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What Drives Indian Inflation? Demand or Supply

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Abstract

Understanding the drivers of inflation is an important issue in business cycle research and has been a matter of debate. In this paper, using data from a large emerging economy, we identify a structural shock (inflation shock) that explains the maximum forecast error variance of consumer prices. The inflation shock explains more than 80 per cent of the forecast error variance of consumer price up to 40 quarters. This shock increases prices and decreases output, implying that it is a supply shock. We also show that the food inflation shock is the primitive shock, which makes the inflation shock a supply shock and also feeds into non-food inflation. A large interest rate reaction to this shock leads to a prolonged decline in credit, investment, and output. Using the shocks obtained from a medium-scale new Keynesian model, we provide additional evidence that most of the variance of estimated inflation and food inflation shocks is explained by model-based supply shocks. These results suggest that central banks in emerging economies need to be more pragmatic in implementing inflation-targeting policies.

Keywords: Inflation; India; SVAR; FEV; supply shock; demand shock;

JEL Code: E43; E44; E52

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1 Introduction

Understanding the drivers of inflation is a perennial question for macroeconomists and has been a matter of debate, Blinder and Rudd (2013). The rise and fall in inflation during the 2010s and subsequent decline in growth rate have ignited this debate again in India. This paper attempts at understanding the drivers of inflation in India in the light of the newly instituted inflation targeting framework[1]. For a brief period during the financial crisis, inflation kept increasing and interest rates kept decreasing in India[2]. Suddenly inflation became double-digit and monetary policy responded aggressively to counter rising inflation. Subsequently, inflation came down but the growth rate of the gross domestic product also declined significantly. The 9-quarter centered moving average of quarterly inflation and growth rate declined from 3.03% to 1.42% and from 2.43% to 1.80% respectively between 2010Q1-2014Q4.

There is also a belief that the hawkish behaviour of the Reserve Bank of India in the post-crisis period hurt growth and was detrimental to the Indian economy, see Kumar et al. (2021b). Goyal (2015) supports flexible inflation targeting but at the same time points out that its over-strict implementation proved very costly and contributed to significantly lower employment growth since 2011. During this period, RBI changed its target from wholesale inflation to consumer inflation and this implied a higher interest rate as for most of the period consumer inflation was higher than wholesale inflation. There are arguments that the inflation rate seen in India was not as detrimental to growth as perceived by the Reserve Bank of India. Other countries in past have faced similar or higher levels of inflation during their growth episodes. Evidence from industrializing countries has shown that inflation rates, if below ten per cent a year, have not only not had any negative effect on growth but have been accompanied by high rates of economic growth. In South Korea, which has achieved an even more successful industrial transition than

[1] Central banks can control inflation mainly by reducing demand. In the workhorse New Keynesian models this happens via inter-temporal substitution. But, if the inflation is mainly arising from adverse supply shocks then using interest rates to control inflation can impose a large output sacrifice. Therefore, it becomes important to understand the main sources of inflation to implement monetary policy in a way that does not hurt growth unnecessarily.

[2] Reserve Bank of India implemented massive monetary stimulus during the financial crisis.

China, the inflation rate throughout its three decades of ‘breakout’ was always above 10 per cent and went as high as 28 per cent in the 1980s (Jha, 2016).

Existing studies on Indian inflation have tried to capture the determinants of inflation, but still, there is no consensus about the dominance of supply or demand-side factors. Economic theory suggests that inflation is demand-pull if both, output and prices, move in the same direction whereas it is supply/cost-push if both move in opposite directions. Goyal and Kumar (2020) suggest that more than 60% of FEV (forecast error variance) of inflation is explained by supply-side shocks (including markup and technology). But evidence from such models can be questioned by arguing about their suitability for emerging economies like India.

Subbarao (2013) suggests that easing of liquidity was more than required as a response to the crisis and this led to the inflationary pressure after the financial crisis[3]. This implies an important role of demand-side factors in determining inflation. Bhalla (2015) attributes the rise in inflation to an increase in the minimum support price of food grains, which hints at cost-push inflation. Chinoy et al. (2015) suggest that the fall in inflation after the implementation of inflation targeting is followed by a combination of factors; rationalization of minimum support price (MSP)[4], external factors such as lower crude oil prices, and monetary policy that lead to moderation of inflation expectations. Even so, they find a very limited role of oil prices in bringing down inflation. Bhattacharya and Sengupta (2015) reach a similar conclusion about the role of crude oil prices in the case of food inflation. Bhalla (2015) argues against the role of external forces. He points out that external forces were in favour during 2008-09, yet inflation increased, whereas during 2014-15 inflation decreased in response to favourable global factors. He attributes this asymmetry to the rationalization of minimum support price.

Mohanty and John (2015), using a time-varying parameter vector autoregression, suggest that the domestic price of crude oil was the predominant factor explaining infla-

[3]Bhoi et al. (2019) and Kumar et al. (2021b) discuss these policy errors in details.
[4]https://indianexpress.com/article/explained/minimum-support-price-msp-farmers-explained-6706253

tion during 2009-2011 (which is in contrast to the findings in Chinoy et al., 2015) and in 2011-12 fiscal deficit became one of the key determinants. Bhattacharya and Jain (2019) suggest that unexpected monetary tightening has a positive and significant effect on food inflation, hinting at a cost-push shock being the major determinant of inflation as a significant pass-through from food inflation to inflation is also estimated in their paper. Ball et al. (2016) suggest that headline inflation feeds into inflation expectation and core inflation[5]. Essentially Ball et al. (2016) suggest the pass-through of food inflation into non-food inflation as headline inflation is primarily driven by food inflation. Results obtained in this paper also suggest that food inflation fed into non-food inflation in the estimation period. The pass-through of headline inflation into core and expected inflation augments the importance of supply shocks as the major variation in headline inflation comes from food and fuel prices, which constitute mainly supply shocks. This made the inflationary process in India different from advanced economies where headline inflation does not feed into inflation expectations (Ball et al. 2016).

In this paper, we adopt a purely data-driven approach using a structural vector autoregression (SVAR) framework in the beginning. Usually, the structural shocks in SVAR are identified by zero and sign restrictions. Often we need to impose restrictions that may have little support in theory. For example, in a three-variable SVAR of interest rate, growth, and inflation, one needs to assume zero contemporaneous correlation between growth and inflation, irrespective of the demand and supply-side framework being used to identify structural shocks. This rules out the short-run trade-off between growth and inflation and casts doubt on the identified structural shocks and their transmission into the economy. Our approach to the identification of the structural shock is similar to Uhlig (2004), Barsky and Sims (2011), Kurmann and Otrok (2013), Francis et al. (2014), and Cascaldi-Garcia and Galvao (2018). We estimate the SVAR models with consumer price index, 3-month Treasury bills rate, real government final consumption expenditure, real bank credit, real gross fixed capital formation, and real gross domestic product. All variables are in the log except the treasury bills rate.

[5]Core inflation is the measure of inflation that excludes the effects of supply shocks such as food and oil prices.

We identify a structural shock that explains the maximum FEV of consumer price between 0 to 40 quarters. This is called the *inflation shock*. This shock explains more than 80% of the FEV of consumer price suggesting that this is the primitive shock driving consumer prices. We also estimate a second inflation shock that explains the maximum FEV of consumer price between 5 to 20 quarters and call it the *medium run inflation shock*. The medium-run inflation shock explains around 80% of the FEV of inflation between 0 to 40 quarters. Then, we obtain responses of other variables due to inflation and medium-run inflation shocks. These two shocks increase the price and decrease output, implying that they are supply shocks. These two shocks also increase interest rate[6] and decrease credit and investment. The inflation shock also explains more than 40 per cent of FEV of credit, output, investment, and interest rate over the same period; *suggesting that this shock is a significant driver of the Indian business cycle*. Goyal and Kumar (2018) show that negative correlations between demand and supply shocks, aggravated by a large interest rate response to cost-push shocks, can switch the economy to a lower growth regime. This can explain persistent effects on output. Reducing the variance of interest rate shock can moderate this output sacrifice. A fall in credit and investment can be expected to persistently reduce output.

Thereafter, we identify the food and non-food inflation shocks using the same approach. Food and non-food inflation shocks explain the maximum FEV of food and non-food prices between 0 to 40 quarters. We find a significant pass-through of food inflation into non-food inflation whereas the non-food inflation does not feed into food inflation which corroborates the arguments made in Ball et al. (2016). The responses of other variables due to the food inflation shock are similar to the responses due to the inflation shock. Non-food inflation shock does not affect output, interest rate, and invest-

[6]Goyal and Kumar (2019) suggest a disproportionate response to inflation in India by the Reserve Bank of India which they call an overreaction. Such overreactions tend to occur if there is a fundamental misunderstanding about the efficacy of interest rates under supply-shock inflation. Goyal and Kumar (2022) show that the interest rate shock explains a significant amount of the FEV of output in India and even the expected interest rate shock (news shock) is contractionary. The demand side transmission is not weak but is primarily to output because of elastic aggregate supply. Therefore the tradeoff between growth and inflation under supply shocks is large and the output sacrifice is high.

ment in a significant way. It suggests that the inflation shock identified is predominantly a food inflation shock and inflation originates in the primary sector of the economy. This gives further credence to our argument that inflation shock is a supply shock because food inflation is mainly a supply-side phenomenon in the monsoon-dependent agriculture sector. This makes the current inflation scenario in India very similar to the inflation scenario in advanced economies in the 1970s and 1980s. Blinder and Rudd (2013) refute the demand-side explanations for the great inflation of the 1970s and argue that it was predominantly a supply-side phenomenon led by oil prices. Ball et al. (2016) argue that present-day Indian inflation is very similar to inflation in advanced economies in the 1970s and 1980s. Holtemoller and Mallick (2016) also argue that inflation in India originates as a supply shock which is fundamentally different from the demand-driven inflation of advanced economies in recent times. Kumar et al. (2021a) also provide evidence that oil price and rainfall shocks are important for the determination of inflation in India and both these factors reflect supply-side issues.

In the next stage, we estimate a new Keynesian model using Bayesian methods and obtain supply and demand shocks from the model. The model is the same as in Kumar et. al. (2021b)[7] and includes investment and borrowing by firms. Borrowed funds are used to finance a significant portion of firm investments. But there are always borrowing limits. Firms face constraints on borrowing which are usually of two types. Borrowing depends upon earning in Townsend (1979), Stiglitz and Weiss (1981), and Holmstrom and Tirole (1997) whereas in Hart and Moore (1994), Shleifer and Vishny (1992), Kiyotaki and Moore (1997), Bernanke et al. (1999), and Brunnermeier and Sannikov (2014), borrowing depends upon the value of assets. The value of assets depends upon the relative price of the assets in the model. Dreschel (2019) argues that a shock to the marginal efficiency of capital lowers the relative price (relative to final consumption good) of assets and hence leads to reduced borrowing with assets-based constraints. Further, the same shock may lead to higher earnings and hence leads to an increase in borrowing with earning-based constraints. The inclusion of earning-based constraints implies a quantita-

[7]Kumar et. al. (2021) use the representative agent New Keynesian model to argue for policy errors in interest rate setting in India which is also the focus of Bhoi et al. (2019).

tively more important role for supply shocks. It also captures excess borrowing by large firms from banks and its after-effects on the Indian economy in this period.

The final good producer aggregates goods produced by intermediate goods producers in a competitive market. The intermediate goods are produced in a monopolistic product market but the factor market is competitive. Pricing power in the product market gives rise to nominal rigidity. Households own intermediate goods producers and receive dividends from them. Intermediate goods producers do capital accumulation and borrowing from households. The borrowing constraint faced by them is a mix of both earning and assets-based constraints. Since the interest paid by the firm is tax-deductible, the effective interest cost for them is lower than the interest received by households. This implies that the firms borrow up to their borrowing constraint and the borrowing constraint is binding in the steady-state. The difference in interest between households and firms is borne by the government which also makes other consumptions driven by an exogenous process. Households pay a lump-sum tax that balances the government budget period by period. The interest rate is set using a modified Taylor rule.

This new Keynesian model has six shocks. Preference, interest rate, and government expenditure shocks are demand-side shocks. Neutral technology, investment-specific technology, and markup shocks are supply-side shocks. In this model, the government expenditure shock is a wealth shock as higher expenditure implies higher taxes and that reduces the lifetime wealth of the households. Households react to this wealth shock by increasing their labour supply and hence the government expenditure shock is effectively a labour supply shock. Government subsidies, and therefore taxation requirements, will also increase under oil and food shocks. Based on this, one can argue that the government expenditure shock in this model is also a supply shock. We obtain smoothed estimates of these shocks and do Shapley decomposition of explained sum of squares for *inflation*, *medium run inflation*, *food inflation*, and *non-food inflation* shocks. A significantly higher amount of the variance of the inflation shock is explained by model-based supply shocks and the importance of supply shocks increases further in the case of the food inflation shock. We find that the model-based supply shocks explain around 80% of the variation of food-inflation shock. This makes sense as the food inflation shock was the major supply shock in the period. In the case of non-food inflation and medium-run inflation shock, the contribution of model-based supply shocks diminishes. This suggests that inflation originates as a supply-side phenomenon but becomes demand-driven over the medium run. The fall in investment and credit may be contributing to persistent effects on output and creating excess demand as the fall in output due to monetary tightening exceeds the fall in demand.

The plan of the paper is as follows. The next section gives a brief overview of the data and some insights from reduced-form regressions. Section 3 presents the agnostic identification framework being used in this paper. This is followed by the presentation of results and discussion in section 4. Section 5 concludes and draws out policy implications. Appendix A at the end gives additional results and appendix B gives the new Keynesian model in detail.

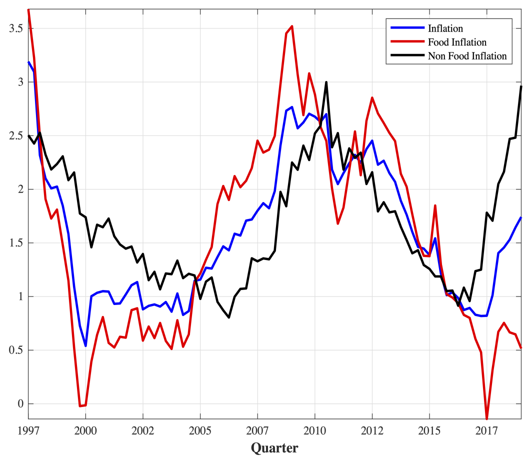
2 Data

The baseline SVAR models in this paper are estimated using the consumer price, 3-month treasury bills rate, real government final consumption expenditure, real bank credit, real gross fixed capital formation, and real gross domestic product. All variables except the treasury bills rate are in the log and seasonally adjusted. The period covered is 1997Q2 to 2019Q1[8]. Quarterly data on national accounts is available from 1996Q2 but banking statistics are available only from 1997Q2. Therefore we consider the period from 1997Q2 onwards. We use oil demand and supply shocks from Caldara et al. (2019). The economic policy uncertainty index used in the paper is based on Baker et al. (2016).

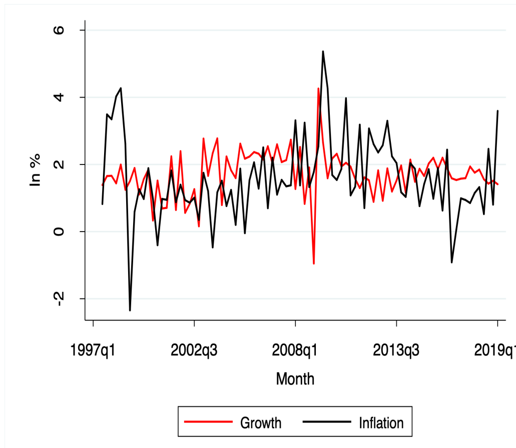
CPI (IW) general index and food price index for the base years 1982 and 2001 are available but there is no existing index for non-food prices. The linking factor (from the base year 1982 to the base year 2001) is 4.63 for the general index and 4.58 for the food

[8]We do not consider the recent period because of distortions caused by COVID-19 that may bias statistical inference.

price index. Using these linking factors we create a continuous general index and food price index. The weight of food items (57 % for the base year 1982 and 46.2 % for the base year 2001) in the general index is also given for these two base years. Using these information a continuous series of non-food price index is calculated[9]. Figure 1a gives the 9-quarter centered moving average of consumer inflation, food inflation, and non-food inflation.



(a) 9-quarter centered moving average inflation



(b) Quarterly growth and inflation

Figure 1: Inflation and growth

Notes: Estimated unconditional correlation between growth and inflation is .07 and not significant. The standard deviation of inflation is 1.75 times growth. Coefficients of variation of growth and inflation are .75 and 2.49 respectively.

