPI is the target variable. This was the Indian experience of slowdown and inflation persistence after 2011 following demand tightening under food price shocks. Policy should ideally sustain demand, which can induce output expansion, and moderate the impact of shocks making the impact of demand and supply shocks more even. India's inflation targeting framework can therefore work better by aiding supply side improvements and anchoring inflation expectations.

Keywords: Correlated demand and supply shocks; asymmetry; monetary policy; horizontal and vertical supply curves; India; structural VAR

JEL Code: C51; C52; E52; E58

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1. Introduction

Emerging market economies like India are frequently subject to transient supply side shocks that cause volatility in food and fuel prices (Mohanty and Klau, 2001, Ramachandran and Kumar, 2017). Food has a large share in the Indian consumption basket and triggers short-term fluctuations in headline inflation. Fuel is also a major shock. Since agriculture continues to be rainfed the south-west monsoon plays a large role in determining food prices. The persistence of inflation can be explained by second-round effects which lead to a permanent upward shift of the aggregate supply (AS) curve from a temporary negative supply side shock. This happens when a self-sustaining wage-price spiral is set off due to poor anchoring of inflation expectations. Then a change in the relative price of food can affect the general price level through wages. Therefore, adverse supply shocks in the form of oil price disruptions, monsoon failures and other cost push shocks are not amenable to standard aggregate demand (AD) management.

With the onset of the Global Financial Crisis of 2008, GDP growth in India hit a record low owing to a shortfall in liquidity and demand slowdown in both domestic and foreign markets. Policy responded quickly to raise demand and preserve the pre-crisis growth impetus. This helped growth to recover in the second half of 2009. Average GDP growth for 2009Q3-2011Q2 stood at 8.8 per cent. The prolonged infusion of liquidity, however, was more than adequate and soon caused inflationary pressures in the economy (Subbarao, 2013). This period recorded high CPI and WPI inflation which stayed near double digits well into 2011 in spite of prices softening in global markets.

In order to control inflation, RBI started reversing the accommodative policy stance in 2010, thereby trying to shift the AD curve back to the left. The repo rate was increased by 375 basis points, from 4.75 per cent in March 2010 to 8.5 per cent in October 2011. In the presence of multiple food price shocks, this monetary tightening although targeted at lowering inflation resulted immediately in slowing down growth instead (Goyal and Kumar, 2019). The European debt crisis followed which lowered exports and aggravated the low aggregate demand situation in the economy. There was a significant decline in output while inflation remained high and sticky. The second round of interest rate increase began in 2013 as a part of currency defense against the Taper-on crisis but failed to control outflows. In spite of raising the cash reserve ratio, credit and investment growth in the economy did not pick up and it was difficult for the government to keep post-crisis deficits in check (Goyal, 2015). GDP growth averaged 5.2 per cent between 2011Q3 and 2013Q3. Persistent current account deficits and currency depreciation added to the environment of macroeconomic fragility and uncertainty. Although inflation finally started to come down in the middle of 2013-2014, the RBI has been critiqued for its hawkish and over reactionary policy response to the temporary supply shocks which stifled growth during this period (Goyal, 2018).

Fiscal and monetary policies often resort to tightening in response to cost push shocks. Estimating the slope of an AS curve is important since it gives a better understanding of output sacrifice involved in a policy-induced AD shock. Advanced economies are likely to have a steep AS, which implies that monetary contraction can keep inflation in check without a large loss of output. This happens if the economy is close to its full capacity output, or economic agents are forward looking so there is an instantaneous adjustment of inflation expectations to shocks. Forward-looking price-setting behavior of firms can keep output at its potential level implying little sacrifice in output with contractionary policy (Goyal and Tripathi, 2015). The Vertical Supply Curve (VSC) is the strict neoclassical case where supply is constant for all price levels. In this case, demand tightening does not affect output but is effective in controlling inflation. There may, however, be an asymmetry in the aggregate supply structures in emerging markets so that the VSC does not hold.

The case for intermediate slopes comes from rigidities in the market for factors of production, such as labour. These can make the price-output relationship positive and persistent over time. This is likely to be observed in India, a labour-surplus emerging market in transition, where factors of production are not utilized to their full capacity. Here, it is possible for demand to have an important effect on output. The AS curve in India is likely to be highly elastic owing to excess capacity but subject to large shocks due to supply side bottlenecks (Goyal, 2017). In this context, a Horizontal Supply Curve (HSC) is a valid long-run approximation until the economy matures and reaches its full-employment output (Goyal and Pujari, 2005). Moreover, demand and supply shocks are likely to be correlated in the presence of firms with excess capacity or an inflation targeting policy regime. Therefore, this asymmetry in AS slopes and identifications between developed and emerging economies warrants a closer examination, taking into account the correlation between AD and AS shocks.

The major contributions of this study therefore are to introduce correlated demand and supply shocks and examine their effects for asymmetric VSC and HSC identifications, using CPI as well as WPI. The results enable (i) inference of which identification is best suited to the Indian economy, (ii) estimation of structural parameters and trade-offs, and (iii) have implications for policy. The correlation between demand and supply shocks has not been studied in the Indian context so far. The current study attempts to fill that research gap by exploring the nature of correlation of shocks governing the Indian economy and what implications it holds for macroeconomic policymaking.

The SVAR model in the current study is estimated with quarterly GDP, WPI and CPI data covering the period between 1997Q2 and 2020Q1. We find demand and supply shocks to be positively correlated under all identifying restrictions. Overall, the HSC identification is a better fit, implying that demand tightening to control inflation has a considerable trade-off in the form of output lost. In fact, under HSC, contractionary policy following negative supply shocks aggravates the output slowdown, more so with headline CPI as the inflation target. This explains the Indian slowdown after 2011 which resulted from demand tightening in an environment of cost push shocks. The flexible inflation targeting framework of the RBI should therefore focus on supply-side improvements to neutralize the effect of shocks instead of large demand contractions.

The rest of the paper is organized as follows. Section 2 reviews the empirical literature on aggregate supply relationships with an emphasis on India. Section 3 describes the data, variables and methodology. Section 4 explains the theoretical correlation between AD and AS shocks and its implications for both VSC and HSC identifications. Section 5 gives a detailed overview of the model and its parameters. Sections 6 and 7 discuss the results from estimation of parameters and Impulse Response Function-Forecast Error Variance Decomposition (IRF-FEVD) analysis. The last section concludes with policy implications, limitations and directions for future research.

2. A Brief Review of the Literature

The Phillips Curve has been a popular area of research in macroeconomic studies since it deals with the trade-off between inflation and unemployment or alternatively, between the output gap and inflation. This AS relationship, when used alongside an AD equation and an interest rate rule, is especially important from the point of view of designing and implementing macroeconomic policy. Many studies have tried to investigate the existence or extent of this trade-off for India. The results have been mixed. Dholakia (1990), in an early study of the Indian economy from 1950 to 1985, concludes that no appreciable relationship exists between inflation and unemployment. Kapur and Patra (2000) use annual data from 1970 to 2001 and estimate the sacrifice ratio between output and WPI inflation to be in the range of 1.9 to 2.7 for the period of estimation. Callen and Chang (1999) find a negative coefficient for the relationship between the two variables when they study Indian inflation and industrial output data between 1982 to 1998. Paul (2009) studies the industrial sector for India and finds that if exogenous supply shocks in the form of droughts and oil crises are accounted for and crop year is used instead of fiscal year, there is evidence of an inflation-industrial output trade-off. Singh et al (2011) similarly report empirical existence of a Phillips curve for the economy for the period 2004 to 2009 after controlling for supply shocks. Mazumder (2011) finds a significant relationship between output gap and inflation – a one per cent increase in the output gap in his study brings about half a per cent rise in inflation. For Ball, Chari and Mishra (2016), the same ratio turns out to be 2.7.

New Keynesian economics supports a positively sloped short-run AS curve derived from the maximization of firms' profits (Gali & Gertler, 2000). In the micro-founded, hybrid New Keynesian Phillips Curve (NKPC), inflation depends on output gap or real marginal cost, lagged inflation and future inflation expectations. Goyal and Tripathi (2015) estimate the NKPC for India using marginal cost as a proxy for output gap, and find that the Indian AS curve has a mild upward slope after accounting for a correctly-measured comprehensive supply shock variable.

Sims (1980) pioneered the use of VAR models to explore the dynamic properties of economic systems. He criticized large scale macroeconomic models, which made strong assumptions about the relationships between model variables, emphasizing that there is no variable which is exogenous in a world with rational, forward-looking agents. Blanchard and Quah (1989) modelled output growth and unemployment data in a bivariate VAR setup to isolate the transitory and permanent components of output. They characterized the shock having no effect on output in the long run as the demand shock. The standard Blanchard Quah (BQ) decomposition works with the assumptions that aggregate demand does not have any long run impact on output, and that, demand and supply shocks are contemporaneously uncorrelated.

The BQ technique has been widely used ever since in empirical macroeconomics to identify the effects of demand and supply shocks on output and inflation using long run identifying restrictions in an SVAR. A few such studies include Mio (2002), who estimates an output-price structural VAR model for Japan to decompose inflation rate time-series into two components using the same long-run identifying restriction, as well as Quah and Vahey (1995), who propose a technique for measuring core inflation by imposing dynamic restrictions on a bivariate VAR system of industrial output and inflation. They assert that core inflation is the component of measured inflation that has no medium to long run impact on real output.

The output neutrality assumption, which implies that the supply curve is vertical in the long run may not be a sound approximation for a developing country like India which is far from full-employment. Goyal and Pujari (2005) estimate the decomposition of structural shocks for Indian industrial output and inflation data from 1971 to 2003 and test whether the HSC or VSC is a valid long-run identification to match the Indian data. They find that the Indian AS curve exhibits high elasticity in the long run since supply shocks and demand shocks are observed to have significant impacts on inflation and output levels respectively. The alternative HSC identification developed by them has been employed in the present study.

The second restriction about orthogonal shocks has also been questioned by many in the literature including Cover, Enders and Hueng (2006) and Enders and Hurn (2007). Following these restrictions, many studies in literature have found AD shocks to have no discernible effect on real economic activity because any change in output resulting from simultaneous shifts in demand and supply is attributed only to the structural supply shock. Cover et al (2006) apply an alternative AD-AS model to identify structural shocks for the US assuming that demand and supply shocks are not uncorrelated and compare it with the results of the standard BQ case. They find using two recursive orderings that the shocks are highly correlated, and that, demand shocks can account for almost 82 per cent of the forecast error variance of real US GDP. Enders and Hurn (2007) study the Australian economy from 1980 to 2003 and find similar results which imply that the assumption of correlated shocks have important consequences for VAR results. Siklos and Zhang (2010) study the Chinese time series data from 1990 to 2004 using BQ as well as the alternative identification proposed by Cover et al and find that inflation has been a purely monetary phenomenon in China.

Bashar (2012) implements the alternative identification for ASEAN countries – and finds that for almost all countries, AD shocks explain larger variations in output levels than what was reported in earlier studies that had used the BQ decomposition. Supply shocks are also observed to have significant impacts on inflation. His findings suggest that if correlation between shocks is ignored, the BQ approach may fail to accurately estimate the impacts of demand and supply shocks on inflation and output. The present study proceeds to examine this relationship for India.

3. Methodology and Data Issues

3.1 Data

We use quarterly data on GDP, WPI Index and CPI Index covering the period from 1997Q2 to 2020Q1. WPI Index data has been sourced from the RBI Database on Indian Economy (DBIE; https://dbie.rbi.org.in/DBIE). CPI Index and seasonally adjusted GDP data are collected from Federal Reserve Economic Data (FRED), St Louis Database (https://fred.stlouisfed.org/). Plots of all three variables are reported in Figure 1.