We estimate additional SVAR models in which we include both food and non-food prices and drop real gross fixed capital formation and real government final consumption expenditure one by one. These SVAR results are used to identify food inflation and non-food inflation shocks using the same methodology used for identifying the inflation shock. Food inflation shock and non-food inflation shock are identified through two different SVAR models and need not be orthogonal to each other.

[9] General Index=αFood Index+$(1-\alpha)$Non Food Index. Where α is the weight of food items in the general index.

Table 1: Reduced form regression

	(1) Consumer Inflation	(2) Consumer Inflation	(3) Consumer Inflation
Treasury Bills Rate	0.184	0.166	0.127
	(1.06)	(1.12)	(0.88)
Growth	0.172	0.151	0.230
	(1.01)	(0.94)	(1.29)
L.Growth	0.370	0.328	0.288
	(1.46)	(1.36)	(1.52)
L2.Growth			-0.366
			(-1.57)
L.Treasury Bills Rate	-0.144	-0.141	-0.109
	(-0.80)	(-0.88)	(-0.52)
L2.Treasury Bills Rate			-0.0277
			(-0.18)
L.Consumer Inflation		0.254^{*}	0.271^{*}
		(2.50)	(2.47)
L2.Consumer Inflation			0.147
			(1.12)
Constant	0.00416	0.00215	0.00735
	(0.50)	(0.27)	(0.80)
R^2	0.066	0.128	0.193
N	86	86	85

Notes: Sample period 1997Q2 to 2019 Q1. Consumer price and gross domestic product have been seasonally adjusted. *, ** and *** denotes significance at 5, 1 and .1 percent respectively.

We estimate another SVAR model with monthly data for robustness using the index of industrial production, consumer price index, bank credit, and treasury bills rate for the same period. Figure 1b gives quarter on quarter growth rate of gross domestic product and consumer price index for the period 1997Q3 and 2019Q1. Inflation is 1.75 times more volatile than growth. The coefficient of variation of growth and inflation are 0.75 and 2.49 respectively. Since inflation is significantly more volatile than growth, the unconditional correlation between these two variables is very weak although positive.

Table 1 presents the reduced form regression of inflation on the treasury bills rate and growth of gross domestic product with different lag lengths. None of these variables is significant except the lag of inflation. Even the coefficient of lag of inflation is less than 0.3 suggesting that quarter-on-quarter inflation is not that persistent. One can argue about the simultaneity and omitted variable bias in this regression. But we do not attempt any instrument variable estimation as we estimate SVAR models in this paper. These regression results suggest that inflation is driven by some primitive shock that is not being captured by these variables and the lag of inflation picks up because of the persistence of the primitive shock. We want to estimate this primitive shock and explore its role in the Indian business cycle. Section 3 gives the empirical methodology being used in the paper to estimate this primitive shock.

The new Keynesian model, used to establish the robustness of our purely data-driven approach, is estimated with a linearly detrended real gross domestic product, real government final consumption expenditure, real gross fixed capital formation[10], and real bank credit. It also includes quarter-to-quarter changes in the natural logarithm of consumer price index and treasury bills rate. All variables are seasonally adjusted except the treasury bills rate.

3 Agnostic Identification in SVAR

In general, a reduced form VAR with l lags can be written as:

$$Y_t = B_1 Y_{t-1} + B_2 Y_{t-2} + ... + B_l Y_{t-l} + u_t$$

[10]There is an issue in creating continuous series for the national accounts variable as we have data from three base years (1999-00, 2004-05 and 2011-12) to compile to create a uniform series. The linking procedures commonly used in the literature generally involve the backward extrapolation of the most recent available series using the growth rates of older series called retropolation or interpolation between the benchmark years of successive series (Fuente, 2009). We use retropolation as it suits our interests and is very simple. Suppose we have two series for an economic variable of interest. We calculate the log difference between the old and new series (when the new series starts and we have data for both series) and add this difference to the old series to create a uniform series thus preserving the growth rate of the old series. The implicit assumption is that the "error" contained in the older series remains constant over time that is, that it already existed at time 0 and that its magnitude, measured in proportional terms, has not changed between 0 and the time the new series starts.

Where Y_t is a vector having two or more variables. The moving average representation of the same is given by:

$$Y_t = C(L)u_t$$

Where $C(L) = \sum_{l=0}^{\infty} C_l L^l$. The reduced form VAR can be estimated using OLS and that gives us reduced form shocks (u_t) and their covariance matrix (Σ); $\Sigma = E\left(u_t u_t'\right)$. The reduced form shocks (u_t) and structural shocks (v_t) are related through matrix A by $u_t = Av_t$. We assume that (v_t) has unit variances and therefore the objective is to find matrix A that satisfies:

$$\Sigma = AE\left(v_t v_t'\right) A' = AA' \quad \text{Where } E\left(v_t v_t'\right) = I$$

We have $n^2 - \frac{n^2-n}{2} = \frac{n(n+1)}{2}$ free elements in Σ, and hence only $\frac{n(n+1)}{2}$ elements of A can be identified. Usually, we put zero restrictions that eliminate contemporaneous relationships. The Cholesky factorisation is one form of zero restrictions that gives rise to recursive structure and identifies all n shocks. We want to identify only one shock i.e. only the first column of A, see Uhlig (2004). We begin with the Cholesky decomposition of Σ. Let $\tilde{A}$ be the Cholesky factorisation:

$$\Sigma = \tilde{A}\tilde{A}' \quad u_t = \tilde{A}\tilde{v}_t$$

We can always find an orthogonal $n \times n$ matrix Q that satisfies $QQ' = I$. Effectively this implies $A = \tilde{A}Q$ where A is another matrix relating structural and reduced form shocks. This is because $\tilde{A}\tilde{A}' = AA' = \tilde{A}QQ'\tilde{A}' = \Sigma$. The impulse responses based on Cholesky factorisation are given by:

$$\tilde{R}(L) = C(L)\tilde{A}$$

The impulse responses based on any arbitrary factorisation are given by:

$$R(L) = C(L)A$$

Because $A = \tilde{A}Q$, this implies:

$$R(L) = C(L)\tilde{A}Q \implies R(L) = \tilde{R}(L)Q$$

In general the impulse responses at time l due to any arbitrary factorisation (R_l) is obtained by multiplying the impulse responses due to Cholesky factorisation ($\tilde{R}_l$) with an orthonormal matrix Q of size $n \times n$. Therefore we can write:

$$Y_t = \tilde{R}(L)\tilde{v}_t = R(L)v_t = \tilde{R}_l Q v_t$$

The k-step ahead prediction error of Y_{t+k}, given all the data up to and including $t-1$ is given by

$$e_{t+k}(k) = \sum_{l=0}^{k} \tilde{R}_l Q v_{t+k-l}$$

The variance of k-step ahead prediction error of Y_{t+k} is given by

$$E\left(e_{t+k}(k), e_{t+k}(k)'\right) = \Sigma(k) = \sum_{l=0}^{k} \tilde{R}_l \tilde{R}_l'$$

Where $\Sigma(0) = \Sigma$. One can decompose $\Sigma(k)$ among n shocks in the model as given below.

$$\Sigma(k) = \sum_{j=1}^{n} \Sigma(k, j)$$

$$\Sigma(k, j) = \sum_{l=0}^{k} \tilde{R}_l q_j \left(\tilde{R}_l q_j\right)'$$

Where q_j is a vector of unit length. Therefore, we can write the share in FEV of the shock of interest as:

$$\Sigma(k, 1) = \sum_{l=0}^{k} \tilde{R}_l q_1 \left(\tilde{R}_l q_1\right)'$$

We can write the forecast error variance (FEV) explained by q_1 for our variable of interest i between time period $\underline{k} \leq k \leq \bar{k}$

$$\Sigma(k,1) = e_i' \left(\sum_{\underline{k}}^{\bar{k}} \sum_{l=0}^{k} \tilde{R}_l q_1 \left(\tilde{R}_l q_1 \right)' \right) e_i$$

Where e_i is a selection vector with one at the ith place. The method in Uhlig (2004) solves for q_1 that maximizes this variance. The objective function is given by:

$$q_1^* = \arg\max_{q_1} e_i' \left(\sum_{\underline{k}}^{\bar{k}} \sum_{l=0}^{k} \tilde{R}_l q_1 \left(\tilde{R}_l q_1 \right)' \right) e_i$$

Subject to $q_1' q_1 = 1$.

$$q_1^* = \arg\max_{q_1} e_i' \left(\sum_{\underline{k}}^{\bar{k}} \sum_{l=0}^{k} \tilde{R}_l q_1 \left(\tilde{R}_l q_1 \right)' \right) e_i = \left(\sum_{\underline{k}}^{\bar{k}} \sum_{l=0}^{k} \text{trace} \left(e_i e_i' \right) \tilde{R}_l q_1 \left(\tilde{R}_l q_1 \right)' \right)$$

$$= \left(\sum_{\underline{k}}^{\bar{k}} \sum_{l=0}^{k} \text{trace} \left(\tilde{R}_l q_1 \right)' \left(e_i e_i' \right) \tilde{R}_l q_1 \right)$$

$$= q_1' \left(\sum_{\underline{k}}^{\bar{k}} \sum_{l=0}^{k} \tilde{R}_l' \left(e_i e_i' \right) \tilde{R}_l \right) q_1$$

$$= q_1' S q_1$$

Subject to $q_1' q_1 = 1$. Where $S = \left(\sum_{\underline{k}}^{\bar{k}} \sum_{l=0}^{k} \tilde{R}_l' \left(e_i e_i' \right) \tilde{R}_l \right)$. We use the fact that for any three square matrices D, E, F of the same dimension; trace (DEF) = trace(FDE). The maximization problem can therefore be expressed as a Lagrangian:

$$L = q_1' S q_1 - \lambda \left(q_1' q_1 - 1 \right)$$

The first-order condition is given by:

$$Sq_1 = \lambda q_1$$

This is the definition of an eigenvalue decomposition, with q_1 being the eigenvector of S that corresponds to eigenvalue λ. Since $q_1'q_1 = 1$, we can rewrite the first-order condition as:

$$q_1'Sq_1 = q_1'\lambda q_1 = \lambda q_1'q_1 = \lambda$$

Since λ is scalar. Thus maximizing $q_1'Sq_1$ amounts to finding the maximum eigenvalue of S. The vector q_1 is the eigenvector associated with the maximum eigenvalue λ. We find the eigenvector corresponding to the highest eigenvalue and that solves the problem. We maximize the FEV of inflation for $0 \leq k \leq 40$ and $5 \leq k \leq 20$. These give us two inflation shocks being identified in the paper which explain maximum FEV of inflation for up to 40 quarters and between 5 to 20 quarters respectively.

We estimate the VAR models with the log of variables except for interest rate as mentioned before. Since the impulse responses are given by $\frac{\partial Y_t}{\partial \nu_t}$, we further multiply the log variables by 100 because it becomes % change caused due to the shock[11]. For example, the response of log price due to the inflation shock is % change in prices i.e. inflation caused by the inflation shock. The response for all other variables except interest rate has the same interpretations. In the case of interest rate, the response is in percentage point change due to the shock. The FEV is obtained using impulse responses as usual. This FEV is of log variables except in the case of interest rate. We estimate shocks which explain the maximum FEV of the log prices (consumer, food and non-food). We then estimate the share of identified shocks in the FEV of respective variables in the model. For FEV, we use the same label as in impulse responses for consistency but these are fractions in FEV explained by the shocks for corresponding variables.

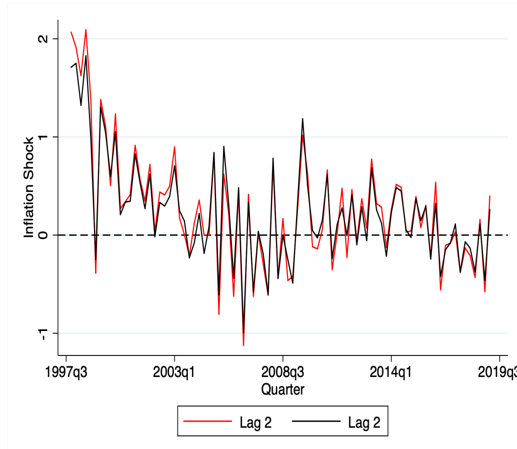
[11] $\frac{\partial log(y_t) \times 100}{d\nu_t} = \frac{\frac{dy_t}{y_t} \times 100}{d\nu_t}$ where $Y_t = log(y_t)$

4 Results and Analysis

4.1 Evidence From SVAR

4.1.1 Inflation and Medium Run Inflation Shocks

(a) VAR with lag length 1



(b) VAR with lag length 2

Figure 2: Inflation and medium run inflation shocks.

Notes: The red line is the inflation shock and the grey line is the medium-run inflation shock. The inflation shock explains the maximum FEV of consumer price between 0 to 40 quarters. Medium run inflation shock explains the maximum FEV of consumer price between 5 to 20 quarters.

We estimate the baseline SVAR model using the consumer price, treasury bills rate, real government final consumption expenditure, real bank credit, real gross fixed capital formation, and real gross domestic product (GDP). All variables are in the log except the treasury bills rate. We estimate the SVAR models with both lag 1 and lag 2. We order the consumer price first for simplicity so that the vector e_i has one in the first row. Figure 2 gives the estimated inflation and medium-run inflation shocks from SVAR models estimated with lags 1 and 2. The inflation shock captures the upward and downward movement in Indian inflation seen in recent years. Figure 3 gives the responses of model variables due to the inflation shock and figure 4 gives the share of inflation shock in the FEV of all variables.

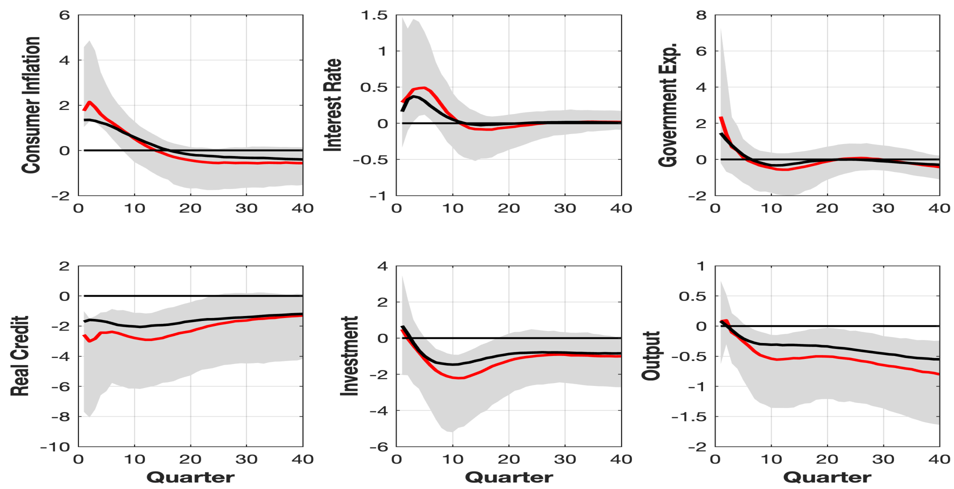


Figure 3: Responses of variables due to the inflation shock.

Notes: Inflation shock explains the maximum FEV of consumer price between 0 to 40 quarters and is obtained from the SVAR model consisting of consumer price, treasury bills rate, real government final consumption expenditure, real bank credit, real gross fixed capital formation and real gross domestic product (GDP). The red line is for VAR with lag length 2 and the black line is for VAR with lag length 1. The shaded area represents one standard deviation confidence band.

The maximum impact on price is about a 2 % increase (implying that the shock creates a 2% quarterly inflation or 8% annual inflation) and happens by the second quarter. Both lag lengths 1 and 2 cause similar responses of model variables due to inflation shock. The impact of the inflation shock disappears around the 8th quarter. Thus, the shock causes inflation for up to 2 years. The inflation shock explains around 90% of the FEV of consumer price in the beginning and by the 20th quarter, the share explained is 80% with a narrow band around it. In general, the FEV of the variables explained by inflation shock estimated with lag 1 is smaller than the FEV explained by inflation shock estimated with lag 2.

Inflation shock increases interest rate at impact. The maximum impact is a 0.5 percentage point increase and is significant. The maximum impact is observed around the fourth quarter. The impact of the inflation shock on interest rates disappears around the 8th quarter. Thus, the inflation shock causes a positive movement in interest rates for up to 2 years. The inflation shock explains around 30% of the FEV of interest rate in the beginning and by the 40th quarter, this becomes around 50%. Inflation shock decreases output. With lag length 2 the effect is more pronounced. The maximum impact is more than a 0.5 per cent decline in output and occurs slightly late (lagged effect of interest rate tightening). Surprisingly the effect on output persists at the end of the 40th quarter. The inflation shock explains around 20% of the FEV of output in the beginning and by the 40th quarter, this becomes around 60%.

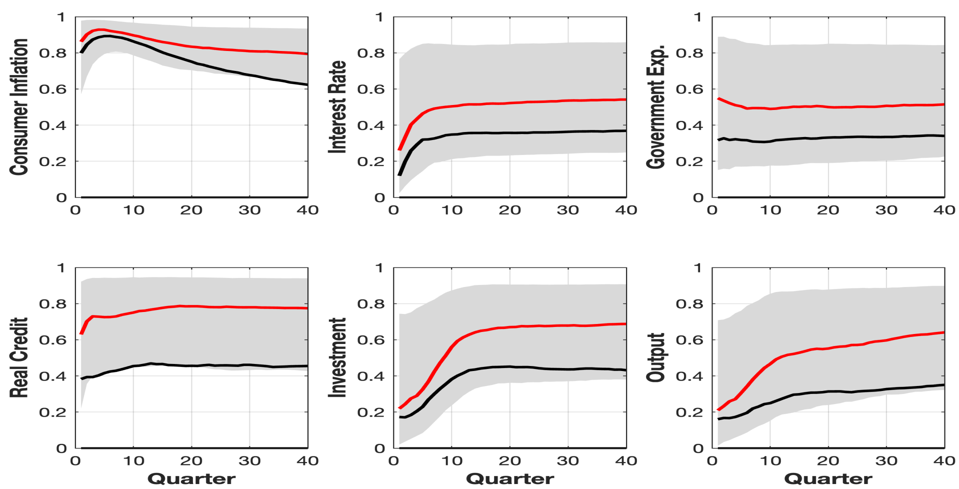


Figure 4: Share of the inflation shock in FEV of variables in the model.

Notes: Inflation shock explains the maximum FEV of consumer price between 0 to 40 quarters and is obtained from the SVAR model consisting of consumer price, treasury bills rate, real government final consumption expenditure, real bank credit, real gross fixed capital formation and real gross domestic product (GDP). The red line is for VAR with lag length 2 and the black line is for VAR with lag length 1. The shaded area represents one standard deviation confidence band.

As we can see inflation shock increases inflation and decreases output, this is a supply shock based on basic economic theory. We find that the interest rate responds significantly to this supply shock. The inflation shock decreases credit and with lag length 2 the effect is more pronounced which translates into a higher impact on investment and output[12].

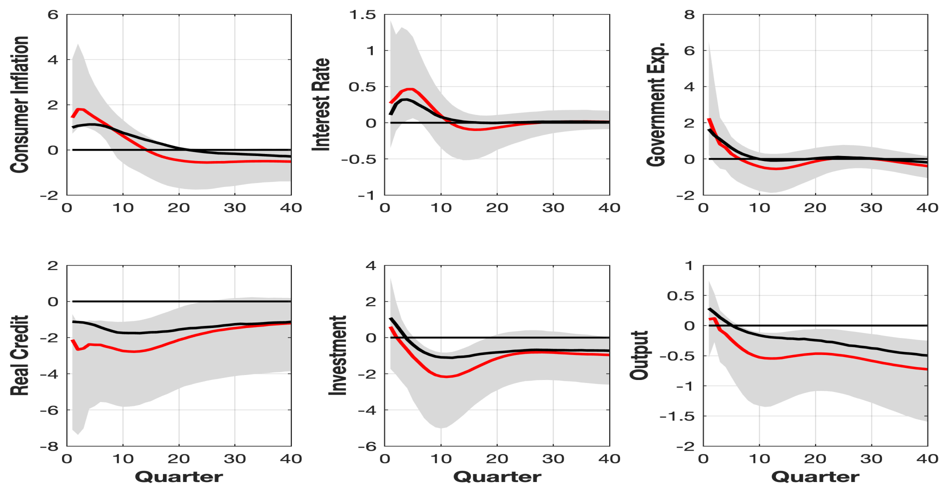


Figure 5: Responses of variables due to the medium run inflation shock.

Notes: Medium run inflation shock explains the maximum FEV of consumer price between 5 to 20 quarters and is obtained from the SVAR model consisting of consumer price, treasury bills rate, real government final consumption expenditure, real bank credit, real gross fixed capital formation and real gross domestic product (GDP). The red line is for VAR with lag length 2 and the black line is for VAR with lag length 1. The shaded area represents one standard deviation confidence band.

The maximum impact is around a 3 per cent decline in credit and occurs slightly late (lagged effect of interest rate tightening). The effect on credit persists by the end of the 40th quarter. The inflation shock explains around 60% of the FEV of credit in the beginning and by the 40th quarter, this becomes around 80%. Inflation shock decreases investment. The share of inflation shock in FEV of nominal credit given in figure A.2 is relatively lower which makes sense because the real credit can change due to the change in prices as well. The maximum impact is around a 2 per cent decline in investment and

[12] The impact effect on credit is negative and significant and output is insignificant because we estimate the model using real credit and inflation shock lowers real credit. This is because real credit is obtained by deflating the nominal credit using the consumer price index. The output deflator in India is not having a similar pattern as the consumer price index hence the difference between the response of output and credit arise. To ensure this, we estimate the model using nominal credit which is given in Appendix A1 of the paper (figures A.1 and A.2).

occurs around the 10th quarter. The effect on investment persists by the 20th quarter i.e. up to 5 years. The inflation shock explains around 20% of the FEV of investment in the beginning and by the 40th quarter, this becomes around 70%.

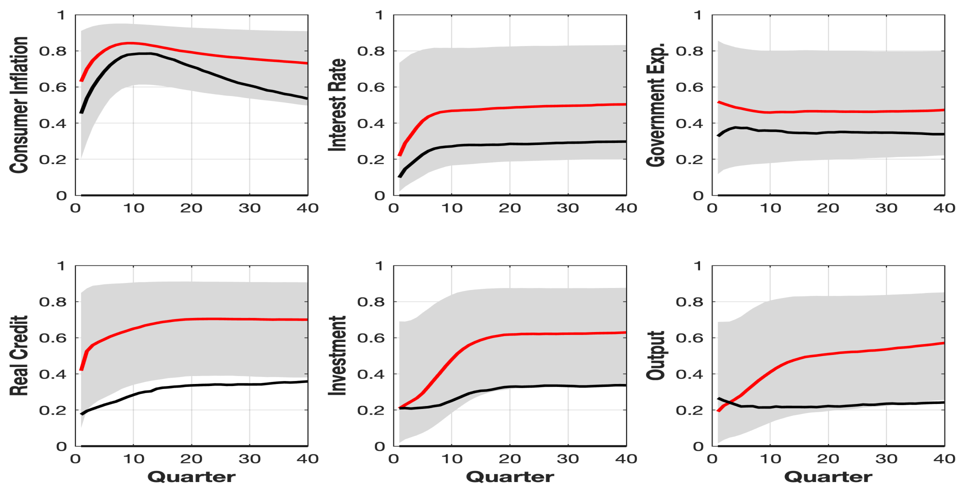


Figure 6: Share of the medium run inflation shock in FEV of variables in the model.

Notes: Medium run inflation shock explains the maximum FEV of consumer price between 5 to 20 quarters and is obtained from the SVAR model consisting of consumer price, treasury bills rate, real government final consumption expenditure, real bank credit, real gross fixed capital formation and real gross domestic product (GDP). The red line is for VAR with lag length 2 and the black line is for VAR with lag length 1. The shaded area represents one standard deviation confidence band.

The inflation shock increases government consumption expenditure at impact and the effect disappears by the 4th quarter. The impact is not significant at the conventional level of significance. The inflation shock explains more than 40% of the FEV of government consumption. Figure 5 gives the responses of variables due to the medium run inflation shock and figure 6 gives the share of the medium run inflation shock in FEV of all variables. Medium-run inflation shock has a similar effect with slightly less share in the FEV of variables. We conclude this section with findings that identified inflation and medium-run inflation shocks are supply shocks and there is evidence that monetary policy reacts to these adverse supply shocks which have substantial real effects.

4.1.2 Food and Non-Food Inflation Shocks

We estimate additional VAR models in which we include both food and non-food prices and drop real government final consumption expenditure. In the first model, we order the food price first and in the second model, we order the non-food price first. These VAR results are used to identify food and non-food inflation shocks using the same method used for identifying inflation shocks.

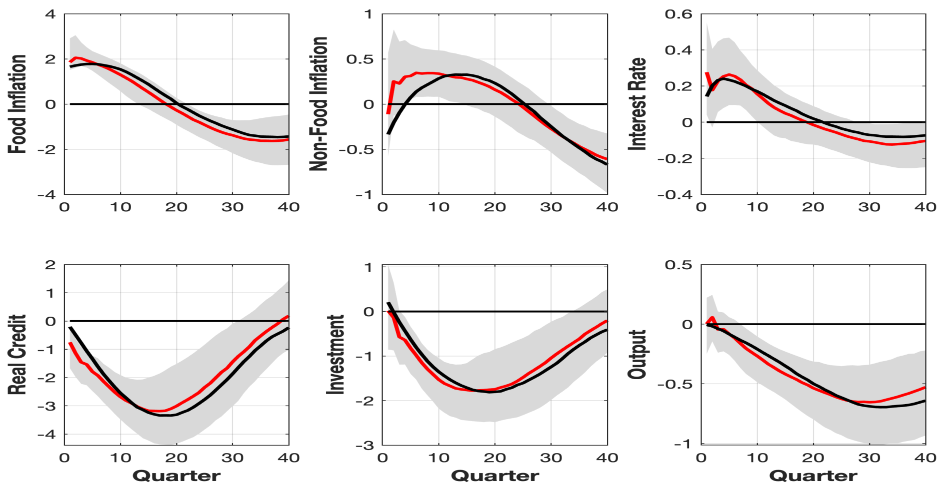


Figure 7: Responses of variables due to the food inflation shock.

Notes: Food inflation shock explains the maximum FEV of food price between 0 to 40 quarters and is obtained from the SVAR model consisting of food price, non-food price, treasury bills rate, real bank credit, real gross fixed capital formation and real gross domestic product (GDP). The red line is for VAR with lag length 2 and the black line is for VAR with lag length 1. The shaded area represents one standard deviation confidence band.

Figure 7 gives the responses of variables due to the food inflation shock and figure 8 gives the share of food inflation shock in the FEV of variables. The food inflation shock is identified from the VAR model consisting of the food price, non-food price, short-term nominal interest rate, real bank credit, real gross fixed capital formation, and real gross domestic product (GDP). Food inflation shock increases food prices by almost 2 per cent. This is very similar to the rise in overall price due to the inflation shock reported earlier.

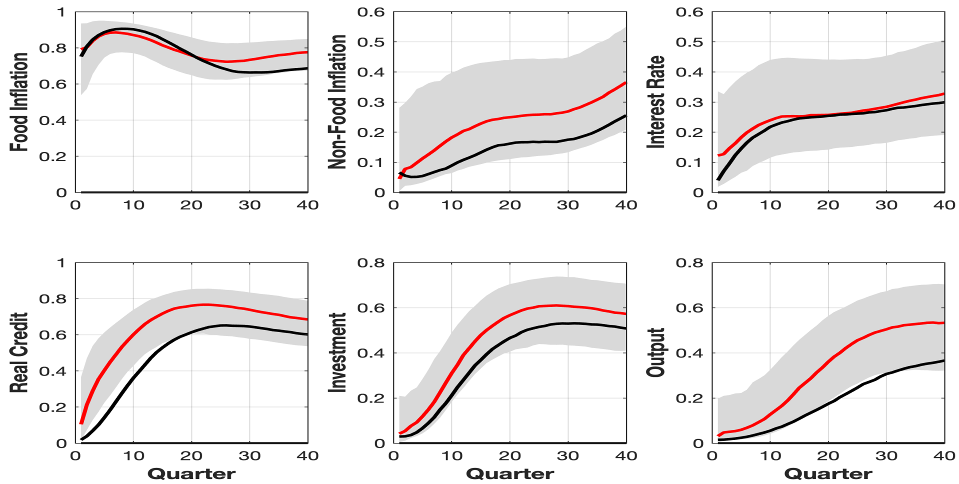


Figure 8: Share of food inflation shock in FEV of variables in the model.

Notes: Food inflation shock explains the maximum FEV of food price between 0 to 40 quarters and is obtained from the SVAR model consisting of food price, non-food price, treasury bills rate, real bank credit, real gross fixed capital formation and real gross domestic product (GDP). The red line is for VAR with lag length 2 and the black line is for VAR with lag length 1. The shaded area represents one standard deviation confidence band.

Food inflation shock does not affect the non-food price at impact but significantly increases (by 0.25%) non-food price with some delay. This is evidence of a significant pass-through of food inflation into non-food inflation. This is expected because higher food inflation may lead to increasing costs of industrial inputs such as labour and material. But given the maximum response of non-food prices due to food inflation shock and its share in the overall price index, this means that the inflation shock is still predominantly a food inflation shock.

The increase in the interest rate due to the food inflation shock is similar to the increase due to the inflation shock but the response is slightly lower in magnitude. Credit and investment contracts significantly due to the food inflation shock. Output also contracts due to food inflation shock and the impact is prolonged. Overall the food inflation shock has similar effects on model variables as given by the inflation shock before.

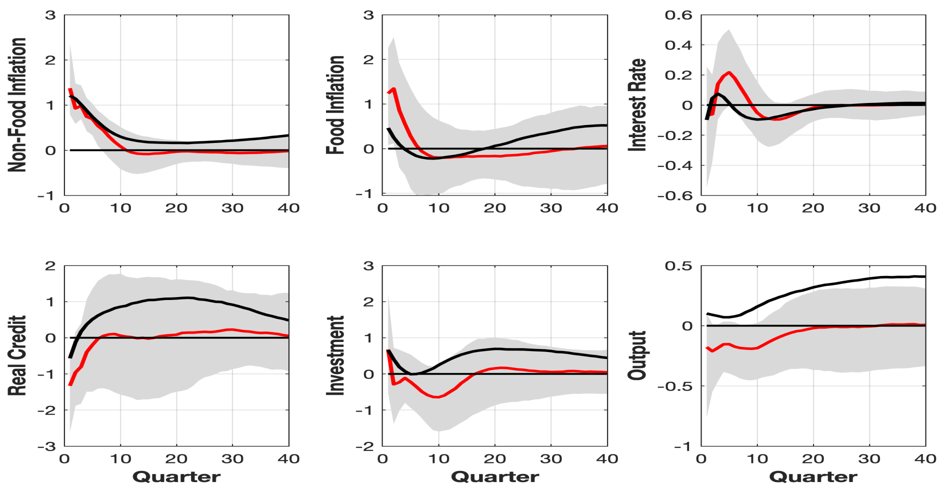


Figure 9: Responses of variables due to non-food inflation shock.

Notes: Non-food inflation shock explains the maximum FEV of non-food price between 0 to 40 quarters and is obtained from the SVAR model consisting of non-food price, food price, treasury bills rate, real bank credit, real gross fixed capital formation and real gross domestic product (GDP). The red line is for VAR with lag length 2 and the black line is for VAR with lag length 1. The shaded area represents one standard deviation confidence band.

Food inflation shock explains approximately 80% of the FEV of food price. Food inflation shock explains about 10% of the FEV of non-food prices in the beginning but the share increases with time and by the 40th quarter, food inflation shock explains about 40% of the FEV of non-food prices. This implies the significant pass-through of food inflation into non-food inflation as argued before. Food inflation shock explains about 10% of the FEV of interest rate in the beginning but the share increases with time and by the 40th quarter, food inflation shock explains about 35% of the FEV of interest rate. Food inflation shock explains about 15% of the FEV of credit in the beginning and by the 40th quarter, this becomes about 70%. Also in the case of both investment and output, the food inflation shock explains very less of FEV at impact but by the 40th quarter, the share increases to about 60%.