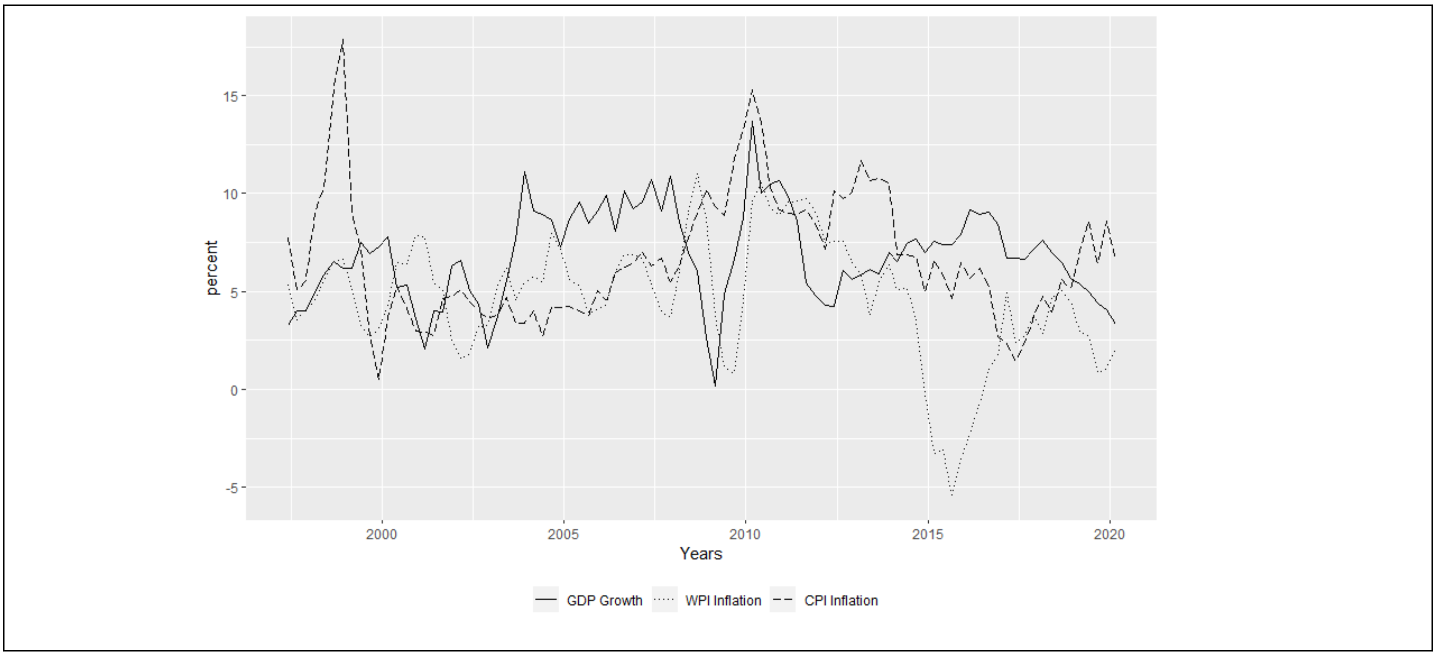


Figure 1: GDP Growth, WPI Inflation and CPI Inflation (1997Q2-2020Q1)
Source: FRED, St Louis Database and RBI DBIE

The composition of WPI and CPI indices have been illustrated in Figures 2 and 3 respectively (see Appendix). WPI gives a greater weightage to fuel and non-food manufactured products while CPI contains a larger weight of food items. CPI includes non-tradeables like services up to one-fourth of its weight which is not represented in WPI. The point of data collection also differs between the two. The data for WPI is collected at the first point of bulk sale in wholesale markets whereas CPI reflects the cost of commodities at the end point which includes transportation costs, taxes as well as the commissions and margins of middlemen. In other words, WPI is closest to producer prices and affects the firms' profitability, and CPI captures the price of the consumption basket and therefore affects household inflation expectations resulting in second round effects on wages and rental contracts. In May 2016, inflation targeting was formally adopted through an amendment of the RBI Act with headline CPI as the nominal anchor.

Augmented Dickey Fuller (ADF), Phillips Perron (PP) and Kwiatkowski–Phillips–Schmidt–Shin (KPSS) unit root tests including an intercept and trend (on visual inspection), are conducted for all three variables. Presence of unit root is detected in all cases. Log-differenced values are found to be stationary at levels and therefore used in the study. Johansen Tests are carried out for cointegration. Neither Trace nor Maximum Eigenvalue Test detects any cointegrating relationship between the levels of GDP-WPI and GDP-CPI, establishing that their differenced values can be used for a VAR analysis.

3.2 Cyclical behavior of variables

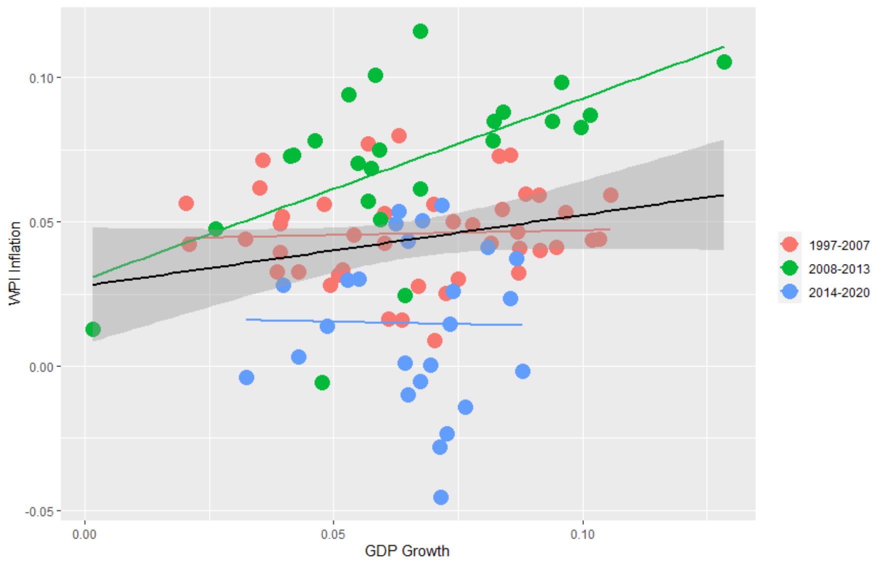
Correlation between output and inflation can shed light on the nature of shocks in an economy. According to Shapiro (1987), a positive correlation would imply that inflation and output move in the same direction, so demand fluctuations are the predominant business cycle shocks in the economy. If the correlation is negative, supply shocks, which move the two variables in two opposite directions, would dominate over the business cycle and the aggregate demand relationship is assumed to be relatively stable. While this is not always true for an open economy in the presence of external shocks generating spillovers, we examine this for India under the assumption that demand and supply shocks in this study individually incorporate the underlying effects of all other shocks.

Comparison of fluctuations in output and inflation (de-trended and log-differenced) for Indian time series data yields no clear cyclical relationship between the two (see Figure 4, Appendix). Some periods show that inflation moves in a pro-cyclical way, while in others it is unclear. WPI shows a weak countercyclical tendency towards the later part of the analysis period, but it is difficult to clearly ascertain whether business cycles in India are demand-driven or supply-driven. Cross correlation is reported in Tables 1 and 2 (see Appendix).

3.3 Visual inspection of the relationship between output growth and inflation

The scatter plot of GDP growth vs WPI inflation shown in Figure 5 (top panel) is divided over three periods 1997 to 2007, 2008 to 2013 and 2014 to 2020. Regression lines have been fitted for each period, and the black line shows the regression line fitted for the entire period. The plot points towards a completely elastic (horizontal) relationship between the first and third periods. Only 2008-2013 shows a positive slope. The overall regression line is essentially flat with a small positive slope.

The corresponding scatter plot between GDP growth and CPI inflation in Figure 5 (bottom panel) show similar trends, i.e., horizontal over 1997-2007 and a little steeper over the next period. In the period 2014-2020, the relationship shows a slight negative slope. However, the overall regression line with CPI has a flatter slope than that with WPI.



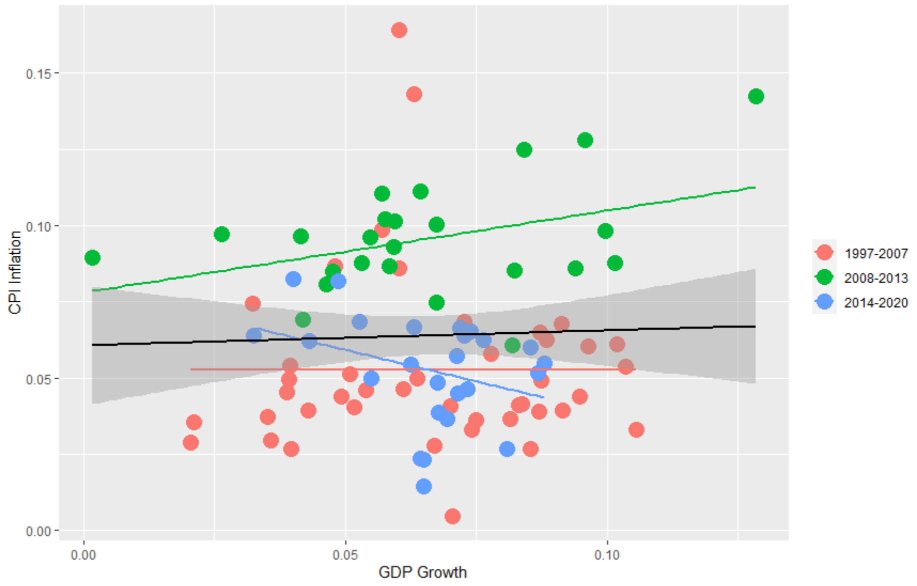


Figure 5: Scatter Plot of GDP Growth vs WPI Inflation (top) and CPI Inflation (bottom)

Source: Author's own estimation over the period 1997-2020 based on data from FRED, St Louis Database and RBI DBIE

3.4 Methodology

Our bivariate Structural Vector Autoregression (SVAR) framework uses long-run identifying restrictions and two recursive orderings of causality between demand and supply shocks - following the alternative AD-AS model adopted by Cover et al (2006). Long-run restrictions pre-specify a relationship between endogenous variables and shocks in the long term. Using this model, we estimate the parameters – contemporaneous correlation between shocks and slope of the AS curve. This is done under VSC and HSC restrictions using CPI as well as WPI. An IRF and FEVD analysis is also conducted to understand the dynamic effects of shocks. The results enable inference of which identification is best suited to the Indian economy. Implications for policy are drawn out.

4. Conceptual Correlation between Demand and Supply Shocks

Demand shocks and supply shocks are likely to be correlated in a variety of different scenarios. Adverse supply shocks, which give rise to lower output and employment, can trigger a demand contraction from economic agents who end up with a lower income. Demand contraction can also be policy induced to stick to a predefined inflation target.

Demand shocks cause the AS curve to shift when higher export demand, for instance, leads to a higher level of employment in the domestic industry and in turn a higher level of output. This is especially true for a labour-surplus country where increases in employment can be made without changes in the wage rate. Lucas (1973) points out how a change in perception about aggregate demand can temporarily affect the production levels of a firm. The concept of 'hysteresis' was also discussed by Blanchard & Summers (1986) in the labour market context. They pointed out that cyclical demand shocks can have persistent and long-term effects on natural rates of unemployment and output.

Illustrations on positively correlated demand and supply shocks follow. Two extreme cases, using an inelastic VSC and a perfectly elastic HSC, show the range of possibilities. Two cases are listed under each specification – a shift in AD and a shift in AS. These cases include two subcases each – one where the shocks are uncorrelated, and another, where the first shock induces a second shock. Under VSC, the demand shock should account for most of the measured inflation; the supply shock should explain a major part of output and have little sustained impact on inflation. Under HSC, demand shocks should explain most of the variation in measured output and its effect on inflation should not be that significant. Supply shocks should account for a major part of inflation.

While in reality the Indian AS curve may lie somewhere in between VSC and HSC, the present study applies both these restrictions to understand what elasticity and correlation structures are better supported by Indian time series data. Below we discuss the dynamics of the shifts in AD and AS curves under the assumptions of correlated and uncorrelated shocks. Figures 6 and 7 depict the outcomes for all the cases.