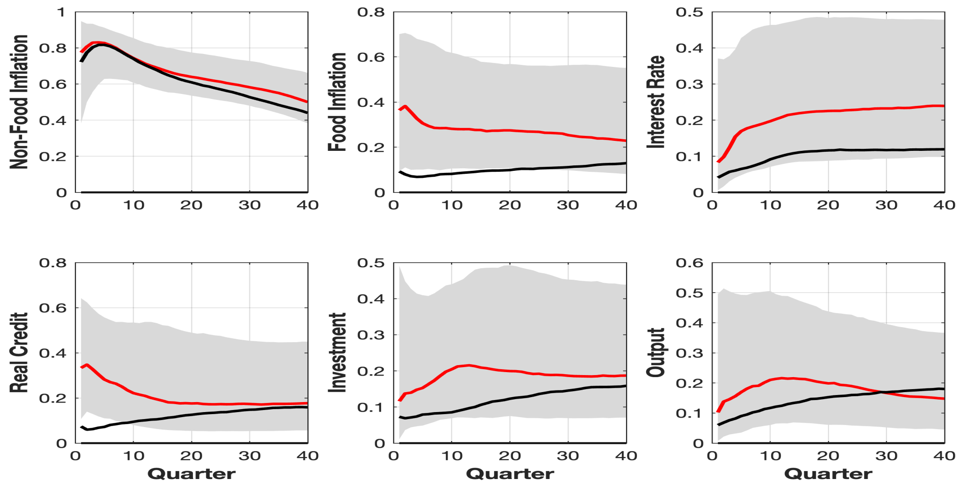


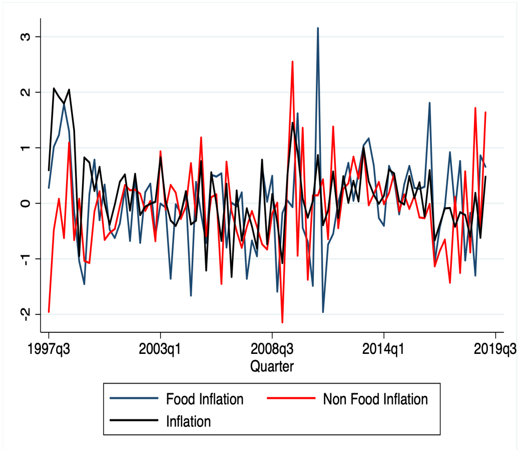
Figure 10: Share of non-food inflation shock in FEV of variables in the model.

Notes: Non-food inflation shock explains the maximum FEV of non-food price between 0 to 40 quarters and is obtained from the SVAR model consisting of non-food price, food price, treasury bills rate, real bank credit, real gross fixed capital formation and real gross domestic product (GDP). The red line is for VAR with lag length 2 and the black line is for VAR with lag length 1. The shaded area represents one standard deviation confidence band.

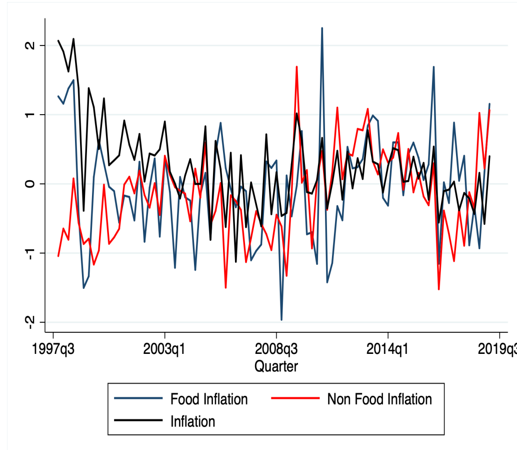
Figure 9 gives the responses of variables due to the non-food inflation shock and figure 10 gives the share of non-food inflation shock in the FEV of variables. The VAR model consists of the non-food price, food price, short-term nominal interest rate, real bank credit, real gross fixed capital formation, and real gross domestic product (GDP). Non-food inflation shock increases the non-food price by almost 1.5 per cent. Non-food inflation shock increases the food price at impact but the effect turns insignificant soon. Non-food inflation shock does not affect the interest rate, credit, investment, and output in a significant way. The response of output due to non-food inflation shock is different with VAR with lag 1 and lag 2. Non-food inflation shock obtained using lag length 1 increase interest rate, price and output which is not theoretically consistent. But we believe that the responses with lag length 2 are more credible and hence do not explore this anomaly further.

Non-food inflation shock explains approximately 80% of the FEV of non-food prices but the share falls with time. This is fundamentally different from the share of food inflation shock in the FEV of food price that does not change over time. This makes sense because as shown in figure 8, the share of food inflation shock in the forecast error variance of non-food prices increases with time. Non-food inflation shock explains about 40% of the FEV of food price in the beginning but the share falls with time and by the 40th quarter, non-food inflation shock explains about 20% of the FEV of food price. Also, the confidence band around this is quite wide reflecting a higher amount of uncertainty. Non-food inflation shock explains about 40% of the FEV of credit in the beginning and by the 40th quarter, this is about 20%. Also, non-food inflation explains around 20 per cent of the FEV of interest rate, investment and output with a wide confidence band around these shares. As we can see, for all variables, the FEV explained by food inflation shock increases over time whereas the FEV explained by non-food inflation either stagnates or decreases over time. This is expected as the monetary policy reacts significantly to food inflation and food inflation feeds into non-food inflation.

Figure 11 gives the estimated inflation, food inflation and non-food inflation shocks. With lag 1, the correlation between inflation and food inflation shock is approx. 0.5 and significant, whereas the correlation between inflation and non-food inflation shock is low (negative) and insignificant. With lag 2, the correlation between inflation and food inflation shock is approx. 0.5 and significant whereas the correlation between inflation and non-food inflation is low (positive) and insignificant. Impulse responses presented above and these correlations suggest that the identified inflation shock moves more closely with food inflation shock rather than non-food inflation shock. Also, the Impulse response given above suggests that the inflation shock is giving responses similar to the food inflation shock. Non-food inflation shock does not affect output, interest rate, investment, and credit, unlike inflation and food inflation shock. Therefore, one can say that the responses given by inflation shock are driven by the food inflation shock.



(a) VAR with lag length 1



(b) VAR with lag length 2

Figure 11: Inflation, food, and non-food inflation shocks

Notes: Inflation, food inflation and non-food inflation shocks explain the maximum FEV of consumer price, food price and non-food price between 0 to 40 quarters. The inflation shock is obtained from the VAR model consisting of consumer price, treasury bills rate, real government final consumption expenditure, real bank credit, real gross fixed capital formation and real gross domestic product (GDP). Food and non-food inflation shocks are obtained from the SVAR model consisting of the food price, non-food price, treasury bills rate, real bank credit, real gross fixed capital formation, and real gross domestic product (GDP). With lag 1, the correlation between inflation and food inflation shock is approx. 0.5 and significant, whereas the correlation between inflation and non-food inflation is low (negative) and insignificant. With lag 2, the correlation between inflation and food inflation shock is approx. 0.5 and significant, whereas the correlation between inflation and non-food inflation is low (positive) and insignificant.

We do robustness exercises with real government final consumption expenditure instead of real gross fixed capital formation. These results are given in figures A.3 to A.7 in appendix A.2. These results give overwhelming evidence that food inflation shock was the primary driver of inflation in this period and also played an important role in the Indian business cycle. These results have been obtained using very minimal restriction and our shock identification is economically intuitive as it explains the maximum share of forecast error variance of respective prices. But the impact of the food inflation shock on both food prices and non-food price turns negative after the 20th and 25th quarters respectively in figure 7. The statistical significance of these negative responses is a bit puzzling although we have instances of negative food inflation in the data. To explore this further, we estimate several additional models. First, we estimate models for inflation, food inflation and non-food inflation shocks with a smaller set of variables containing the corresponding prices, output and interest rate. These models (figures A.8, A.9 and A.10) in appendix A.3 produce similar results as in the paper (except the response of output is not significant in the case of inflation shock unlike with a larger set of variables reported in figure 3). These models do not have a statistically significant decline in prices (including prices) but do have a relatively permanent effect on output (A.9) due to food inflation shock.

Second, we estimate the models with only food price and non-food price instead of having both of these variables. These results (figures A.11, A.12, A.13 and A.14) given in appendix A.4 are similar to the results reported in the paper. Food price continues to have a negative response due to food inflation shock after 20 quarters (figure A.11). Third we estimate the models with a higher number of lags with both food price and non-food price. These results (figures A.15, A.16, A.17 and A.18) given in appendix A.5 are also similar to the results reported in the paper. Although, Increasing the lag length leads to a relatively faster transition to the steady state but negative price response persists (figure A.15) and a higher number of lags brings a lot of noise as we can see in the responses. Further, the responses with 4 lag lengths lie within the confidence band for the response with 2 lag lengths. Some exceptions are there but since none of the information criteria suggests 4 lag lengths, we stick with 2 lag lengths.

Finally, we estimate the food and non-food inflation shocks for a smaller duration i.e. the shocks that explain maximum FEV of food and non-food prices between 0 to 20 quarters. These results (figures A.19, A.20, A.21 and A.22) given in appendix A.6 still give the permanent effect of food inflation shock on credit, investment and output although the negative effect on prices does not appear anymore. But that is primarily due to the reduction in the number of periods as these price responses due to food inflation shock seem to be crossing the horizontal axis. These permanent responses of credit, investment, and output are likely to be arising because the food inflation shock of the 2010s was accompanied by other macroeconomic developments that had a large impact on financial intermediation. The decline in food inflation after 2012 was followed by a sharp decline in non-energy commodity prices. These declines in prices led to a decline in profitability of non-financial firms and affected their loan repayment capacity. A significant number of firms in commodity-sensitive sectors such as iron and steel filed for bankruptcy which led to the creation of a large amount of non-performing assets in the banking sector. Due to scarcity of capital, the banks reduced their lending and it hurt investment and growth. Hence these responses suggest a balance sheet crisis in aftermath of a crash in food prices (non-energy prices).

Appendix A.7 gives results with monthly inflation shock identified with monthly data on consumer price, short-term nominal interest rate, bank credit, and index of industrial production for the same period. We estimate the VAR with lag 2 and lag 6. Since, we have more observations, we use a higher number of lags with monthly data. Results are similar to the ones obtained with quarterly data. The monthly inflation shock increases monthly inflation by 1 per cent by the 5th month. This implies a maximum increase of 12% in inflation (annualized) which is higher than the increase obtained using quarterly data. Monthly inflation shock has a slightly higher share in FEV of consumer prices. The response of interest rate due to monthly inflation shock is similar. It increases interest by a maximum of 0.2 per cent. We use the same annual interest rate in estimating models with quarterly as well as monthly data. The timing of maximum response of interest rate is different with lag 2 and lag 6 but both have a similar maximum response. The medium-run effect of monthly inflation shock on the index of industrial production and credit is similar to the effect of inflation shock on quarterly GDP and credit explained before.

4.2 Evidence From New Keynesian Model

Results presented in the previous section give overwhelming evidence that Indian inflation is supply-driven and food inflation shock is the primitive shock that drives inflation. The new-Keynesian model briefly outlined in the introduction has six shocks. Appendix B at the end gives the model in detail.

Table 2: Shapley decomposition of the inflation shock

Shock	Share	Share	Share
Preference Shock	13.33	39.01	20.24
Interest Rate Rate	1.78		
Government Expenditure Shock	30.12		
Technology Shock	22.83	60.99	79.76
Markup Shock	18.39		
Investment Specific Technology Shock	13.56		

Notes: Second column gives the share of variance of estimated inflation shock explained by model-based shocks. The third column gives the share explained by model-based demand and supply shocks. The fourth column gives the share explained by model-based demand and supply shocks in absence of government expenditure shock.

Table 3: Shapley decomposition of the medium run inflation shock

Shock	Share	Share	Share
Preference Shock	19.94	51.07	37.71
Interest Rate Rate	2.96		
Government Expenditure Shock	37.37		
Technology Shock	18.31	48.93	62.29
Markup Shock	17.43		
Investment Specific Technology Shock	4		

Notes: Second column gives the share of variance of estimated medium run inflation shock explained by model-based shocks. The third column gives the share explained by model-based demand and supply shocks. The fourth column gives the share explained by model-based demand and supply shocks in absence of government expenditure shock.

Preference, interest rate, and government expenditure shocks are demand-side shocks. Technology, investment-specific technology, and markup shocks are supply-side shocks. We do Shapley explained sum of squares decomposition[13] which gives the contribution of model-based shocks in explaining the variation in inflation shocks estimated in this paper. We present the decomposition for shocks estimated with lag 1 as lag 2 gives similar shocks. Table 2 presents the share of the explained sum of squares of inflation shock due to different model-based shocks and combinations of model-based shocks.

[13]Appendix A.10 at the end gives details of Shapley decomposition.

Table 2 depicts that the major share is explained by a supply shock, i.e. more than 50 %. If we remove government expenditure from the model[14] based shock, then the share explained by supply shocks becomes 4 times the share explained by demand shocks.

Table 4: Shapley decomposition of the inflation shock

Shock	Share	Share	Share
Preference Shock	10.17	40.30	40.24
Interest Rate Rate	1.33		
Government Expenditure Shock	33.28		
Technology Shock	13.13	39.71	49.32
Markup Shock	14.06		
Investment Specific Technology Shock	7.06		
Oil Demand Shock	3.9	9.60	
Oil Supply Shock	6.63		
Uncertainty Shock	10.44	10.39	10.44

Notes: Second column gives the share of variance of estimated inflation shock explained by model-based and other shocks. The third column gives the share explained by model-based demand and supply, oil price, and uncertainty shocks. The fourth column gives the share explained by model-based demand and supply shocks (including oil price shocks).

Table 3 depicts the share explained by model-based shocks for medium-run inflation shock. Now demand and supply shock explain roughly the same share i.e. 50% each. If we remove government expenditure from the model-based shocks, then the share explained by supply shocks becomes more than 1.5 times the share explained by demand shocks. These two tables suggest that inflation originates as a supply shock but becomes more demand-driven after a year when the effect of interest rate tightening picks up. This is expected because there exists a lag in the transmission of increased interest rates to households and firms.

Table 4 depicts the share explained by model-based shock as well as a few other shocks for the inflation shock. We have taken oil demand and supply shocks from Caldara et

[14] We do this because one can argue that government expenditure shock is essentially a labour supply shock.

al. (2019) and economic policy uncertainty from Baker et al. (2016)[15]. Now demand and supply shocks explain roughly the same share i.e. 40% each. 10% each is attributed to oil and uncertainty shocks respectively. The low share of oil prices corroborates the findings of Bhattacharya and Sengupta (2015) and Chinoy et al. (2015). If we include oil shocks in supply shock then the share of supply shocks again dominates. Kumar et al. (2021a) argue that uncertainty shocks are supply shocks in India and if we consider that, then again the contribution of supply shocks becomes 1.5 times the demand shocks[16].

Table 5: Shapley decomposition of the medium run inflation shock

Shock	Share	Share	Share
Preference Shock	15.11	49.17	49.21
Interest Rate Rate	2.33		
Government Expenditure Shock	39.71		
Technology Shock	12.74	38.65	47.24
Markup Shock	14.53		
Investment Specific Technology Shock	2.84		
Oil Demand Shock	1.93	8.67	
Oil Supply Shock	7.28		
Uncertainty Shock	3.54	3.51	3.55

Notes: Second column gives the share of variance of estimated medium run inflation shock explained by model-based and other shocks. The third column gives the share explained by model-based demand and supply, oil price, and uncertainty shocks. The fourth column gives the share explained by model-based demand and supply shocks (including oil price shocks).

Table 5 depicts the share explained by model-based shock as well as a few other shocks for the medium-run inflation shock. Now demand shock dominates and explains around 50% of the explained sum of squares. 9% share is attributed to oil shocks and 3.5% to uncertainty shocks. Even if we include oil and uncertainty shocks in supply shocks then also the share of demand shocks is roughly equal to the share of supply shocks.

[15]Figures A.25 and A.26 in appendix A.8 contain twenty periods rolling correlation of inflation and medium run inflation shocks with economic policy uncertainty index.

[16]Kim et al. (2021) show that the same uncertainty shocks behave as demand-side shocks in major Asian economies which is similar to the findings in Kumar et al. (2021a) for the US economy.

Table 6 depicts the share explained by model-based shock as well as few other shocks for the food inflation shock obtained with gross fixed capital formation. The decomposition for the food inflation shock estimated with government final consumption expenditure gives similar results and is presented in table A.1 of appendix A.9. As we can see, now the supply shocks explain around 80% of the variation in the food inflation shock. This is expected because the food inflation shock is the primitive supply shock which makes inflation shock a supply shock. Also, uncertainty shock is important. Kumar et al. (2021a) document that economic policy uncertainty for India reflects a significant amount of uncertainty about the primary sector of the economy.

Table 6: Shapley decomposition of the food inflation shock

Shock	Share	Share	Share
Preference Shock	10.26	14.34	14.45
Interest Rate Rate	3.31		
Government Expenditure Shock	1.95		
Technology Shock	14.16	74.58	78.23
Markup Shock	26.71		
Investment Specific Technology Shock	32.07		
Oil Demand Shock	0.22	3.81	
Oil Supply Shock	3.92		
Uncertainty Shock	7.38	7.26	7.33

Notes: Second column gives the share of variance of estimated food inflation shock explained by model-based and other shocks. The third column gives the share explained by model-based demand and supply, oil price, and uncertainty shocks. The fourth column gives the share explained by model-based demand and supply shocks (including oil price shocks). Food inflation shock is obtained from the SVAR model consisting of the food price, non-food price, short-term nominal interest rate, real bank credit, real gross fixed capital formation, and real gross domestic product (GDP).

Table 7 depicts the share explained by model-based shock as well as few other shocks for the non-food inflation shock estimated with gross fixed capital formation. The decomposition for the non-food inflation shock estimated with government final consumption expenditure gives similar results and is presented in table A.2 of appendix A.9. For non-food inflation shock, the contribution of supply and uncertainty shocks is significantly lower in comparison to the food inflation shock. This suggests that the non-food inflation shock has more demand characteristics which are expected.

Table 7: Shapley decomposition of the non-food inflation shock

Shock	Share	Share	Share
Preference Shock	15.56	42.28	42.50
Interest Rate Rate	1.37		
Government Expenditure Shock	29.57		
Technology Shock	8.86	50.93	56.69
Markup Shock	30.51		
Investment Specific Technology Shock	7.78		
Oil Demand Shock	3.90	5.99	
Oil Supply Shock	1.64		
Uncertainty Shock	0.83	0.81	0.81

Notes: Second column gives the share of variance of estimated non-food inflation shock explained by model-based and other shocks. The third column gives the share explained by model-based demand and supply, oil price, and uncertainty shocks. The fourth column gives the share explained by model-based demand and supply shocks (including oil price shocks). Non-food inflation shock is obtained from the SVAR model consisting of the non-food price, food price, short-term nominal interest rate, real bank credit, real gross fixed capital formation, and real gross domestic product (GDP).

Results obtained in this section suggest that supply shocks from the model explain a higher amount of variation in inflation and food inflation shocks. But in the case of medium-run inflation and non-food inflation shocks, the share of demand shocks increases. Uncertainty shock explains significantly more variation of the inflation and food inflation shocks, i.e. it is more related to inflation in the short-run (up to one year). Thus, we can say that inflation originates mainly from supply shocks but becomes more demand-driven after a year when the effect of interest rate tightening reduces supply more than demand.

5 Concluding Remarks and Policy Implications

Understanding the drivers of inflation is important for understanding the business cycle. In this paper, we estimate *inflation shock* (structural shock that explains maximum FEV of consumer price between 0 to 40 quarters) and *medium run inflation shock* (structural shock that explains maximum FEV of consumer price between 5 to 20 quarters). Our identification is agnostic and not based on sign and zero restrictions commonly used in SVAR literature. The inflation shock explains more than 80 per cent of FEV of consumer price between 0 to 40 quarters. This shock increases price and decreases output; implying that it is a supply shock. It also increases interest rates and decreases credit and investment. The shock also explains more than 40 per cent of the FEV of credit, output, investment, and interest rate over the same period; suggesting that this shock is a significant driver of the Indian business cycle. Medium-run inflation shock has similar effects.

Thereafter, we identify food and non-food inflation shocks (structural shocks that explain maximum FEV of food and non-food prices respectively between 0 to 40 quarters). Careful observation of impulse responses and correlation between estimated shocks suggests that the inflation shock is giving responses similar to the food inflation shock. Also, the non-food inflation shock does not affect output, interest rate, investment, and credit, unlike inflation and food inflation shocks. Therefore, one can say that the responses given by inflation shock are driven by the food inflation shock which further suggests that inflation is mainly supply-driven. Also, for model variables, the FEV explained by the food inflation shock increases over time whereas the FEV explained by the non-food inflation shock either stagnates or decreases over time. This is expected as the monetary policy reacts significantly to food inflation.

We also estimate shocks from a medium-scale new Keynesian model and conduct Shapley's decomposition of the explained sum of squares of inflation, food inflation, non-food inflation, and medium-run inflation shocks. Shapley's decomposition suggests that food inflation and inflation shocks are mainly explained by the model-based supply shock. In the case of non-food inflation and medium-run inflation shocks, we find that the importance of model-based demand shocks is slightly higher. Also, the effect on output is less strong in the model without credit and investment. This suggests that inflation originates as a supply shock but becomes more demand-driven in the medium run due to the lagged effect of interest rate tightening that may be reducing supply more than it reduces demand. The findings in this paper have significant policy implications. Inflation is mainly driven by supply shocks and excess monetary policy reaction hurts the real economy. Excess tightening would not improve credibility if excess demand due to supply-side deterioration causes inflation persistence.

A food inflation shock of 3% leads to a .5% maximum response in non-food inflation (figure A.15). Given the weight of the non-food component in CPI(IW) considered in this paper, this amounts to a 0.3% contribution to inflation. Hence the inflation shock is still a predominantly supply shock- originating and operating through food inflation. The central bank may indeed respond (as happens in data) to such inflation under an inflation targeting regime but it leads to a permanent effect on output as the range of estimates in this paper indicate. Our main argument is that a more calibrated and flexible approach is required under the inflation targeting framework. The recent policy decisions by the Reserve Bank of India have been in the right direction where the bank approached the inflation originating from a food price shock more pragmatically.

References

[1] Baker, S. R., N. Bloom, and S. J. Davis, 2016. "Measuring Economic Policy Uncertainty," Quarterly Journal of Economics, 131, no. 4 (November), 1593-1636.

[2] Ball, L., Chari, A. and Mishra, P., 2016. Understanding inflation in India (No. w22948). National Bureau of Economic Research.

[3] Barsky, R.B. and Sims, E.R., 2011. News shocks and business cycles. Journal of monetary Economics, 58(3), pp.273-289.

[4] Bernanke, B.S., Gertler, M. and Gilchrist, S., 1999. The financial accelerator in a quantitative business cycle framework. Handbook of macroeconomics, 1, pp.1341-1393.

[5] Bhalla, S. S., 2015. http://indianexpress.com/article/opinion/columns/no-proof-required-why-inflation-fell/

[6] Bhattacharya, R. and Gupta, A.S., 2015. Food inflation in India: Causes and consequences. National Institute of Public Finance and Policy, Working Paper, (2015-151).

[7] Bhattacharya, R. and Jain, R., 2019. Can monetary policy stabilise food inflation? Evidence from advanced and emerging economies. Economic Modelling.

[8] Bhoi, B.K., Kumar, A. and Parab, P.M., 2019. Aggregate demand management, policy errors and optimal monetary policy in India (No. 2019-029). Indira Gandhi Institute of Development Research, Mumbai, India.

[9] Blinder, A.S. and Rudd, J.B., 2013. 2. The Supply-Shock Explanation of the Great Stagflation Revisited (pp. 119-178). University of Chicago Press.

[10] Brunnermeier, M.K. and Sannikov, Y., 2014. A macroeconomic model with a financial sector. American Economic Review, 104(2), pp.379-421.

[11] Caldara, D., Cavallo, M. and Iacoviello, M., 2019. Oil price elasticities and oil price fluctuations. Journal of Monetary Economics, 103, pp.1-20.

[12] Cascaldi-Garcia, D. and Galvao, A.B., 2018. News and uncertainty shocks. FRB International Finance Discussion Paper, (1240).

[13] Chinoy, S.Z., Kumar, P. and Mishra, P., 2016. What is Responsible for India's Sharp Disinflation?. In Monetary Policy in India (pp. 425-452). Springer India.

[14] Christiano, L.J., Eichenbaum, M. and Evans, C.L., 2005. Nominal rigidities and the dynamic effects of a shock to monetary policy. Journal of political Economy, 113(1), pp.1-45.

[15] Drechsel, T., 2019. Earnings-Based Borrowing Constraints and Macroeconomic Fluctuations (No. pdr141). Job Market Papers

[16] Francis, N., Owyang, M.T., Roush, J.E. and DiCecio, R., 2014. A flexible finite-horizon alternative to long-run restrictions with an application to technology shocks. Review of Economics and Statistics, 96(4), pp.638-647.

[17] Goyal, A., 2015. http://blogs.economictimes.indiatimes.com/FindingtheCenter/raghuram-rajans-conservative-approach-has-served-well-for-economy/

[18] Goyal, A. and Kumar, A., 2018. Active monetary policy and the slowdown: Evidence from DSGE based Indian aggregate demand and supply. The Journal of Economic Asymmetries, 17, pp.21-40.

[19] Goyal, A. and Kumar, A., 2019. Overreaction in Indian monetary policy. Economic and Political Weekly, 54(12).

[20] Goyal, A. and Kumar, A., 2020. A DSGE model-based analysis of the Indian slowdown. Journal of International Commerce, Economics and Policy, 11(01), p.2050004.

[21] Goyal, A. and Kumar, A., 2022. News, noise, and Indian business cycle. Bulletin of Economic Research, 74(2), pp.503-538.

[22] Hart, O. and Moore, J., 1994. A theory of debt based on the inalienability of human capital. The Quarterly Journal of Economics, 109(4), pp.841-879.

[23] Hennessy, C.A. and Whited, T.M., 2005. Debt dynamics. The journal of finance, 60(3), pp.1129-1165.

[24] Holmstrom, B. and Tirole, J., 1997. Financial intermediation, loanable funds, and the real sector. the Quarterly Journal of economics, 112(3), pp.663-691.

[25] Holtemoller, O. and Mallick, S., 2016. Global food prices and monetary policy in an emerging market economy: The case of India. Journal of Asian Economics, 46, pp.56-70.

[26] Iacoviello, M., 2015. Financial business cycles. Review of Economic Dynamics, 18(1), pp.140-163.

[27] Jha, P. S., 2016. thewire.in/42392/raghuram-rajan-has-got-it-wrong-on-inflation-and-interest-rates/

[28] Justiniano, A., Primiceri, G. and Tambalotti, A., 2009. Investment Shocks and the Relative Price of Investment, Discussion Paper 7598.

[29] Kim, J., Kumar, A., Mallick, S. and Park, D., 2021. Financial uncertainty and interest rate movements: is Asian bond market volatility different?. Annals of Operations Research, pp.1-29.

[30] Kiyotaki, N. and Moore, J., 1997. Credit cycles. Journal of political economy, 105(2), pp.211-248.

[31] Kumar, A., Mallick, S. and Sinha, A., 2021a. Is uncertainty the same everywhere? Advanced versus emerging economies. Economic Modelling, 101, p.105524.

[32] Kumar, A., Mallick, S. and Sinha, A., 2021b. Policy errors and business cycle fluctuations: Evidence from an emerging economy. Journal of Economic Behavior Organization, 192, pp.176-198.

[33] Kurmann, A. and Otrok, C., 2013. News shocks and the slope of the term structure of interest rates. American Economic Review, 103(6), pp.2612-32.

[34] Mohanty, D. and John, J., 2015. Determinants of inflation in India. Journal of Asian Economics, 36, pp.86-96.

[35] Rotemberg, J.J., 1982. Sticky prices in the United States. The Journal of Political Economy, pp.1187-1211.

[36] Rotemberg, J., 1987. The new Keynesian microfoundations. In NBER Macroeconomics Annual 1987, Volume 2 (pp. 69-116). The MIT Press.

[37] Shleifer, A. and Vishny, R.W., 1992. Liquidation values and debt capacity: A market equilibrium approach. The Journal of Finance, 47(4), pp.1343-1366.

[38] Stiglitz, J.E. and Weiss, A., 1981. Credit rationing in markets with imperfect information. The American economic review, 71(3), pp.393-410

[39] Subbarao, D., 2013. https://www.rbi.org.in/scripts/BS_SpeechesView.aspx?Id=833

[40] Townsend, R.M., 1979. Optimal contracts and competitive markets with costly state verification. Journal of Economic theory, 21(2), pp.265-293.

[41] Uhlig, H., 2004, August. What moves GNP?. In Econometric Society 2004 North American Winter Meetings (No. 636). Econometric Society.

Online Appendix

A Supplementary Results

A.1 Baseline Model with Nominal Credit

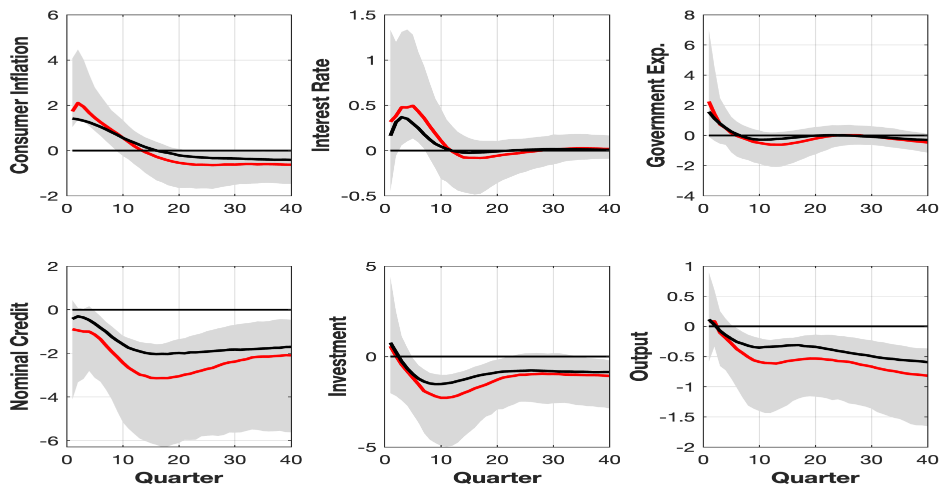


Figure A.1: Responses of variables due to the food inflation shock.

Notes: Inflation shock explains the maximum FEV of consumer price between 0 to 40 quarters and is obtained from the SVAR model consisting of consumer price, treasury bills rate, real government final consumption expenditure, nominal bank credit, real gross fixed capital formation and real gross domestic product (GDP). The red line is for VAR with lag length 2 and the black line is for VAR with lag length 1. The shaded area represents one standard deviation confidence band.

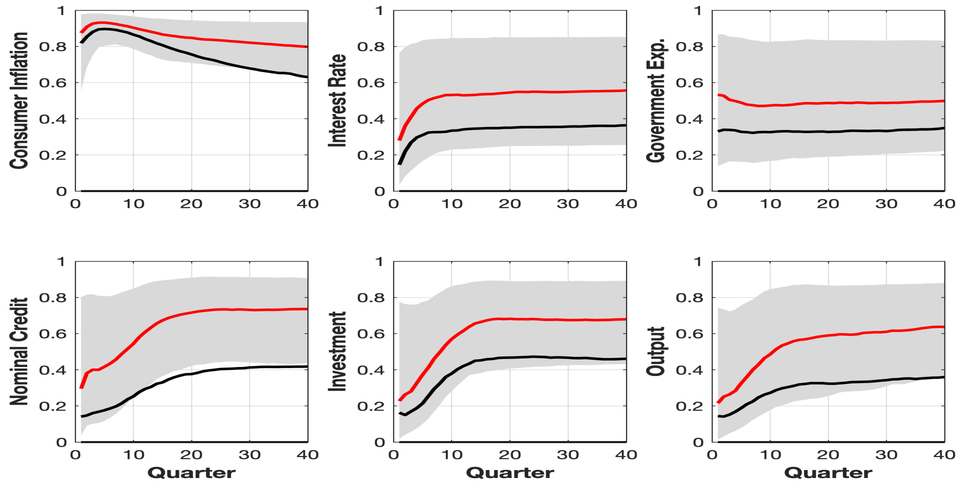


Figure A.2: Share of the inflation shock in FEV of variables in the model.

Notes: Inflation shock explains the maximum FEV of consumer price between 0 to 40 quarters and is obtained from the SVAR model consisting of consumer price, treasury bills rate, real government final consumption expenditure, nominal bank credit, real gross fixed capital formation and real gross domestic product (GDP). The red line is for VAR with lag length 2 and the black line is for VAR with lag length 1. The shaded area represents one standard deviation confidence band.