4.1 VSC Case

a. A positive AD shock - Shift in AD alone raises price without any change in output *y.* If AD induces a shift in AS, price should decrease from its previous level but overall increase if the magnitude of change in AD is less than that of AS. Therefore, if shocks are correlated, AD shock can influence output; and its contribution to change in price is lower. This would be the case of demand led productivity improvements.

b. A positive AS shock – A shift in AS alone should lower prices and increase output. In case AS induces a shift in AD, price increases without any change in output, from the AD shift. The final change in price level should depend on the magnitude of AD shock relative to the AS shock. If change in AD is smaller than that in AS price should overall fall, which means that an AS shock brings about a lower decrease in the price level in the correlated case as compared to the uncorrelated case.

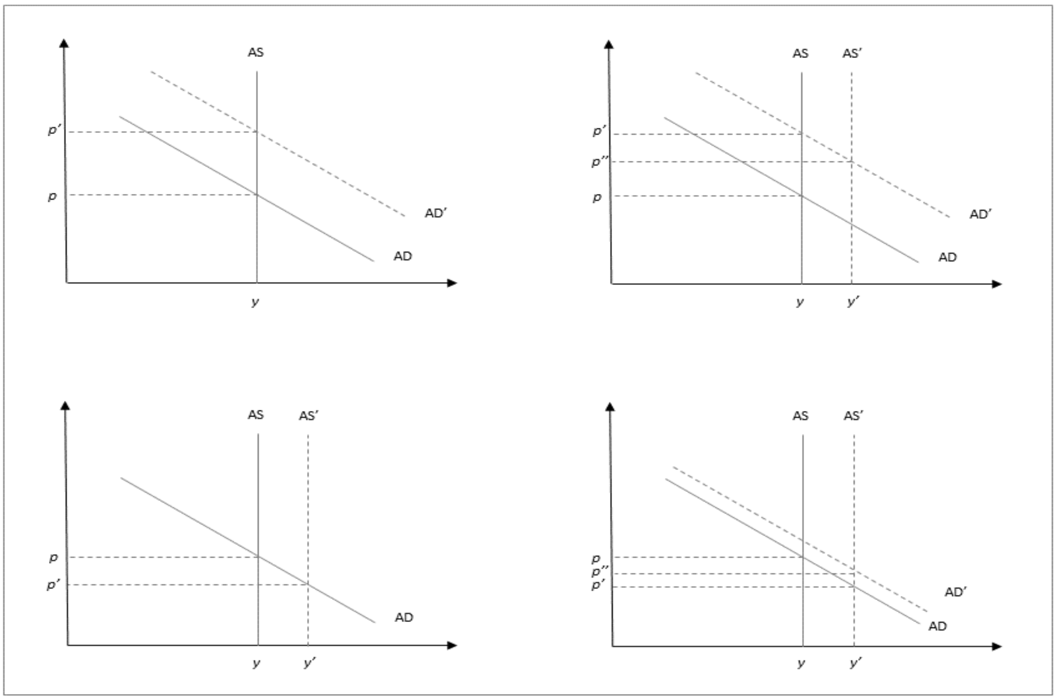


Figure 6: VSC case: Shift in AD and AS curves for correlated and uncorrelated shocks
Source: Author

4.2 HSC Case

a. A positive AD shock - A shift in AD alone would raise output with price levels remaining unchanged. If shocks are correlated, that is, if AD induces a shift in AS, price falls and output increases further. Therefore, AD can influence price levels under HSC if shocks are correlated. Contribution of AD to output change is also greater. This is the case of demand induced rise in productivity that reduces prices.

b. A positive AS shock – A shift in AS alone should lower prices and increase output. If AS causes AD to shift, output increases again without any further change in price. Therefore, under correlated shocks, contribution of AS to a change in output is higher.

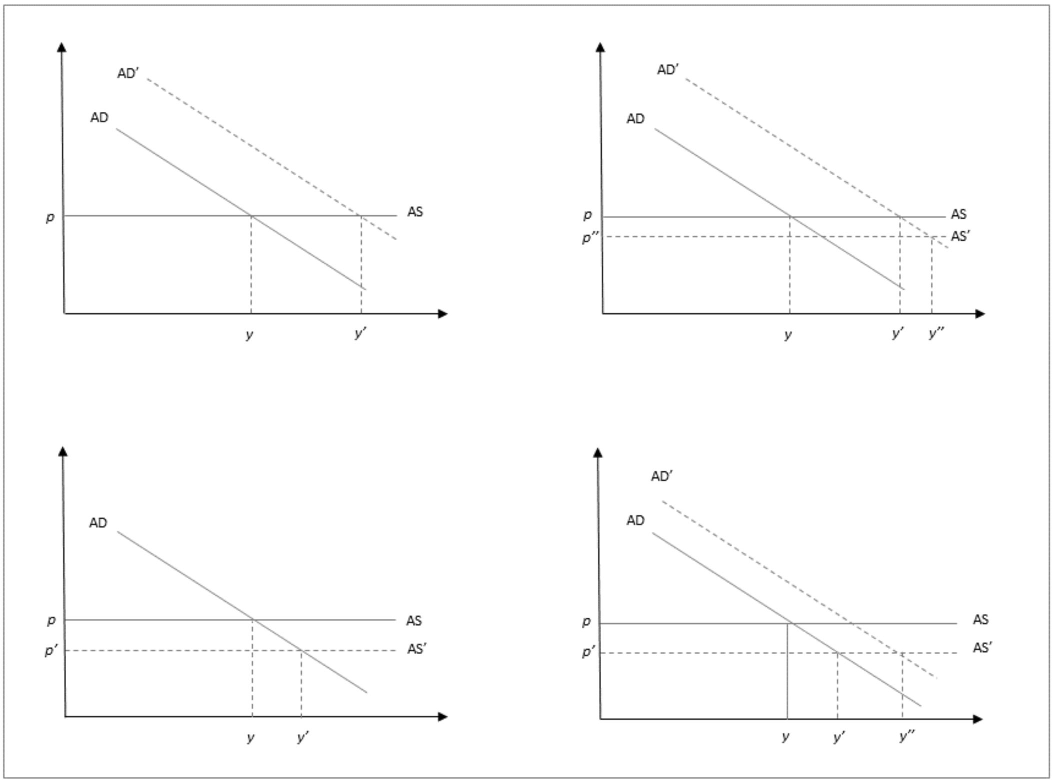


Figure 7: HSC case: Shift in AD and AS curves for correlated and uncorrelated shocks
Source: Author

5. Overview of the Model

This model follows from the alternative identification model first proposed by Cover et al (2006) and later used by Bashar (2011, 2012) and Mendieta-Munoz (2018).

In the simple three-equation system for the standard AD-AS model, we have

$$y_t^s = E_{t-1}y_t^s + \alpha(\pi_t - E_{t-1}\pi_t) + \vartheta_t^s, \ \ \alpha > 0 \qquad (1.1.1)$$

$$\left(y_t{}^d + \pi_t\right) = E_{t-1}\left(y_t{}^d + \pi_t\right) + \vartheta_t^d, \qquad (1.1.2)$$

$$y_t^d = y_t^s \qquad (1.1.3)$$

The first equation represents a variant of the Lucas AS curve, where aggregate supply is determined by the expectation of its value in the previous period, unanticipated changes in the price level, and a random supply shock ϑ_t^s. The second equation is the AD relationship which relates nominal aggregate demand to its expected value plus a random disturbance, ϑ_t^d. The third equation represents the equilibrium condition.

The independent supply and demand shocks are expressed as $b_{11}\varepsilon_t^s$ and $b_{22}\varepsilon_t^d$, with ε_t^s and ε_t^d being independent and having unit variance each; b_{11} and b_{22} are the standard deviations of the actual demand and supply shocks ϑ_t^d and ϑ_t^s. If the shocks are uncorrelated, we write

$$\begin{bmatrix}\vartheta_t^d \\ \vartheta_t^s\end{bmatrix} = \begin{bmatrix} b_{11} & 0 \\ 0 & b_{22}\end{bmatrix}\begin{bmatrix}\varepsilon_t^d \\ \varepsilon_t^s\end{bmatrix} \quad (1.2)$$

a. If demand shocks are causally prior to the supply shocks, we can write the aggregate supply shock as the sum of an independent supply shock and a component induced from the demand shock. Therefore, $\vartheta_t^d = b_{11}\varepsilon_t^d$ and $\vartheta_t^s = \rho\left(b_{11}\varepsilon_t^d\right) + b_{22}\varepsilon_t^s$, that is

$$\begin{bmatrix}\vartheta_t^d \\ \vartheta_t^s\end{bmatrix} = \begin{bmatrix} b_{11} & 0 \\ \rho b_{11} & b_{22}\end{bmatrix}\begin{bmatrix}\varepsilon_t^d \\ \varepsilon_t^s\end{bmatrix} \quad (1.3)$$

b. If on the other hand, supply shocks are causally prior to demand shocks, we have $\vartheta_t^d = \gamma(b_{22}\varepsilon_t^s) + b_{11}\varepsilon_t^d$; and $\vartheta_t^s = b_{22}\varepsilon_t^s$, that is

$$\begin{bmatrix}\vartheta_t^d \\ \vartheta_t^s\end{bmatrix} = \begin{bmatrix} b_{11} & \gamma b_{22} \\ 0 & b_{22}\end{bmatrix}\begin{bmatrix}\varepsilon_t^d \\ \varepsilon_t^s\end{bmatrix} \quad (1.4)$$

Here γ and ρ denote the contemporaneous response of the two shocks to each other.

Now, assuming that $E_{t-1}y_t = y_{t-1}$ and $E_{t-1}\pi_t = \pi_{t-1}$, we solve the first set of equations and get expressions for Δy_t and $\Delta\pi_t$. Assuming uncorrelated shocks in the first case and adding lagged values of inflation and output thereafter, we can get the structural VAR form as:

$$\Delta y_t + \Delta\pi_t = \sum_{j=1}^{k}\theta_{yj}\ \Delta y_{t-j} + \sum_{j=1}^{k}\theta_{\pi j}\ \Delta\pi_{t-j} + b_{11}\varepsilon_t^d \quad (1.5.1)$$

$$\Delta y_t - \alpha\Delta\pi_t = \sum_{j=1}^{k}\theta_{yj}\ \Delta y_{t-j} + \sum_{j=1}^{k}\theta_{\pi j}\ \Delta\pi_{t-j} + b_{22}\varepsilon_t^s \quad (1.5.2)$$

This is similar to a structural VAR model

$$A_0X_t = A_1(L)X_t + B\varepsilon_t \quad (1.5)$$

Where $X_t = \begin{bmatrix}\Delta y_t \\ \Delta\pi_t\end{bmatrix}$, $\varepsilon_t = \begin{bmatrix}\varepsilon_t^d \\ \varepsilon_t^s\end{bmatrix}$, $A_1(L)$ is the lag polynomial, and B contains the standard deviations and correlations between the two shocks, taking the forms $\begin{bmatrix} b_{11} & 0 \\ 0 & b_{22}\end{bmatrix}$, $\begin{bmatrix} b_{11} & 0 \\ \rho b_{11} & b_{22}\end{bmatrix}$ and $\begin{bmatrix} b_{11} & \gamma b_{22} \\ 0 & b_{22}\end{bmatrix}$ with respect to the three cases under consideration- i) uncorrelated demand and supply shocks, ii) causality from demand to supply, and iii) causality from supply to demand.

Since ε_t^s and ε_t^d are unobservable in (1.5), we estimate the Reduced Form VAR:

$$X_t = C(L)X_t + e_t \quad (1.6)$$

with the reduced form VAR residual vector $e_t = \begin{bmatrix} e_t^y \\ e_t^\pi \end{bmatrix}$ and the structural shock vector ε_t related by

$$e_t = A_0{}^{-1}B\varepsilon_t = D_0\varepsilon_t \quad (1.7)$$

This shows that the errors are a linear combination of the structural shocks. We identify from the first three equations that $A_0 = \begin{bmatrix} 1 & 1 \\ 1 & -\alpha \end{bmatrix}$. Therefore,

$$D_0 = \begin{bmatrix} d_{11}^0 & d_{21}^0 \\ d_{21}^0 & d_{22}^0 \end{bmatrix} = A_0{}^{-1}B = \begin{bmatrix} 1 & 1 \\ 1 & -\alpha \end{bmatrix}^{-1} B = \begin{bmatrix} \alpha/(1+\alpha) & 1/(1+\alpha) \\ 1/(1+\alpha) & -1/(1+\alpha) \end{bmatrix} B$$

The reduced form VAR is estimated in the following form

$$\Delta y_t = \sum_{j=1}^{k} c_{11}{}^j\ \Delta y_{t-j} + \sum_{j=1}^{k} c_{12}{}^j\ \Delta\pi_{t-j} + e_t^y \quad (1.8.1)$$

$$\Delta\pi_t = \sum_{j=1}^{k} c_{21}{}^j\ \Delta y_{t-j} + \sum_{j=1}^{k} c_{22}{}^j\ \Delta\pi_{t-j} + e_t^\pi \quad (1.8.2)$$

We can estimate the $C(L)$ matrix which contains the coefficient parameters from the results of the Reduced Form VAR. We use these values to arrive at the estimates of the parameters α, ρ and γ. The correlation parameters can be estimated by expanding the variance-covariance matrix of the residuals:

$$\Sigma_e = D_0\, E(\varepsilon_t\, \varepsilon_t')\, D_0{}' = D_0 D_0{}' \quad (1.9)$$

When causality is from demand to supply,

$$e_t = A_0{}^{-1}B\varepsilon_t = D_0\varepsilon_t$$

$$\begin{bmatrix} e_t^y \\ e_t^\pi \end{bmatrix} = \begin{bmatrix} \alpha/(1+\alpha) & 1/(1+\alpha) \\ 1/(1+\alpha) & -1/(1+\alpha) \end{bmatrix} \begin{bmatrix} b_{11} & 0 \\ \rho b_{11} & b_{22} \end{bmatrix} \begin{bmatrix} \varepsilon_t^d \\ \varepsilon_t^s \end{bmatrix}$$

Here,

$$D_0 = \begin{bmatrix} (\alpha+\rho)b_{11}/(1+\alpha) & b_{22}/(1+\alpha) \\ (1-\rho)b_{11}/(1+\alpha) & -b_{22}/(1+\alpha) \end{bmatrix} \quad (2.0)$$

From (1.9), therefore,

$$\begin{bmatrix} var(e_{yt}) & cov(e_{yt}, e_{\pi t}) \\ cov(e_{yt}, e_{\pi t}) & var(e_{\pi t}) \end{bmatrix} =$$

$$\begin{bmatrix} (\alpha+\rho)b_{11}/(1+\alpha) & b_{22}/(1+\alpha) \\ (1-\rho)b_{11}/(1+\alpha) & -b_{22}/(1+\alpha) \end{bmatrix} \begin{bmatrix} (\alpha+\rho)b_{11}/(1+\alpha) & b_{22}/(1+\alpha) \\ (1-\rho)b_{11}/(1+\alpha) & -b_{22}/(1+\alpha) \end{bmatrix}' =$$

$$\begin{bmatrix} \{(\alpha+\rho)^2\, b_{11}^2 + b_{22}^2\}/(1+\alpha)^2 & \{(\alpha+\rho)(1-\rho)\, b_{11}^2 - b_{22}^2\}/(1+\alpha)^2 \\ \{(\alpha+\rho)(1-\rho)\, b_{11}^2 - b_{22}^2\}/(1+\alpha)^2 & \{(1-\rho)^2\, b_{11}^2 + b_{22}^2\}/(1+\alpha)^2 \end{bmatrix} \quad (2.1)$$

The supply to demand ordering is outlined in the Appendix. In both the cases, we have three unique elements in the left side which can be estimated from the reduced form VAR, but four unknowns in the right side. This requires one long-run restriction for the model to be exactly identified.

The long-run level effects of structural shocks on the model $X_t = C(L)X_t + D_0\varepsilon_t$ is represented by the long-run impact matrix L, where

$$L = \begin{bmatrix} l_{11} & l_{12} \\ l_{21} & l_{22} \end{bmatrix} = (I + C + C^2 + \cdots)D_0 = (I - C)^{-1}D_0$$

a. If VSC is assumed, $L = \begin{bmatrix} 0 & l_{12} \\ l_{21} & d_{22} \end{bmatrix}$

   This implies that the demand shock has no long-run effect on output,

b. If HSC is assumed, $L = \begin{bmatrix} l_{11} & l_{12} \\ 0 & d_{22} \end{bmatrix}$

   This implies that the demand shock has no long-run effect on inflation.

Using the Wold moving average representations of X_t with respect to shocks and residuals, we can write

$$M_i = D_i D_0^{-1} \qquad (2.2)$$

This equation is important since it connects VAR impulse responses (with respect to residuals e_t) with the SVAR impulse responses (with respect to actual structural shocks ε_t). The Appendix contains the detailed processes of identifying structural shocks in the SVAR, deriving the last equation and estimating the parameters of the model.

6. Estimation of the Model

Two alternate bivariate VAR models are estimated – one with GDP Growth and WPI Inflation and the other with GDP Growth and CPI Inflation. The analysis is carried out using two lags for each model. We refrain from using too many lags so as not to lose scarce degrees of freedom due to overfitting. If too many coefficients are estimated without a large number of data points, coefficients are poorly estimated and out of sample forecasts are not reliable.

6.1 Results from the unrestricted VAR and SVAR models

The unrestricted VAR responses from GDP-WPI model (Figure 8) show that unit positive shocks to GDP growth move GDP growth and WPI inflation in the same, positive direction; and unit positive shocks to WPI inflation raise inflation and lower GDP growth. In the absence of any structural restrictions on the model, shocks to WPI Inflation affect GDP Growth for a longer period of time (at least 12 quarters) while that to WPI Inflation converges to zero within 6 quarters. Response plots of the second model with GDP growth and CPI inflation are similar and available on request.

Standard diagnostic tests for residual autocorrelation (VAR residual autocorrelation LM test) and heteroscedasticity (White test) for the model suggest no autocorrelation or heteroscedasticity in the models. A visual inspection of the residuals in both VAR models shows them to be randomly distributed (see Figures 9 and 10, Appendix).

Long-run coefficients of the SVAR, i.e., elements of the L matrix are then estimated applying two different restrictions – VSC and HSC. Results are reported in Tables 3 and 4 (Appendix).

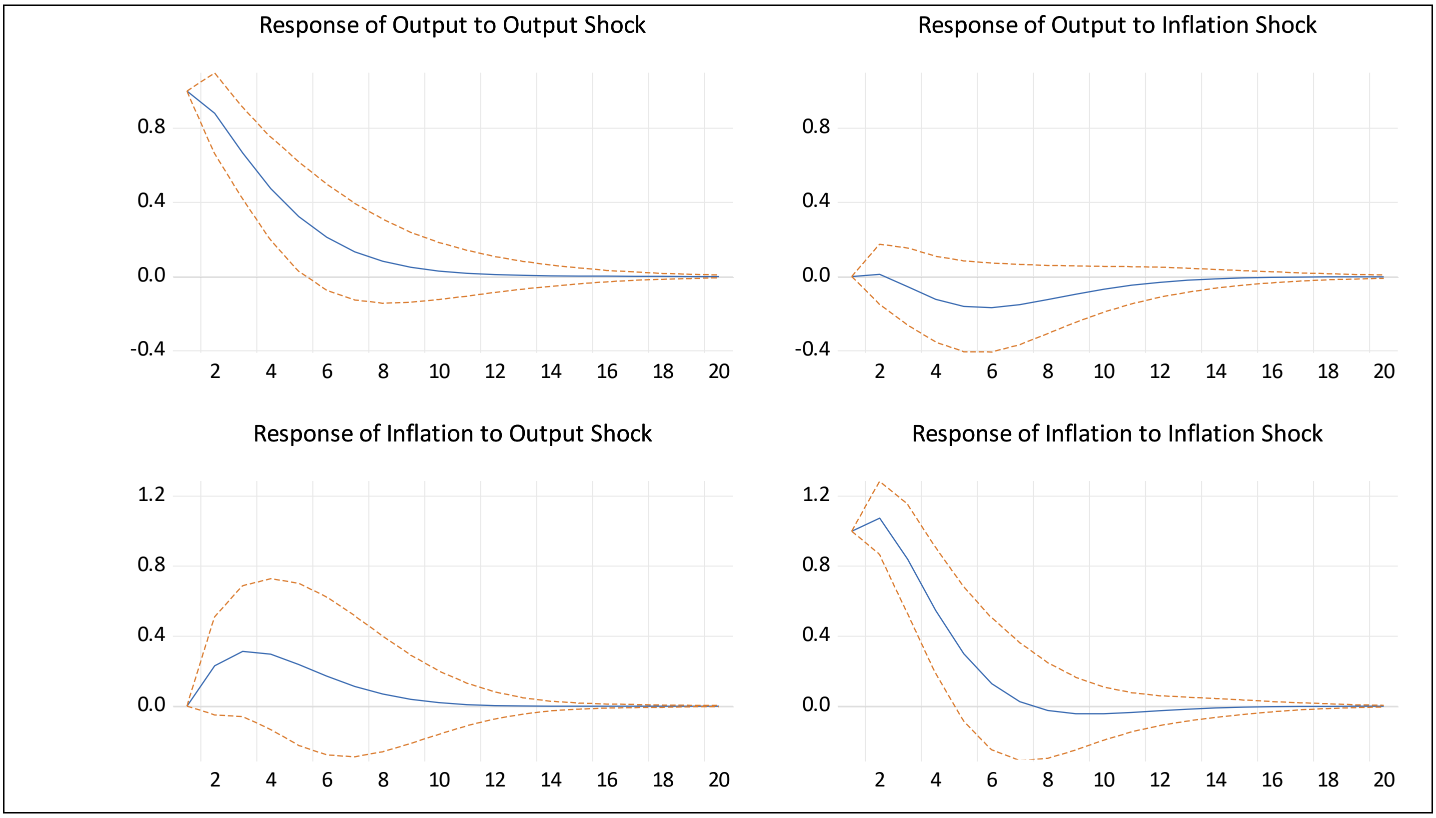


Figure 8: Unrestricted Impulse Response Functions for Output (GDP Growth) and Inflation (WPI Inflation)

Source: Author's own estimation over the period 1997-2020 based on data from FRED, St Louis Database and RBI DBIE

6.2 Estimation of Parameters

To elaborate, γ and ρ are not by construction the correlation coefficients between the shocks. Rather, they are the slope coefficients when the shocks ϑ_t^s and ϑ_t^d are regressed on one another. ρ is a proxy for the extent of forward-looking behaviour of firms in the economy, while γ can be interpreted as the extent of policy response to supply shocks. (1/ α) reflects the slope of the short-run AS curve, or the sensitivity of output to a change in inflation. Tables 5 and 6 (Appendix) report the parameters estimated from the VSC model for the two causalities.

Cover et al (2006) estimate structural parameters for US and find $\alpha = 1.55$, and overall higher correlation (γ and ρ) values for both causalities. Mendieta-Munoz (2018) estimates $\alpha = 0.210$ for the Mexican economy. Bashar (2012) finds α varying between 0.099 to 1.389 for the five ASEAN countries. The present study when conducted for India under the same VSC restriction gives us $\alpha = 0.27$ for GDP-WPI and $\alpha = 0.64$ for GDP-CPI. This implies that the Indian AS curve is sufficiently elastic, even under the VSC restriction. Relationship between GDP Growth and CPI Inflation comes out to be more elastic than that between GDP Growth and WPI Inflation.

The correlation between demand and supply shocks in all eight cases come out to be positive**,** implying that AD and AS are likely to move together. This is consistent with literature. It is also observed that in the Indian case, policy response parameter is greater than the forward-looking parameter. Applying the HSC restriction provides us with another set of slope and correlation parameters. The new parameters obtained from HSC are reported in Tables 7 and 8 (Appendix); and all the slopes are compared in Figure 11.

7. Results from Impulse Response and Variance Decomposition Analysis

The dynamic impacts of the shocks on the policy variables are observed by constructing IRF plots and deriving FEVD tables for all cases. Impulse responses trace the effects of structural shocks on each endogenous variable over time and FEVDs give us the proportion of the forecast error variance that can be attributed to each shock in the model at different forecast horizons.