A.2 Food and Non-Food Inflation Shocks with Government Expenditure instead of Investment

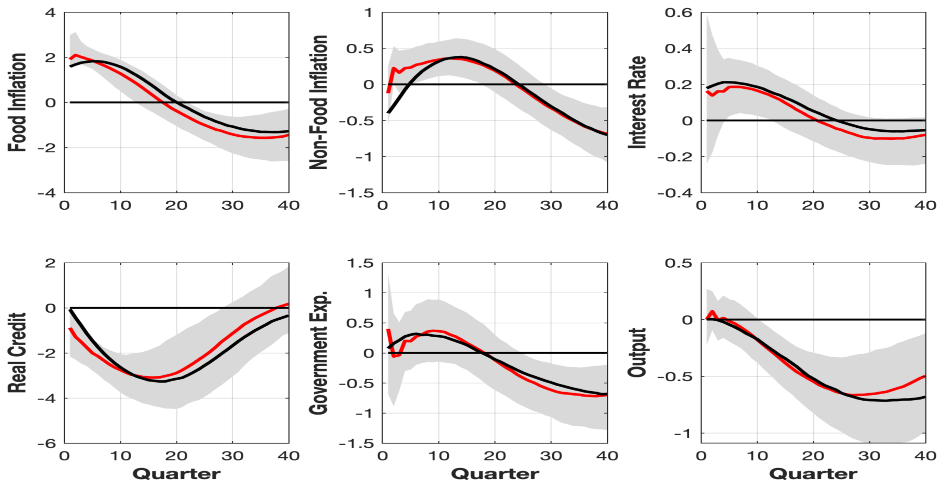


Figure A.3: Responses of variables due to the food inflation shock.

Notes: Food inflation shock explains the maximum FEV of food price between 0 to 40 quarters and is obtained from the SVAR model consisting of food price, non-food price, treasury bills rate, real bank credit, real government final consumption expenditure, and real gross domestic product (GDP). The red line is for VAR with lag length 2 and the black line is for VAR with lag length 1. The shaded area represents one standard deviation confidence band.

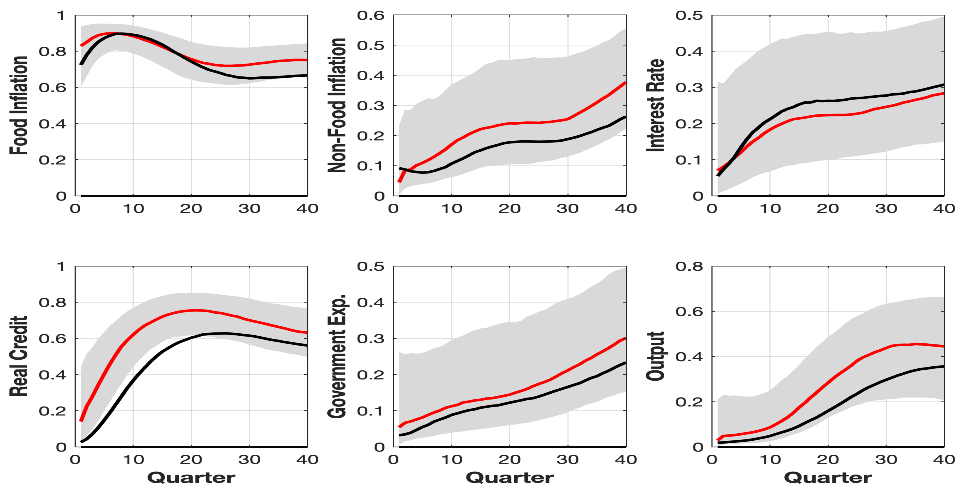


Figure A.4: Share of the food inflation shock in FEV of variables in the model.

Notes: Food inflation shock explains the maximum FEV of food price between 0 to 40 quarters and is obtained from the SVAR model consisting of food price, non-food price, treasury bills rate, real bank credit, real government final consumption expenditure, and real gross domestic product (GDP). The red line is for VAR with lag length 2 and the black line is for VAR with lag length 1. The shaded area represents one standard deviation confidence band.

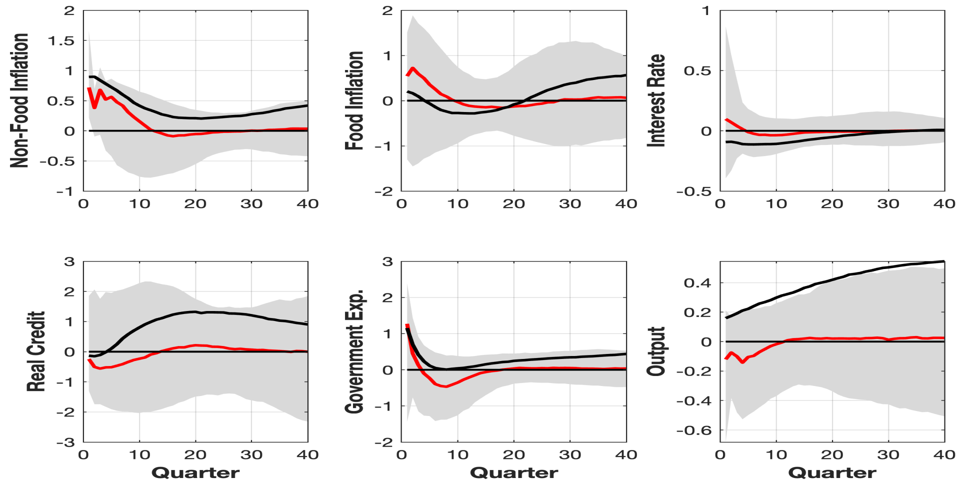


Figure A.5: Responses of variables due to the non-food inflation shock.

Notes: Non-food inflation shock explains the maximum FEV of non-food price between 0 to 40 quarters and is obtained from the SVAR model consisting of non-food price, food price, treasury bills rate, real bank credit, real government final consumption expenditure, and real gross domestic product (GDP). The red line is for VAR with lag length 2 and the black line is for VAR with lag length 1. The shaded area represents one standard deviation confidence band.

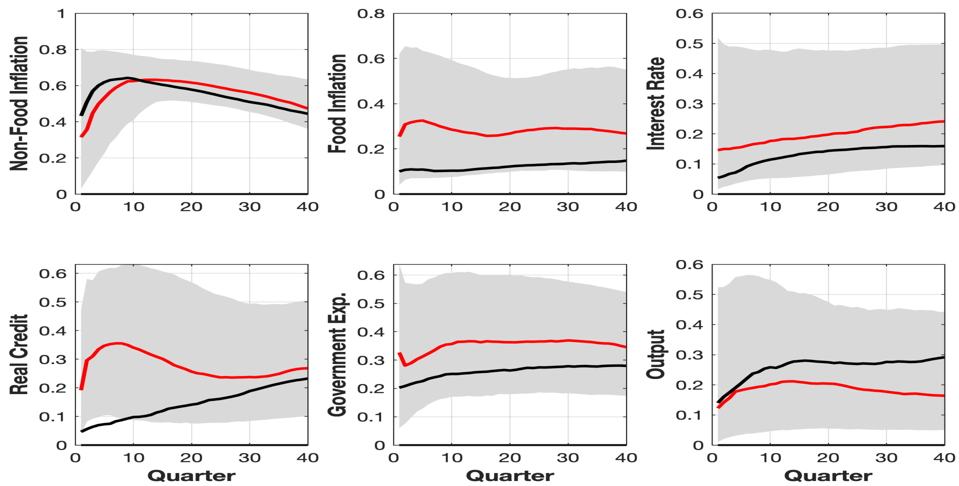
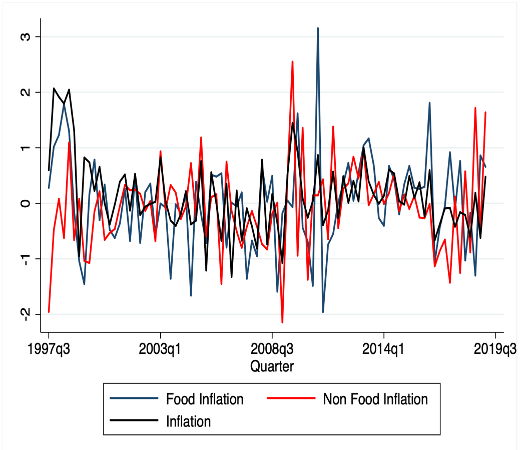
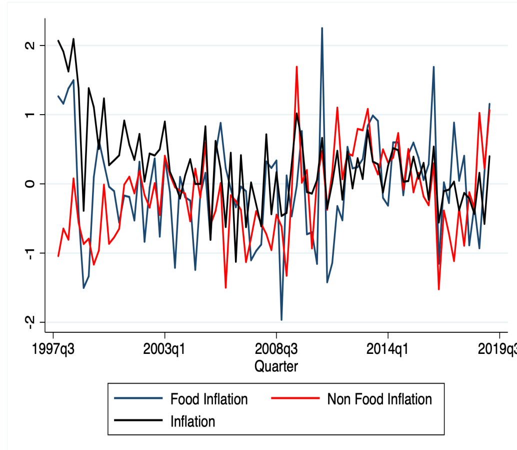


Figure A.6: Share of the non-food inflation shock in FEV of variables in the model.

Notes: Non-food inflation shock explains the maximum FEV of non-food price between 0 to 40 quarters and is obtained from the SVAR model consisting of non-food price, food price, treasury bills rate, real bank credit, real government final consumption expenditure, and real gross domestic product (GDP). The red line is for VAR with lag length 2 and the black line is for VAR with lag length 1. The shaded area represents one standard deviation confidence band.



(a) VAR with lag length 1



(b) VAR with lag length 2

Figure A.7: Inflation, food and non-food inflation shocks

Notes: Inflation, food inflation and non-food inflation shocks explain the maximum FEV of consumer price, food price and non-food prices between 0 to 40 quarters. The inflation shock is obtained from the VAR model consisting of consumer price, treasury bills rate, real government final consumption expenditure, real bank credit, real gross fixed capital formation and real gross domestic product (GDP). Food and non-food inflation shocks are obtained from the SVAR model consisting of the food price, non-food price, treasury bills rate, real bank credit, real government final consumption expenditure, and real gross domestic product (GDP). With lag 2, the correlation between inflation and food inflation shock is approx. 0.6 and significant, whereas the correlation between inflation and non-food inflation is .25 and significant. With lag 1, the correlation between inflation and food inflation shock is approx. 0.5 and significant, whereas the correlation between inflation and non-food inflation is low (negative) and insignificant.

A.3 Evidence from VAR with Three Variables

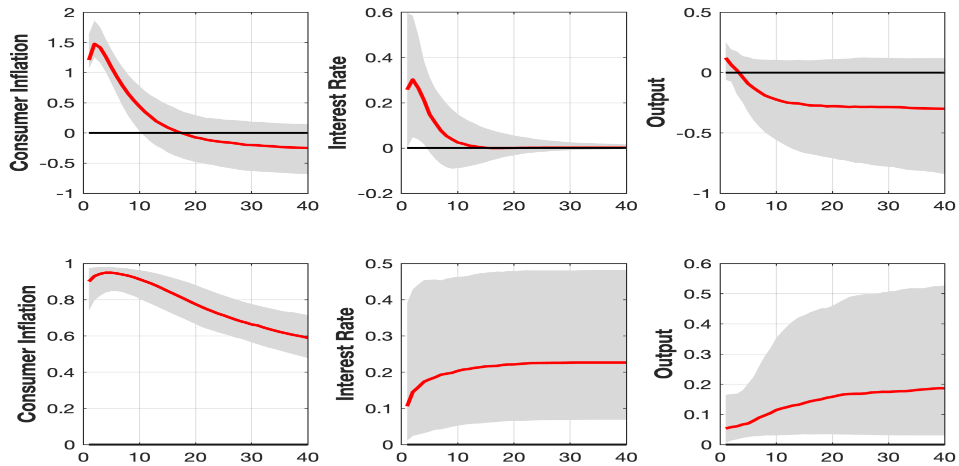


Figure A.8: Response of model variables due to the inflation shock and share of inflation shock in FEV of these variables.

Notes: First row represent responses and the second row represents the share in FEV. Inflation shock explains the maximum FEV of consumer price between 0 to 40 quarters and is obtained from the SVAR model consisting of consumer price, treasury bills rate, and real gross domestic product (GDP). The red line is for VAR with lag length 2. The shaded area represents one standard deviation confidence band.

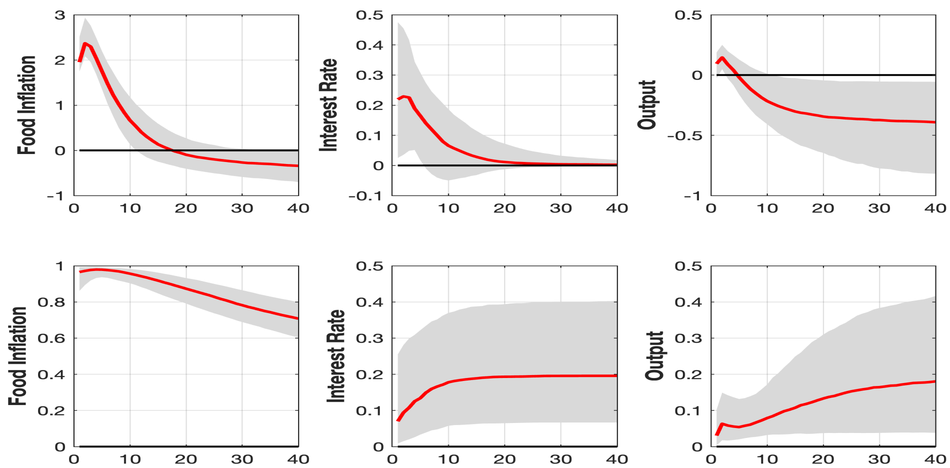


Figure A.9: Response of model variables due to the food inflation shock and share of food inflation shock in FEV of these variables.

Notes: First row represent responses and the second row represents the share in FEV. Food inflation shock explains the maximum FEV of food price between 0 to 40 quarters and is obtained from the SVAR model consisting of food price, treasury bills rate, and real gross domestic product (GDP). The red line is for VAR with lag length 2. The shaded area represents one standard deviation confidence band.

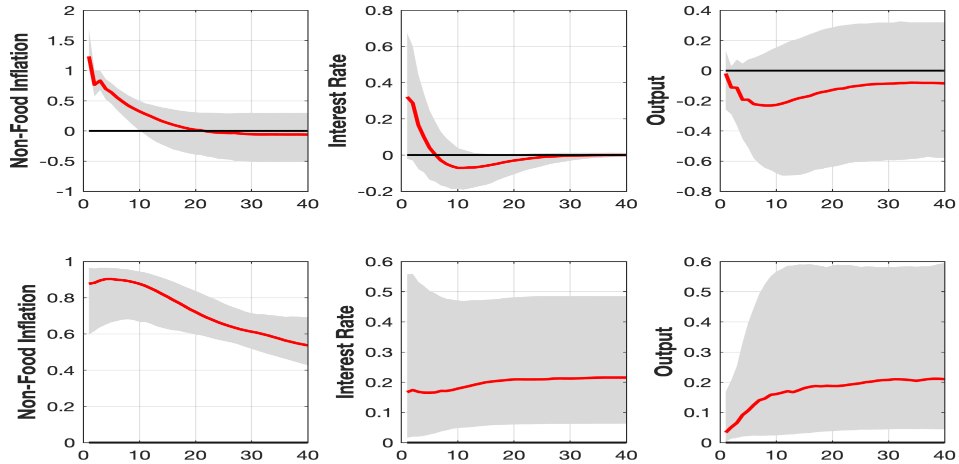


Figure A.10: Response of model variables due to the non-food inflation shock and share of non-food inflation shock in FEV of these variables.

Notes: First row represent responses and the second row represents the share in FEV. Non-food inflation shock explains the maximum FEV of non-food price between 0 to 40 quarters and is obtained from the SVAR model consisting of non-food price, treasury bills rate, and real gross domestic product (GDP). The red line is for VAR with lag length 2. The shaded area represents one standard deviation confidence band.

A.4 Food and Non-Food Inflation Shocks in Absence of each other

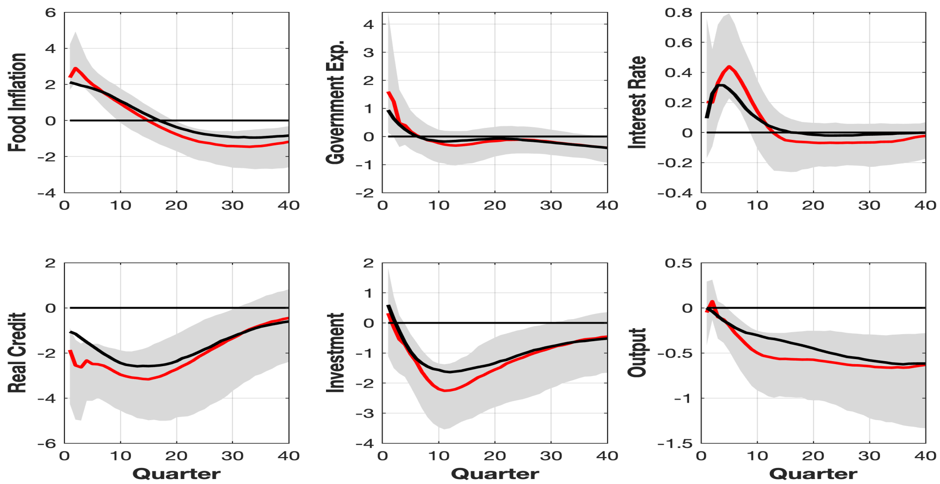


Figure A.11: Responses of variables due to the food inflation shock.

Notes: Food inflation shock explains the maximum FEV of food price between 0 to 40 quarters and is obtained from the SVAR model consisting of food price, treasury bills rate, real bank credit, real government final consumption expenditure, real gross fixed capital formation, and real gross domestic product (GDP). The red line is for VAR with lag length 2 and the black line is for VAR with lag length 1. The shaded area represents one standard deviation confidence band.

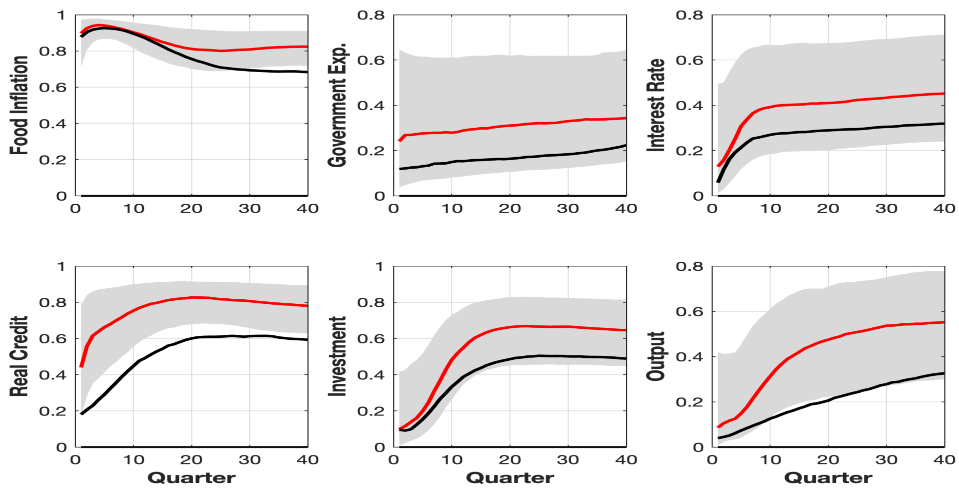


Figure A.12: Share of the food inflation shock in FEV of variables in the model.

Notes: Food inflation shock explains the maximum FEV of food price between 0 to 40 quarters and is obtained from the SVAR model consisting of food price, treasury bills rate, real bank credit, real government final consumption expenditure, real gross fixed capital formation, and real gross domestic product (GDP). The red line is for VAR with lag length 2 and the black line is for VAR with lag length 1. The shaded area represents one standard deviation confidence band.

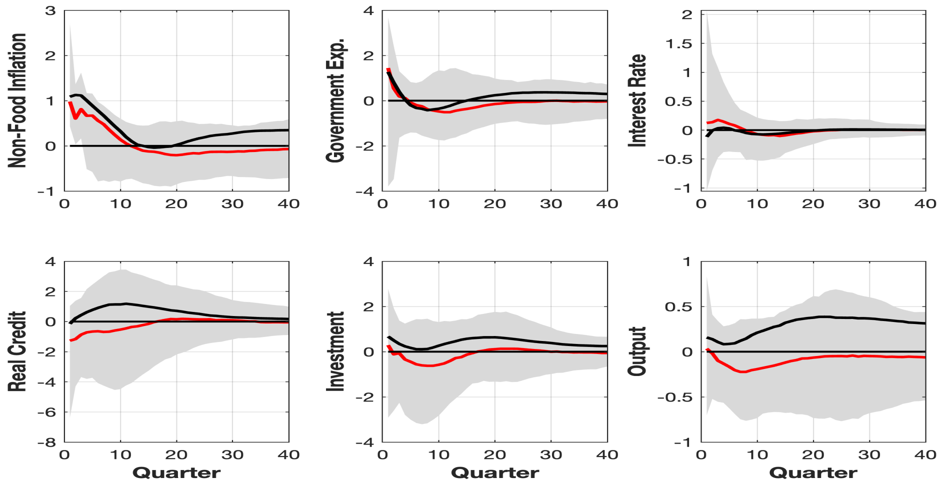


Figure A.13: Responses of variables due to the non-food inflation shock.

Notes: Non-food inflation shock explains the maximum FEV of non-food price between 0 to 40 quarters and is obtained from the SVAR model consisting of non-food price, treasury bills rate, real bank credit, real government final consumption expenditure, real gross fixed capital formation, and real gross domestic product (GDP). The red line is for VAR with lag length 2 and the black line is for VAR with lag length 1. The shaded area represents one standard deviation confidence band.

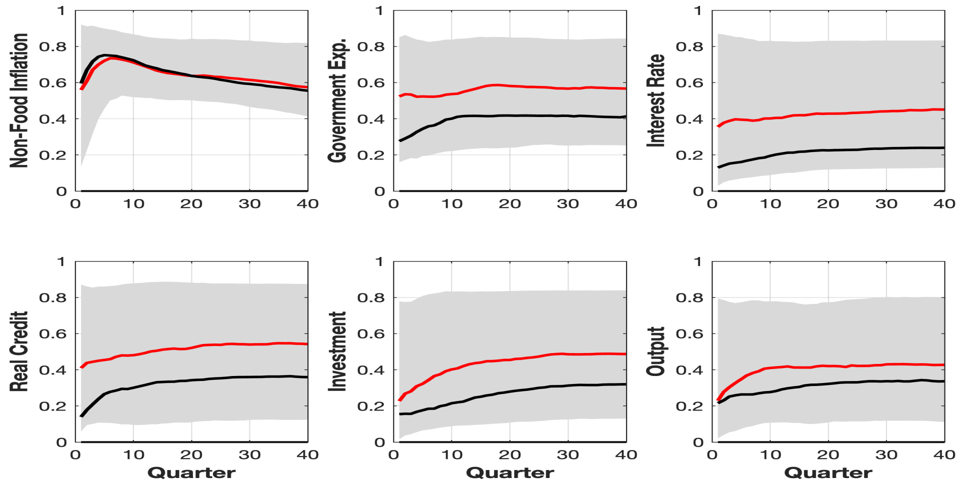


Figure A.14: Share of the non-food inflation shock in FEV of variables in the model.

Notes: Non-food inflation shock explains the maximum FEV of non-food price between 0 to 40 quarters and is obtained from the SVAR model consisting of non-food price, treasury bills rate, real bank credit, real government final consumption expenditure, real gross fixed capital formation, and real gross domestic product (GDP). The red line is for VAR with lag length 2 and the black line is for VAR with lag length 1. The shaded area represents one standard deviation confidence band.

A.5 Food and Non-Food Inflation Shocks with Higher Lags

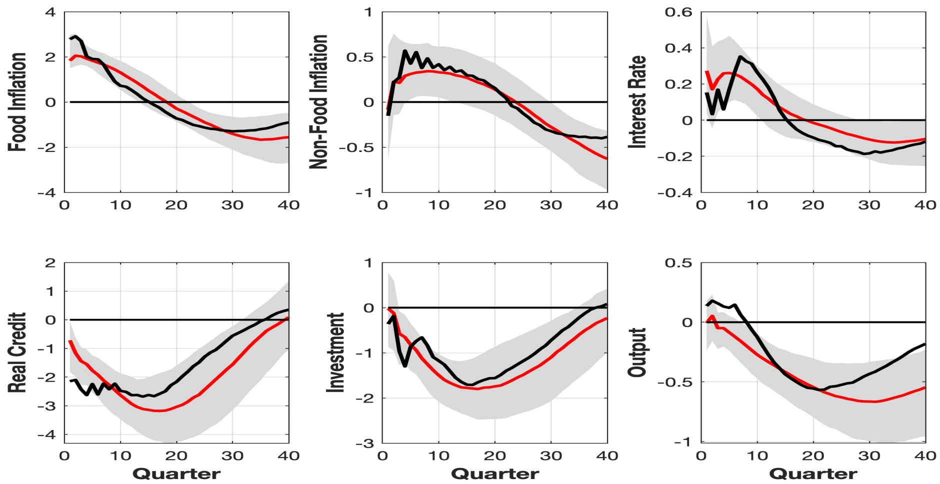


Figure A.15: Responses of variables due to the food inflation shock.

Notes: Food inflation shock explains the maximum FEV of food price between 0 to 40 quarters and is obtained from the SVAR model consisting of food price, non-food price, treasury bills rate, real bank credit, real gross fixed capital formation, and real gross domestic product (GDP). The red line is for VAR with lag length 2 and the black line is for VAR with lag length 4. The shaded area represents one standard deviation confidence band.

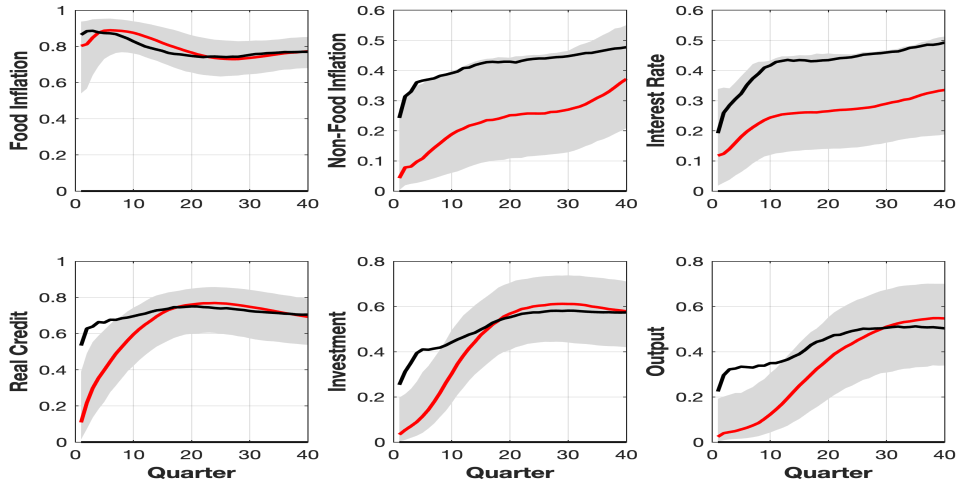


Figure A.16: Share of the food inflation shock in FEV of variables in the model.

Notes: Food inflation shock explains the maximum FEV of food price between 0 to 40 quarters and is obtained from the SVAR model consisting of food price, non-food price, treasury bills rate, real bank credit, real gross fixed capital formation, and real gross domestic product (GDP). The red line is for VAR with lag length 2 and the black line is for VAR with lag length 4. The shaded area represents one standard deviation confidence band.

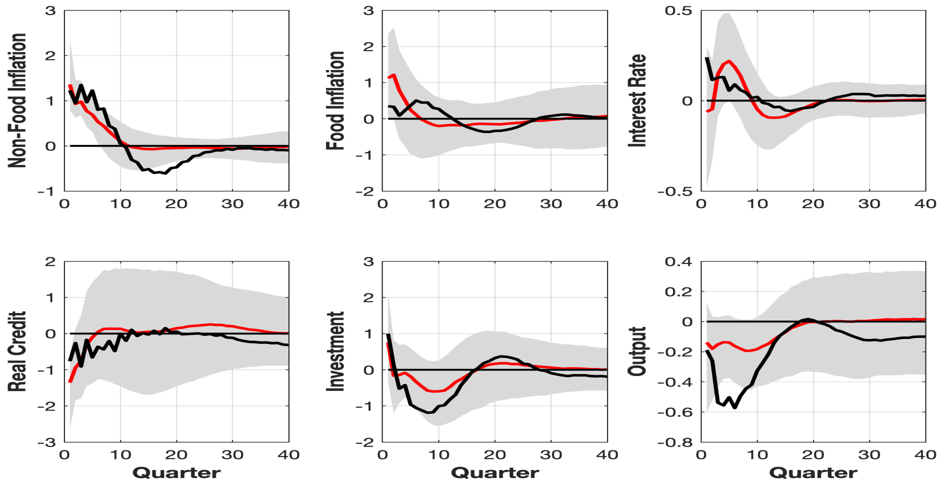


Figure A.17: Responses of variables due to the non-food inflation shock.

Notes: Non-food inflation shock explains the maximum FEV of non-food price between 0 to 40 quarters and is obtained from the SVAR model consisting of non-food price, food price, treasury bills rate, real bank credit, real gross fixed capital formation, and real gross domestic product (GDP). The red line is for VAR with lag length 2 and the black line is for VAR with lag length 4. The shaded area represents one standard deviation confidence band.

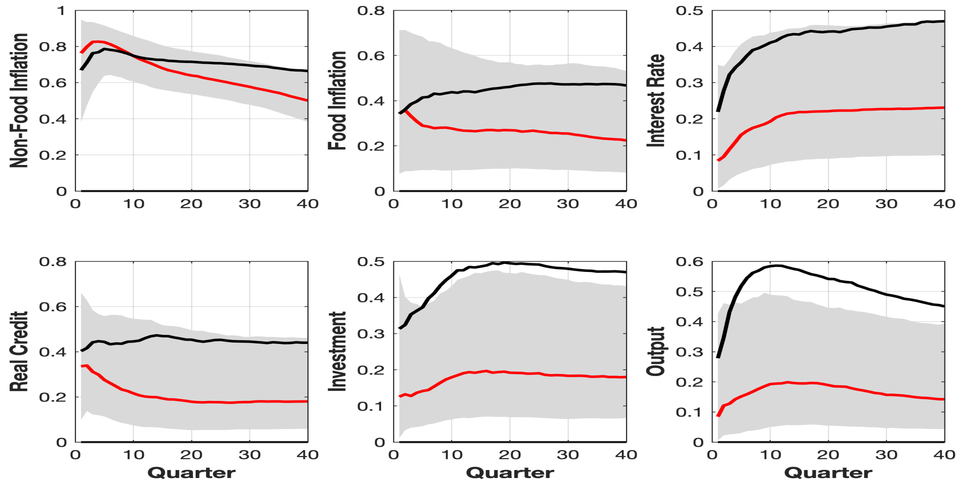


Figure A.18: Share of the non-food inflation shock in FEV of variables in the model.

Notes: Non-food inflation shock explains the maximum FEV of non-food price between 0 to 40 quarters and is obtained from the SVAR model consisting of non-food price, food price, treasury bills rate, real bank credit, real gross fixed capital formation, and real gross domestic product (GDP). The red line is for VAR with lag length 2 and the black line is for VAR with lag length 4. The shaded area represents one standard deviation confidence band.

A.6 Food and Non-Food Inflation Shocks of Smaller Durations

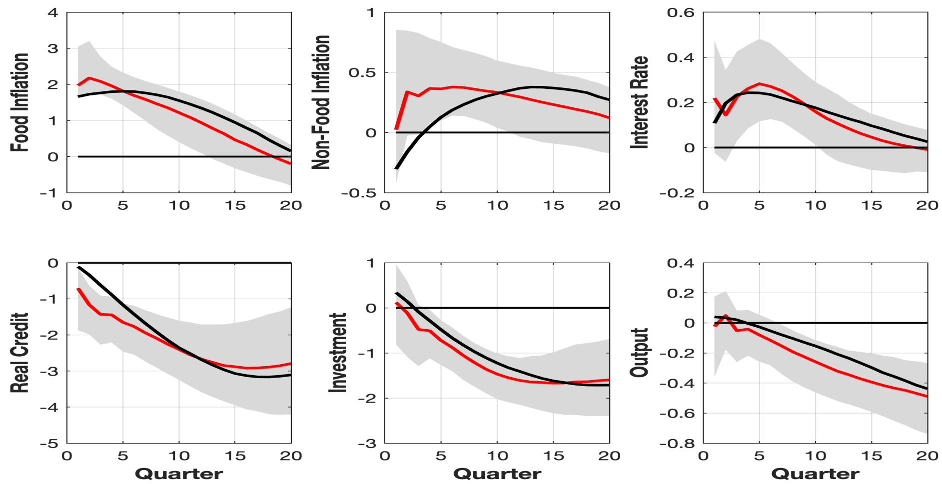


Figure A.19: Responses of variables due to the food inflation shock.

Notes: Food inflation shock explains the maximum FEV of food price between 0 to 20 quarters and is obtained from the SVAR model consisting of food price, non-food price, treasury bills rate, real bank credit, real gross fixed capital formation, and real gross domestic product (GDP). The red line is for VAR with lag length 2 and the black line is for VAR with lag length 1. The shaded area represents one standard deviation confidence band.