We report the findings from IRFs and FEVD for all correlated and uncorrelated cases for the GDP-WPI SVAR as well as the GDP-CPI SVAR. This is done under both VSC and HSC identifying assumptions. It should be noted that demand and supply shocks in the following analysis are both positive shocks. FEVD tables are placed in the appendix. IRF plots not present in the appendix are available on request.

7.1 VSC Identification (GDP and WPI)

Comparison between FEVD of the three cases under VSC (GDP and WPI) is summarized in Table 9. In the uncorrelated shock case of GDP-WPI under VSC, response of demand shock to output is not significant. Supply shock is significant and the main contributor to the variations in output (80 per cent in the first quarter) while demand shock explains most of the inflation (83 per cent in the first quarter). The share of each also rises over time, consistent with the long-run restrictions imposed. The IRFs (Figure 12) show directionally consistent responses of output and inflation to the shocks – output rises with respect to both shocks while inflation falls with a supply shock and rises with a demand shock.

When AD is assumed to induce changes in AS, the contribution of AD shock to the variation in output increases (to 46 per cent) and that to the variation in inflation decreases (see Table 7). Demand shock becomes significant for output till the 3rd quarter. This result is consistent with the findings of Cover et al – that under VSC, with assumption of correlation of shocks and causality running from demand to supply, the contribution of demand shocks to output rises.

When AS induces AD to shift in the same direction under VSC, output should ultimately rise and price should fall due to the shift in AS and then rise because of the shift in AD. Given that the magnitude of shift in AD is less than that of the AS, the AS shock should finally bring about a lower fall in prices in the case of correlated shocks. This is confirmed by the lower contribution of AS shock to inflation. The variation in output explained by AS is similar to the uncorrelated case, as expected.

7.2 VSC Identification (GDP and CPI)

Comparison between FEVD of the three cases under VSC (GDP and CPI) is summarized in Table 10. The main difference of the CPI uncorrelated case with that of the WPI uncorrelated case is that supply shock explains a greater variation of inflation in this case - 51 per cent in the 20th quarter, as opposed to 12 per cent in the WPI case. The effect is significant, large, sustained, and rises over time. This is expected because the CPI basket contains a large share of commodities which are vulnerable to supply shocks. Moreover, demand shock also plays a larger role in explaining output variation – 44 per cent in the last quarter compared to 14 per cent for WPI. The size of this demand shock also rises over time. Therefore, even under the VSC restriction, the CPI analysis shows that the AS curve is considerably elastic.

The effect of demand shock on output increases when AS also shifts with AD. Inflation variation explained by AD shock decreases, although the results do not differ significantly from the uncorrelated case. Therefore, a larger impact of AD on output under VSC in the presence of correlated shocks is observed. On the other hand, when causality is from AS to AD, the contribution of AS shock to output increases and that to inflation decreases. However, the results are similar to that of the uncorrelated case.

7.3 HSC Identification (GDP and WPI)

Comparison between FEVD of the three cases under VSC (GDP-CPI) is summarized in Table 11. When HSC is assumed under uncorrelated shocks, demand shock becomes the main explanatory shock for output – at 60 per cent in the first quarter - which settles at 55 per cent in the last quarter. AS shock, on the other hand, now has a large and persistent effect on inflation – 91 per cent in the first quarter and stays at 87 per cent till the end.

When causality is from demand to supply, the contribution of demand shock to price rises, as expected. In fact, demand shock now has a greater effect on inflation than the uncorrelated case. When causality is from supply to demand, supply shock has a large and persistent effect on inflation – at more than 98 per cent in both the first quarter and the last. Contribution of demand shock to output variation also increases compared to the uncorrelated case – starts at 83 per cent and settles at 86 per cent in the last quarter. Both these results are consistent with the HSC restriction. Impulse responses are plotted in Figure 13.

7.4 HSC Identification (GDP and CPI)

Comparison between FEVD of the three cases under HSC (GDP-CPI) is summarized in Table 12. Under HSC, in the CPI case of uncorrelated shocks, size of AS shock affecting inflation is a little higher than that of the WPI case with uncorrelated shocks. AS shock explains more than 99 per cent of the variation in inflation in the first quarter and remains stable till the last quarter. On the other hand, demand shock explains more output variation (62 per cent, first quarter) than does the supply shock. Inflation does not respond significantly to the demand shock.

When causality is from demand to supply, contribution of AD shock to variation in inflation rises as expected. Contributions of supply and demand shocks to output are similar in size, with supply shock contributing a little more. When causality is from supply to demand, demand shock has a huge effect on output and supply shock has a huge effect on inflation. Both these effects are significant, highly persistent and their sizes are greater than 99 per cent. Therefore, this approximation might be well-suited for Indian time series data on inflation and output.

7.5 Analysis

The HSC and VSC identifications hold in the long-run and therefore do not constrain short-run impulse responses. However, even in the long-run (ten quarters) when impulse responses have stabilized, the contribution of demand and supply shocks to output and inflation is mixed and differs for CPI as compared to

WPI inflation. One reason for this could be correlated shifts in demand and supply. Therefore, we estimate the models with correlated shifts.

As expected in all equivalent simulations the initial contribution of supply shocks to CPI inflation remains larger than to WPI inflation, since the weight of food is higher in the consumption basket. Therefore, CPI is more vulnerable to supply side shocks. If causality is from demand to supply, output variation explained by demand shocks rises under VSC as in Cover et.al (2006). The reverse causality from supply to demand is close to the uncorrelated VSC. This is the neo-classical case of forward-looking agents whose demand adjusts to supply determined by technology, or of a policy contraction following a supply shock. Under HSC, however, it is when causality is from supply to demand that output becomes almost fully demand determined while supply determines inflation. And this holds for both WPI and CPI.

If the causality runs from demand to supply, there is not much change in the shares of demand and supply shocks. The slight changes are in expected directions. The differences in CPI and WPI remain. If the causality runs from supply to demand, however, for both CPI and WPI inflation, the share of output due to demand shocks rises steeply under the HSC and inflation becomes almost wholly determined by supply shocks.

8. Conclusion

The main research question that we explore through this work is finding out the relative shares of demand and supply shocks on output and inflation, allowing correlation between shocks. We obtain point estimates of the contemporaneous correlation between shocks and slope of the short-run AS slope under different identifying assumptions. We find a positive correlation between demand and supply shocks under all assumptions. In our estimation, policy response parameter is greater than the forward-looking parameter. This supports policy reactions as the drivers of positive correlations.

Estimations and other model results support an elastic AS curve for India. This poses a significant challenge to the inflation targeting framework of RBI since the structure of the Indian AS curve is such that demand tightening policy under negative supply shocks hurts growth more than it controls inflation. We also find supply side factors to be an important determinant of inflation in India, thus reaffirming the asymmetry in structure between the aggregate supply relationships of emerging markets and advanced economies. Due to a larger share of food items in CPI basket, CPI is found to be more sensitive to relative price changes than WPI.

The results give an important policy lesson. In the Indian case where unemployment makes the long-run aggregate supply elastic, but bottlenecks and rigidities make it subject to a large number of shocks, a sharp policy response to a supply shock actually increases the impact of demand shocks on output and supply shocks on inflation. Monetary authorities should therefore avoid reacting to temporary cost push shocks in the short run. The inflation targeting framework should instead focus on anchoring inflation expectations. Transparent and credible communication on the part of RBI will prevent inflationary wage-price spirals. Fiscal and monetary policies should also coordinate to foster structural supply-side improvements. This will help move the Indian AS curve downwards over time.

The study is limited in its use of a simplified bivariate model under the assumption that aggregate demand and supply shocks capture the dynamic effects of many other underlying shocks. Future studies can expand the present model to include more macroeconomic variables such as world interest rates and exchange rates to isolate the effects of shocks on output and inflation more clearly.

9. Appendix

a. Figures

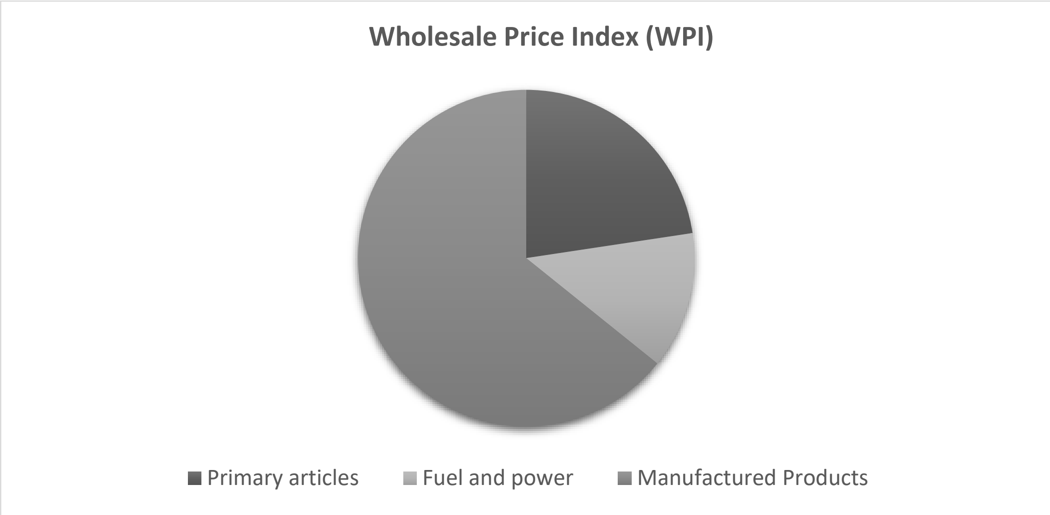


Figure 2: Composition of WPI

Source: MANUAL ON WHOLESALE PRICE INDEX (Base 2011-12=100), Office of the Economic Advisor, Department of Industrial Policy and Promotion, Ministry of Commerce and Industry, Government of India (https://eaindustry.nic.in/)

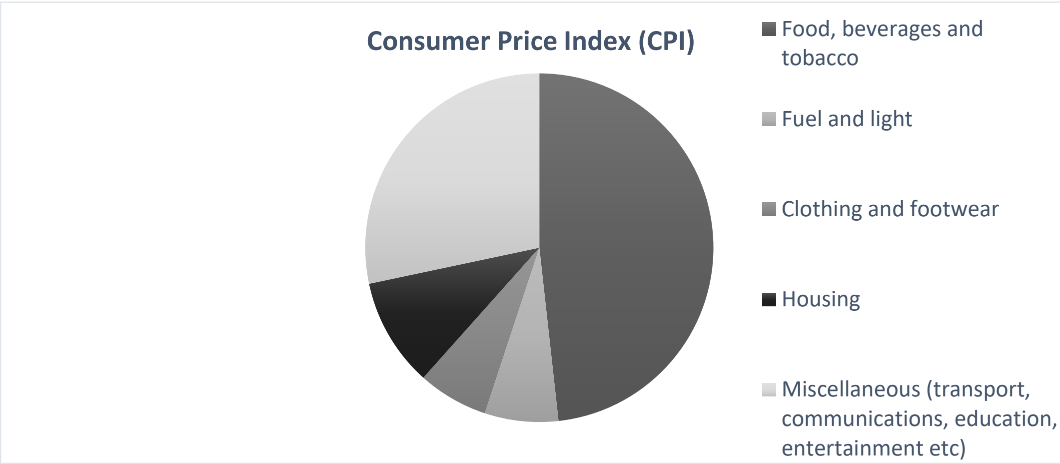


Figure 3: Composition of CPI

Source: CONSUMER PRICE INDEX, Changes in the Revised Series (Base Year 2012=100), Ministry of Statistics and Programming Implementation, Central Statistics Office, National Accounts Division, Prices and Cost of Living Unit (2015)

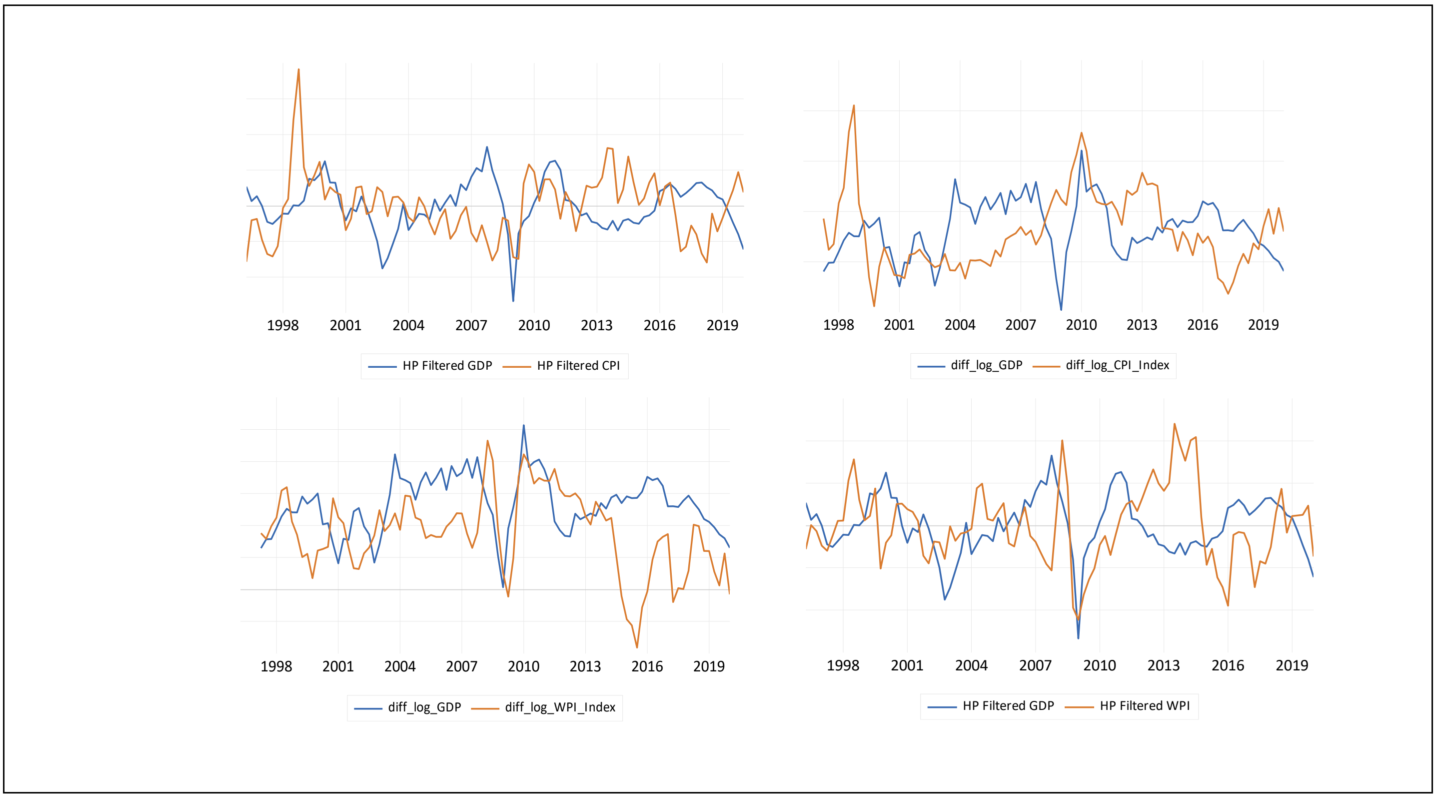


Figure 4: Fluctuations in cyclical GDP and Inflation (1997Q2-2020Q1)

Source: Author's own estimation over the period 1997-2020 based on data from FRED, St Louis Database and RBI DBIE

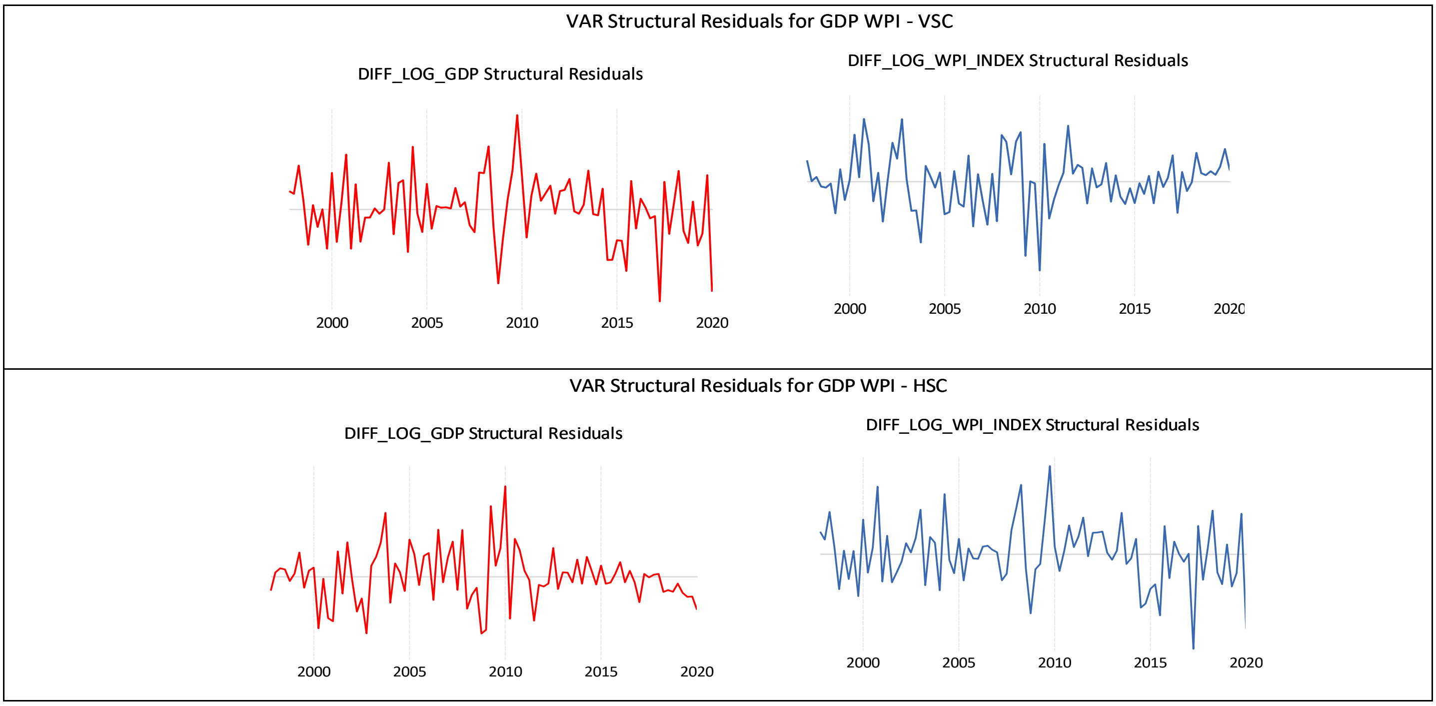


Figure 9: Residuals for GDP WPI VAR model- VSC (top panel) and HSC (bottom panel)

Source: Author's own estimation over the period 1997-2020 based on data from FRED, St Louis Database and RBI DBIE

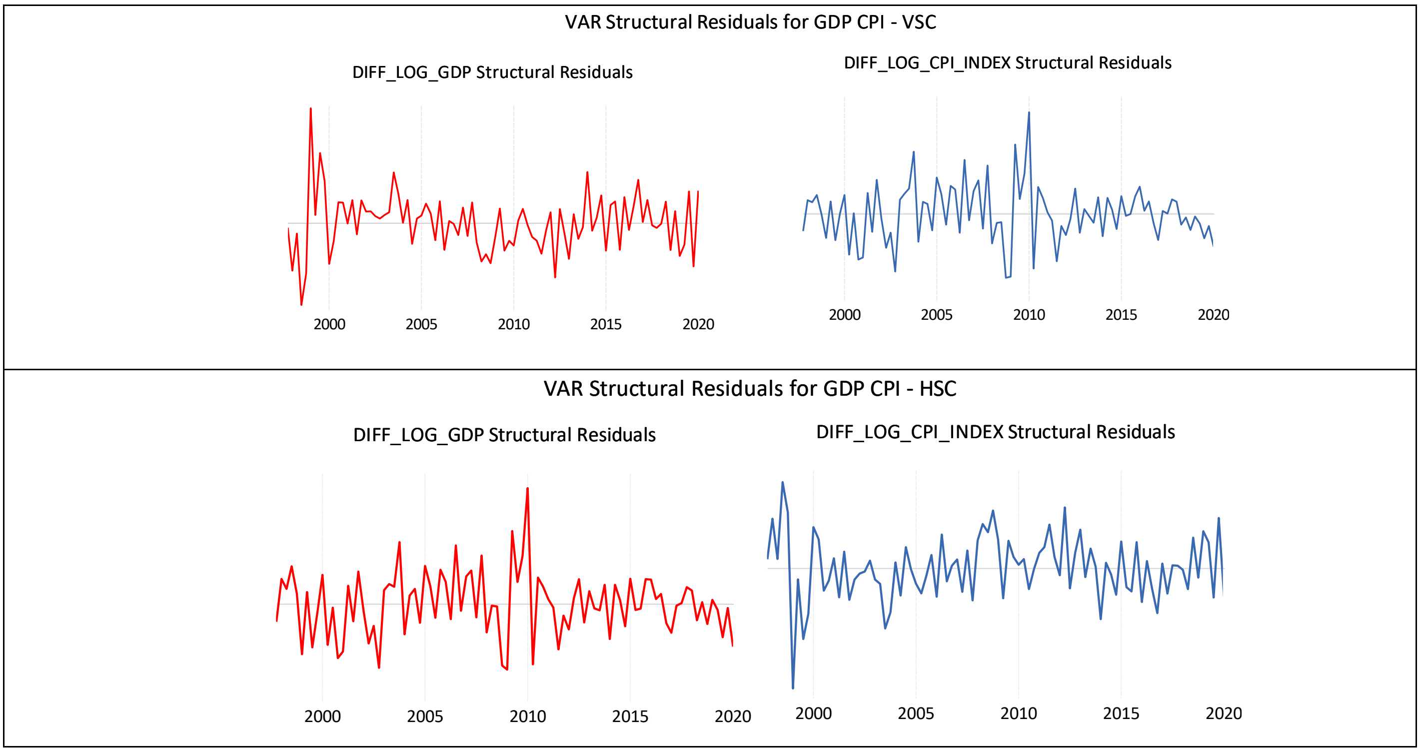


Figure 10: Residuals for GDP CPI VAR model- VSC (top panel) and HSC (bottom panel)

Source: Author's own estimation over the period 1997-2020 based on data from FRED, St Louis Database and RBI DBIE

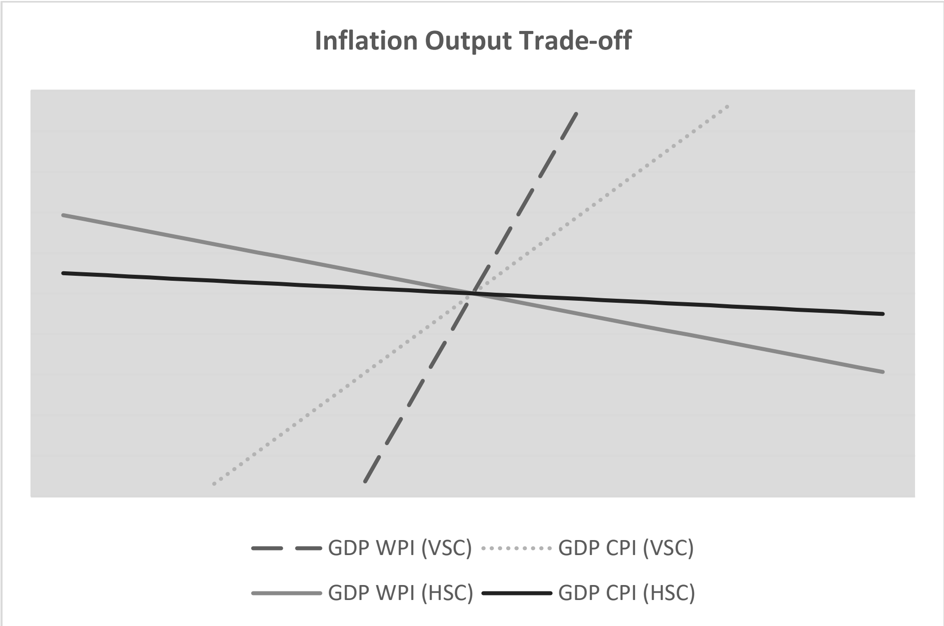


Figure 11: Inflation Output Trade-off for all cases

Source: Author's own estimation over the period 1997-2020 based on data from FRED, St Louis Database and RBI DBIE

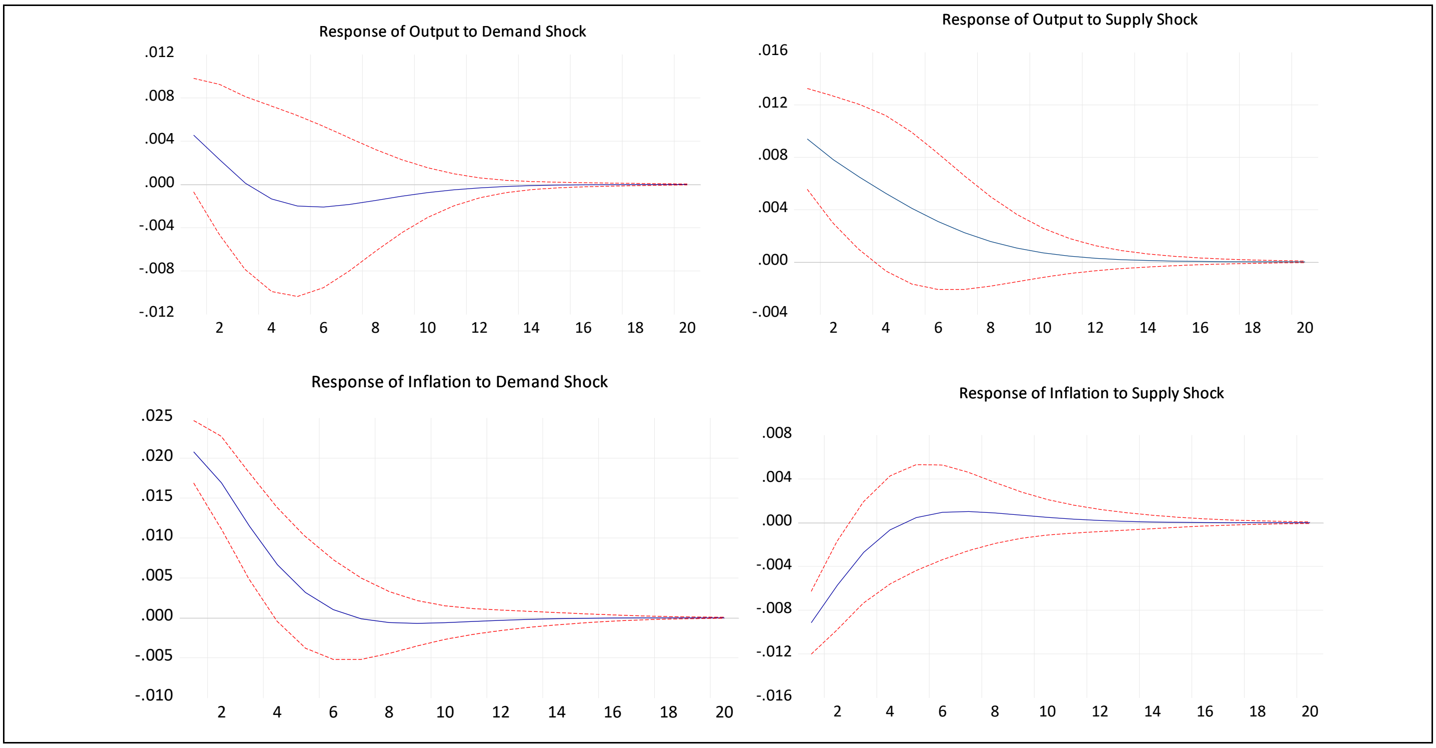


Figure 12: Structural IRFs for Uncorrelated Shocks - VSC (GDP and WPI)

Source: Author's own estimation over the period 1997-2020 based on data from FRED, St Louis Database and RBI DBIE

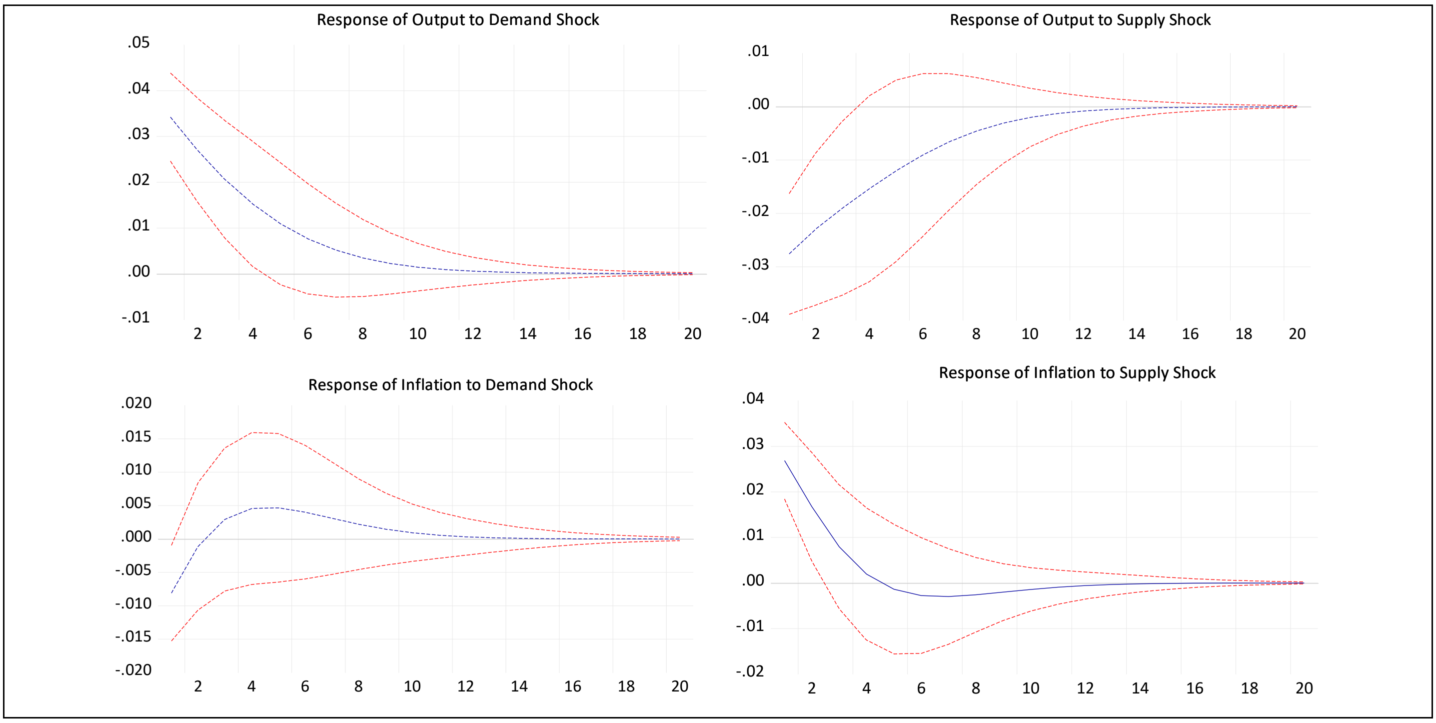


Figure 13: Structural IRFs for Uncorrelated Shocks - HSC (GDP and WPI)

Source: Author's own estimation over the period 1997-2020 based on data from FRED, St Louis Database and RBI DBIE

b. Tables

Source of all tables is author's own estimation based on data from FRED, St Louis Database and RBI Database on Indian Economy. Period of estimation is 1997Q2 to 2020Q1.

Table 1: Cross Correlation of GDP with lags/leads of WPI (log-differenced)

i	lag	lead
0	0.1751	0.1751
1	0.0378	0.2358
2	-0.0827	0.2165
3	-0.1131	0.1313
4	-0.0629	0.0392
5	-0.0231	-0.0074

Table 2: Cross Correlation of GDP with lags/leads of CPI (log-differenced)

	lag	lead
0	0.0356	0.0356
1	0.0569	-0.0045
2	0.0950	-0.1134
3	0.1060	-0.1920
4	0.1363	-0.2057
5	0.1435	-0.1514

Table 3: Long-run SVAR coefficients - VSC Identification

	GDP-WPI		GDP-CPI	
	Coefficient	Standard Error (p-value in brackets)	Coefficient	Standard Error (p-value in brackets)
d_{12}	0.069729	0.005197 (0.0000)	-0.085837	0.006398 (0.0000)
d_{21}	-0.053773	0.004008 (0.0000)	0.053803	0.004010 (0.0000)
d_{22}	-0.004234	0.007357 (0.5650)	-0.016430	0.009131 (0.0719)

Table 4: Long-run SVAR coefficients - HSC Identification

	GDP-WPI		GDP-CPI	
	Coefficient	Standard Error (p-value in brackets)	Coefficient	Standard Error (p-value in brackets)
d_{11}	0.053674	0.004001 (0.0000)	0.052843	0.003939 (0.0000)
d_{12}	0.003259	0.005663 (0.5650)	-0.010115	0.005621 (0.0719)
d_{22}	0.069857	0.005207 (0.0000)	0.087395	0.006514 (0.0000)

Table 5: Parameters estimated for VSC - Supply to Demand Case

	α	γ	${b_{11}}^2$	${b_{22}}^2$
GDP-WPI	0.27	0.629	1.90E-04	4.64E-04
GDP-CPI	0.64	0.104	2.75e-05	0.000451

Table 6: Parameters estimated for VSC - Demand to Supply Case

	α	ρ	${b_{11}}^2$	${b_{22}}^2$
GDP-WPI	0.27	0.221	5.39e-04	1.63e-04
GDP-CPI	0.64	0.063	5.63e-05	3.48e-05

Table 7: Parameters estimated for HSC – Supply to Demand Case

	α	γ	${b_{11}}^2$	${b_{22}}^2$
GDP-WPI	-2.45	0.475	5.39e-05	2.15e-03
GDP-CPI	-9.46	0.116	0.000145	2.27e-02

Table 8: Parameters estimated for HSC – Demand to Supply Case

	α	ρ	${b_{11}}^2$	${b_{22}}^2$
GDP-WPI	-2.45	1.893	5.39e-04	2.15e-04
GDP-CPI	-9.46	5.832	4.54e-04	7.28e-03

Table 9: FEVD Tables - VSC (GDP and WPI)

Quarters	Uncorrelated Shocks				Demand to Supply				Supply to Demand			
	Response of Output to		Response of Inflation to		Response of Output to		Response of Inflation to		Response of Output to		Response of Inflation to	
	AD Shock	AS Shock	AD Shock	AS Shock	AD Shock	AS Shock	AD Shock	AS Shock	AD Shock	AS Shock	AD Shock	AS Shock
1	0.19	0.81	0.837	0.163	0.462	0.538	0.807	0.193	0.127	0.873	0.995	0.005
2	0.149	0.851	0.86	0.14	0.418	0.582	0.839	0.161	0.102	0.898	0.997	0.003
3	0.12	0.88	0.873	0.127	0.375	0.625	0.856	0.144	0.086	0.914	0.994	0.006
5	0.113	0.887	0.878	0.122	0.345	0.655	0.863	0.137	0.084	0.916	0.99	0.01
7	0.119	0.881	0.879	0.121	0.329	0.671	0.865	0.135	0.091	0.909	0.987	0.013
9	0.129	0.871	0.878	0.122	0.322	0.678	0.864	0.136	0.101	0.899	0.985	0.015
11	0.137	0.863	0.878	0.122	0.32	0.68	0.863	0.137	0.108	0.892	0.983	0.017
13	0.142	0.858	0.877	0.123	0.32	0.68	0.863	0.137	0.113	0.887	0.983	0.017
17	0.145	0.855	0.877	0.123	0.32	0.68	0.862	0.138	0.116	0.884	0.983	0.017
20	0.146	0.854	0.876	0.124	0.32	0.68	0.862	0.138	0.117	0.883	0.983	0.017

Table 10: FEVD Tables - VSC (GDP and CPI)

Quarters	Uncorrelated Shocks				Demand to Supply				Supply to Demand			
	Response of Output to		Response of Inflation to		Response of Output to		Response of Inflation to		Response of Output to		Response of Inflation to	
	AD Shock	AS Shock	AD Shock	AS Shock	AD Shock	AS Shock	AD Shock	AS Shock	AD Shock	AS Shock	AD Shock	AS Shock
1	0.364	0.636	0.731	0.269	0.414	0.586	0.712	0.288	0.335	0.665	0.783	0.217
2	0.378	0.622	0.692	0.308	0.428	0.572	0.67	0.33	0.348	0.652	0.743	0.257
3	0.396	0.604	0.64	0.36	0.444	0.556	0.613	0.387	0.365	0.635	0.688	0.312
5	0.412	0.588	0.592	0.408	0.459	0.541	0.561	0.439	0.379	0.621	0.636	0.364
7	0.424	0.576	0.553	0.447	0.47	0.53	0.521	0.479	0.39	0.61	0.593	0.407
9	0.432	0.568	0.526	0.474	0.477	0.523	0.493	0.507	0.398	0.602	0.562	0.438
11	0.437	0.563	0.507	0.493	0.482	0.518	0.474	0.526	0.403	0.597	0.541	0.459
13	0.44	0.56	0.495	0.505	0.484	0.516	0.462	0.538	0.406	0.594	0.527	0.473
17	0.442	0.558	0.487	0.513	0.485	0.515	0.454	0.546	0.407	0.593	0.518	0.482
20	0.442	0.558	0.482	0.518	0.486	0.514	0.45	0.55	0.408	0.592	0.512	0.488

Table 11: FEVD Tables - HSC (GDP and WPI)

Quarters	Uncorrelated Shocks				Demand to Supply				Supply to Demand			
	Response of Output to		Response of Inflation to		Response of Output to		Response of Inflation to		Response of Output to		Response of Inflation to	
	AD Shock	AS Shock	AD Shock	AS Shock	AD Shock	AS Shock	AD Shock	AS Shock	AD Shock	AS Shock	AD Shock	AS Shock
1	0.606	0.394	0.083	0.917	0.461	0.539	0.807	0.193	0.83	0.17	0.018	0.982
2	0.596	0.404	0.062	0.938	0.417	0.583	0.838	0.162	0.859	0.141	0.011	0.989
3	0.585	0.415	0.066	0.934	0.374	0.626	0.855	0.145	0.881	0.119	0.011	0.989
5	0.575	0.425	0.082	0.918	0.344	0.656	0.862	0.138	0.888	0.112	0.0122	0.987
7	0.568	0.432	0.099	0.9	0.328	0.672	0.864	0.136	0.884	0.116	0.015	0.985
9	0.564	0.436	0.11	0.89	0.321	0.679	0.863	0.137	0.877	0.123	0.017	0.983
11	0.561	0.439	0.116	0.884	0.319	0.681	0.862	0.138	0.871	0.129	0.0182	0.981
13	0.56	0.44	0.119	0.881	0.319	0.681	0.862	0.138	0.867	0.133	0.0188	0.981
17	0.559	0.441	0.12	0.88	0.319	0.681	0.861	0.139	0.864	0.136	0.019	0.981
20	0.559	0.441	0.121	0.879	0.319	0.681	0.861	0.139	0.863	0.137	0.019	0.981

Table 12: FEVD Tables - HSC (GDP and CPI)

Quarters	Uncorrelated Shocks				Demand to Supply				Supply to Demand			
	Response of Output to		Response of Inflation to		Response of Output to		Response of Inflation to		Response of Output to		Response of Inflation to	
	AD Shock	AS Shock	AD Shock	AS Shock	AD Shock	AS Shock	AD Shock	AS Shock	AD Shock	AS Shock	AD Shock	AS Shock
1	0.628	0.372	0.004	0.996	0.414	0.586	0.712	0.288	0.991	0.009	0.001	0.999
2	0.633	0.367	0.009	0.991	0.428	0.572	0.67	0.33	0.987	0.013	0.003	0.997
3	0.638	0.362	0.048	0.952	0.444	0.556	0.613	0.387	0.981	0.019	0.02	0.98
5	0.643	0.357	0.096	0.904	0.459	0.541	0.561	0.439	0.98	0.02	0.046	0.954
7	0.646	0.354	0.137	0.863	0.471	0.529	0.521	0.479	0.969	0.031	0.076	0.924
9	0.648	0.352	0.169	0.831	0.477	0.523	0.493	0.507	0.964	0.036	0.103	0.897
11	0.649	0.351	0.192	0.808	0.482	0.518	0.474	0.526	0.961	0.039	0.125	0.875
13	0.651	0.349	0.208	0.792	0.484	0.516	0.462	0.538	0.957	0.043	0.142	0.858
17	0.651	0.349	0.22	0.78	0.485	0.515	0.454	0.546	0.955	0.045	0.154	0.846
20	0.651	0.349	0.228	0.772	0.486	0.514	0.45	0.55	0.954	0.046	0.162	0.838

c. Econometric Derivations

i. Supply to Demand Expansion

$$e_t = A_0{}^{-1}B\varepsilon_t = D_0\varepsilon_t$$

$$\begin{bmatrix} e_t^y \\ e_t^\pi \end{bmatrix} = \begin{bmatrix} \alpha/(1+\alpha) & 1/(1+\alpha) \\ 1/(1+\alpha) & -1/(1+\alpha) \end{bmatrix} \begin{bmatrix} b_{11} & \gamma b_{22} \\ 0 & b_{22} \end{bmatrix} \begin{bmatrix} \varepsilon_t^d \\ \varepsilon_t^s \end{bmatrix}$$

Here,

$$D_0 = \begin{bmatrix} \alpha b_{11}/(1+\alpha) & (1+\alpha\gamma)b_{22}/(1+\alpha) \\ b_{11}/(1+\alpha) & (\gamma-1)b_{22}/(1+\alpha) \end{bmatrix} \quad \text{(A1)}$$

From (1.9),

$$\begin{bmatrix} var(e_{yt}) & cov(e_{yt}, e_{\pi t}) \\ cov(e_{yt}, e_{\pi t}) & var(e_{\pi t}) \end{bmatrix} =$$

$$\begin{bmatrix} \alpha b_{11}/(1+\alpha) & (1+\alpha\gamma)b_{22}/(1+\alpha) \\ b_{11}/(1+\alpha) & (\gamma-1)b_{22}/(1+\alpha) \end{bmatrix} \begin{bmatrix} \alpha b_{11}/(1+\alpha) & (1+\alpha\gamma)b_{22}/(1+\alpha) \\ b_{11}/(1+\alpha) & (\gamma-1)b_{22}/(1+\alpha) \end{bmatrix}' =$$

$$\begin{bmatrix} \{\alpha^2 b_{11}^2 + (1+\alpha\gamma)^2 b_{22}^2\}/(1+\alpha)^2 & \{\alpha b_{11}^2 + (1+\alpha\gamma)(\gamma-1)b_{22}^2\}/(1+\alpha)^2 \\ \{\alpha b_{11}^2 + (1+\alpha\gamma)(\gamma-1)b_{22}^2\}/(1+\alpha)^2 & \{b_{11}^2 + (\gamma-1)^2 b_{22}^2\}/(1+\alpha)^2 \end{bmatrix} \quad \text{(A2)}$$

ii. Estimation of parameters

First step is calculating the matrix $(I-C)^{-1}D_0$ and equating it to the long run matrix *L*. By marking one of its four elements as 0 for both the cases, we get a relationship between the coefficient parameters of the *C* matrix and the matrix D_0 which had equated the residuals and the structural shocks.

1. In the VSC case, $d_{11}^0(1-c_{22}) + d_{21}^0 c_{12} = 0$

$$d_{11}^0/d_{21}^0 \ = -\frac{\sum_{j=1}^{q} c_{12}^j}{1-\sum_{j=1}^{q} c_{22}^j} = \alpha \qquad \text{(A3)}$$

2. In the HSC case, $d_{11}^0 c_{21}$+ $d_{21}^0(1- \ c_{11}) = 0$

$$d_{11}^0/d_{21}^0 \ = -\frac{(1-\sum_{j=1}^{q} c_{11}^j)}{\sum_{j=1}^{q} a_{21}^j} = \alpha \qquad \text{(A4)}$$

We know the values of c_{ij} from the VAR estimation results, so we next calculate the slope α from (2.5) and (2.6). Substituting the value of α for each of the cases, we obtain unique values for the other parameters.

iii. Identification of structural shocks in the SVAR

The SVAR form $A_0X_t = A_1(L)X_t + B\varepsilon_t$ in (1.5) can be written in terms of the two structural shocks as

$$X_t = \left(A_0 - A_1(L)\right)^{-1} B\varepsilon_t \ = D(L)\varepsilon_t \qquad \text{(A5)}$$

This is the Wold moving average representation which expresses X_t as

$$X_t = D_0\varepsilon_t + \ D_1\varepsilon_{t-1} + \ D_2\varepsilon_{t-2} + \cdots = (D_0 + \ D_1L + \ D_2L^2 + \cdots)\varepsilon_t = \sum_{i=0}^{\infty} D_i \, \varepsilon_{t-i}$$

The matrix $D(L)$ consists of the elements which represent the impulse response functions with respect to structural shocks of the SVAR, i.e., $\frac{dX_t}{d\varepsilon_{t-j}{'}} = D_j$, or $\frac{dX_{t+j}}{d\varepsilon_t{'}} = D_j$. This means that the row i, column k element of D_j denotes the consequences of a unit increase in the kth variable's innovation at date t for the value of the ith variable at time t + j.

X_t can also be expressed in a moving average (MA) form from (1.6) in terms of the reduced VAR residuals as

$$X_t = \left(I - C(L)\right)^{-1} e_t = \ (I + \ C(L) + \ C(L)^2 + \cdots)e_t \ = (I + \ M_1L + \ M_2L^2 + \cdots)e_t = \sum_{i=0}^{\infty} M_i \, e_{t-i}$$

i.e.

$$X_t = M(L)e_t \qquad \text{(A6)}$$

Similarly, $M(L)$ consists of the elements which represent the impulse response functions with respect to residuals of the VAR. Therefore, we can write

$$X_t = (D_0 + \ D_1L + \ D_2L^2 + \cdots)\varepsilon_t = (I + \ M_1L + \ M_2L^2 + \cdots)e_t$$

Using $\varepsilon_t \ = D_0^{-1}e_t$, we get

$$M_i = D_i {D_0}^{-1} \qquad \text{(A7)}$$

We will use (A7) later to construct our IRFs, after D_0 is obtained. This is substituted to find $D(L)$.

This matrix gives us the newly constructed impulse responses of the SVAR with respect to the structural shocks. The impulse response plots help us to explore the dynamic impacts of the structural shocks on output and inflation, and we use them later to derive the forecast error variance decompositions.

10. List of Acronyms and Abbreviations

ASEAN	Association of Southeast Asian Nations
AD	Aggregate Demand
AS	Aggregate Supply
BQ	Blanchard Quah
CPI	Consumer Price Index
FEVD	Forecast Error Variance Decomposition
FRED	Federal Reserve Economic Data
GDP	Gross Domestic Product
HSC	Horizontal Supply Curve
IRF	Impulse Response Function
LM	Lagrange Multiplier
NKPC	New Keynesian Phillips Curve
Q1	Quarter 1
Q2	Quarter 2
Q3	Quarter 3
Q4	Quarter 4
RBI	Reserve Bank of India
SVAR	Structural Vector Autoregression
VAR	Vector Autoregression
VSC	Vertical Supply Curve
US	United States
WPI	Wholesale Price Index

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