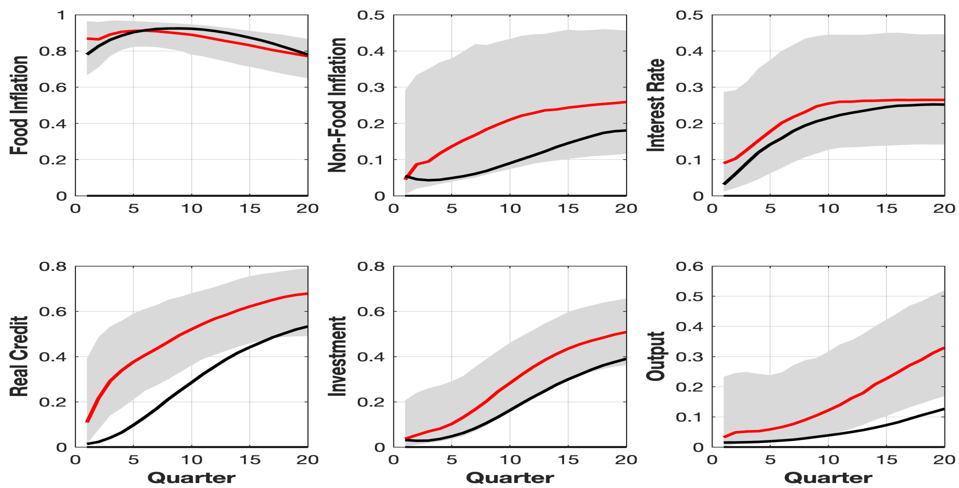


Figure A.20: Share of the food inflation shock in FEV of variables in the model.

Notes: Food inflation shock explains the maximum FEV of food price between 0 to 20 quarters and is obtained from the SVAR model consisting of food price, non-food price, treasury bills rate, real bank credit, real gross fixed capital formation, and real gross domestic product (GDP). The red line is for VAR with lag length 2 and the black line is for VAR with lag length 1. The shaded area represents one standard deviation confidence band.

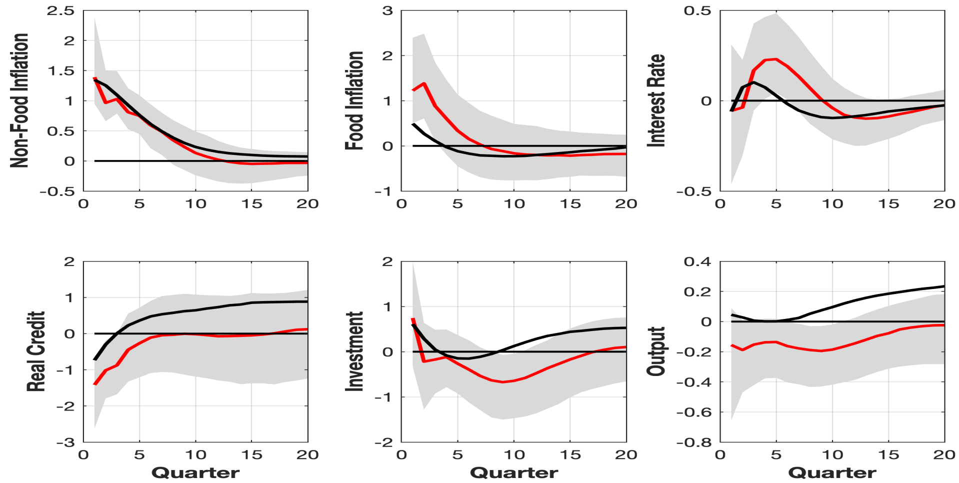


Figure A.21: Responses of variables due to the non-food inflation shock.

Notes: Non-food inflation shock explains the maximum FEV of non-food price between 0 to 20 quarters and is obtained from the SVAR model consisting of non-food price, food price, treasury bills rate, real bank credit, real gross fixed capital formation, and real gross domestic product (GDP). The red line is for VAR with lag length 2 and the black line is for VAR with lag length 1. The shaded area represents one standard deviation confidence band.

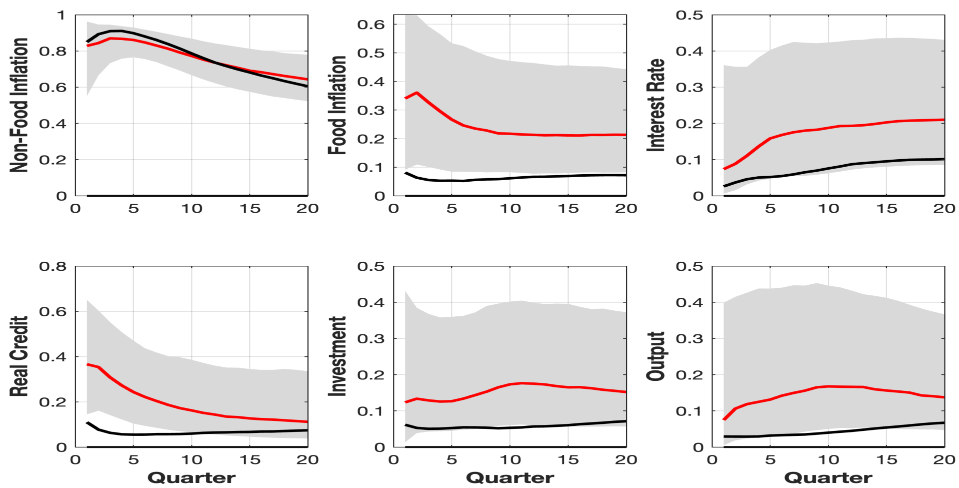


Figure A.22: Share of the non-food inflation shock in FEV of variables in the model.

Notes: Non-food inflation shock explains the maximum FEV of non-food price between 0 to 20 quarters and is obtained from the SVAR model consisting of non-food price, food price, treasury bills rate, real bank credit, real gross fixed capital formation, and real gross domestic product (GDP). The red line is for VAR with lag length 2 and the black line is for VAR with lag length 1. The shaded area represents one standard deviation confidence band.

A.7 Inflation Shock using Monthly Data

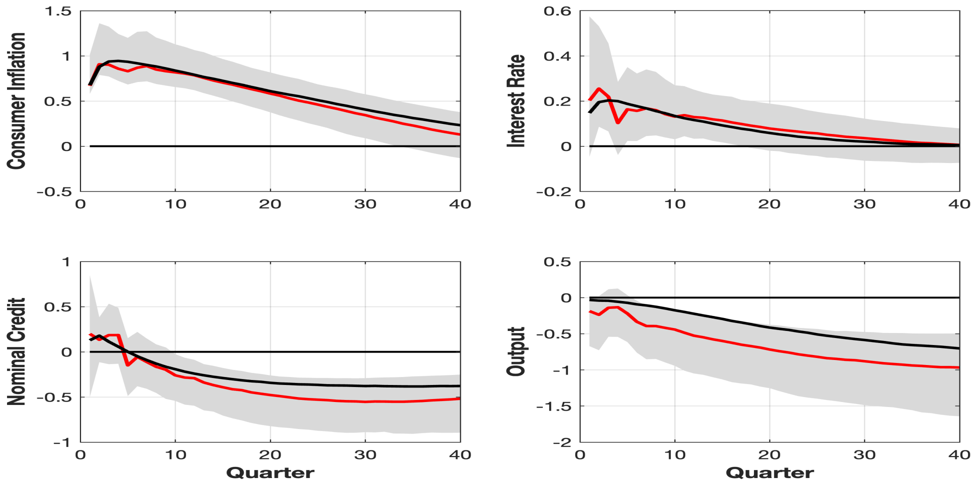


Figure A.23: Responses of variables due to the monthly inflation shock.

Notes: Inflation shock explains the maximum FEV of consumer price between 0 to 40 months and is obtained from the SVAR model consisting of consumer price, treasury bills rate, nominal bank credit, and index of industrial production. The red line is for VAR with lag length 6 and the black line is for VAR with lag length 2. The shaded area represents one standard deviation confidence band.

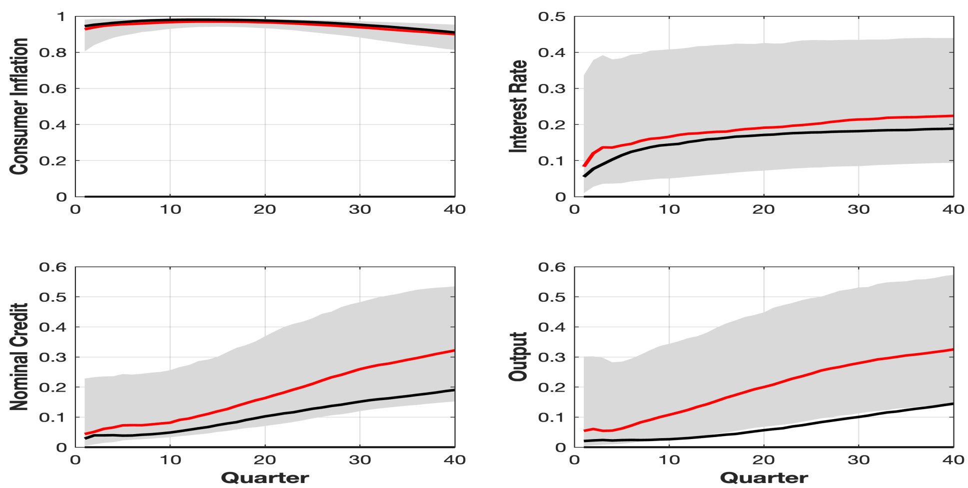
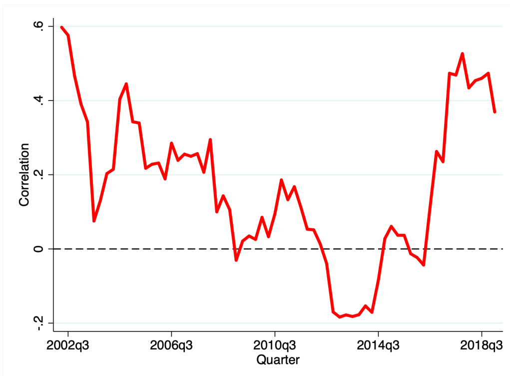


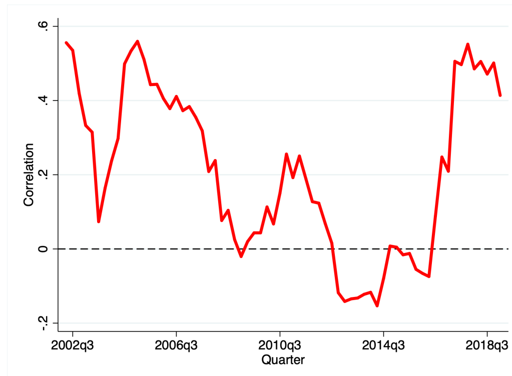
Figure A.24: Share of the monthly inflation shock in FEV of variables in the model.

Notes: Inflation shock explains the maximum FEV of consumer price between 0 to 40 months and is obtained from the SVAR model consisting of consumer price, treasury bills rate, nominal bank credit, and index of industrial production. The red line is for VAR with lag length 6 and the black line is for VAR with lag length 2. The shaded area represents one standard deviation confidence band.

A.8 Rolling Correlation between Inflation Shock and Economic Policy Uncertainty for India

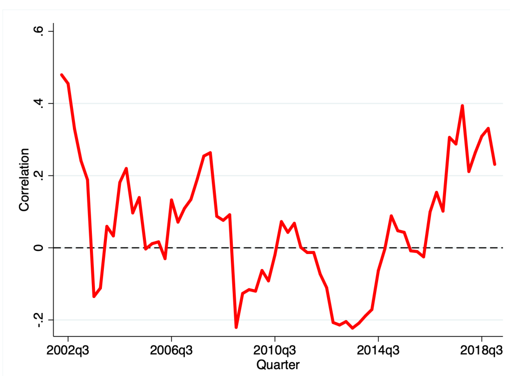


(a) Inflation shock: Lag 1

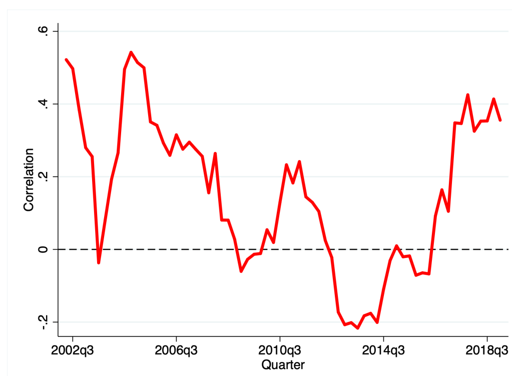


(b) Inflation shock: Lag 2

Figure A.25: Correlation between inflation shock and economic policy uncertainty.
Notes: Twenty-period rolling correlation between inflation shock and economic policy uncertainty. Inflation shock explains the maximum FEV of consumer prices between 0 to 40 quarters.



(a) Medium run inflation shock: Lag 1



(b) Medium run inflation shock: Lag 2

Figure A.26: Correlation between medium run inflation shock and economic policy uncertainty.
Notes: Twenty-period rolling correlation between medium run inflation shock and economic policy uncertainty. Medium run inflation shock explains the maximum FEV of consumer prices between 5 to 20 quarters.

A.9 Shapley Decomposition of Food and Non-Food Inflation Inflation Shocks

Table A.1: Shapley decomposition of food inflation shock

Shock	Share	Share	Share
Preference Shock	10.87	13.53	13.64
Interest Rate Rate	3.59		
Government Expenditure Shock	2.67		
Technology Shock	13.51	71.71	76.78
Markup Shock	21.20		
Investment Specific Technology Shock	32.72		
Oil Demand Shock	0.42	5.24	
Oil Supply Shock	5.34		
Uncertainty Shock	9.68	9.52	9.58

Notes: Second column gives the share of variance of estimated food inflation shock explained by model-based and other shocks. The third column gives the share explained by model-based demand and supply, oil price, and uncertainty shocks. The fourth column gives the share explained by model-based demand and supply shocks (including oil price shocks). Food inflation shock is obtained from the SVAR model consisting of food price, non-food price, short-term nominal interest rate, real bank credit, real government final consumption expenditure, and real gross domestic product (GDP).

Table A.2: Shapley decomposition of non-food inflation shock

Shock	Share	Share	Share
Preference Shock	27.14	47.97	47.89
Interest Rate Rate	1.64		
Government Expenditure Shock	23.02		
Technology Shock	19.59	48.33	51.97
Markup Shock	16.76		
Investment Specific Technology Shock	8.21		
Oil Demand Shock	1.50	3.55	
Oil Supply Shock	1.88		
Uncertainty Shock	0.26	0.15	0.14

Notes: Second column gives the share of variance of estimated non-food inflation shock explained by model-based and other shocks. The third column gives the share explained by model-based demand and supply, oil price, and uncertainty shocks. The fourth column gives the share explained by model-based demand and supply shocks (including oil price shocks). Non-food inflation shock is obtained from the SVAR model consisting of the non-food price, food price, short-term nominal interest rate, real bank credit, real government final consumption expenditure, and real gross domestic product (GDP).

A.10 Shapley Decomposition

Suppose the regression model is given by:

$$y_i = \beta_0 + \sum_{j=1}^{p} \beta_j x_{ji} + \epsilon_i$$

We can calculate R^2 of the above model easily once the OLS estimates of βs are available. Shapley decomposition allows us to calculate the contribution of each variable in the R^2 such that $R^2 = \sum_j R_j^2$. The total number of regression with 0, 1,..., p regressors is given by 2^p. This is because the number of combinations of p object taking $1, 2, ..., p$ at a time is $2^p - 1$ and in this case, one regression without any regressor is also possible, giving us the total number of regressions as 2^p. The partial R_j^2 for a regressor j is given by:

$$R_j^2 = \sum_{T \subseteq Z \setminus \{x_j\}} \frac{k!(p-k-1)!}{p!} \left[R^2 \left(T \cup \{x_j\} \right) - R^2(T) \right]$$

Where T is the model with k regressors not including x_j and $(T \cup \{x_j\})$ is same model including $\{x_j\}$. The set Z contains all models with combinations of regressors[17].

B New Keynesian Model

B.1 Household

In the beginning of period t, households own B_{t-1} amount of one-period bond which is given in real terms as $\frac{B_{t-1}/p_{t-1}}{p_t/p_{t-1}} = \frac{b_{t-1}}{\pi_t}$; where $\pi_t = \frac{p_t}{p_{t-1}}$ is the gross inflation. In the period t, households supply total n_t hours to intermediate goods producers and receive real wage $w_t = \frac{W_t}{p_t}$ for each hour. Households receive $d_t = \frac{D_t}{p_t}$ amount of dividend from intermediate goods producers. In the period t, households issue $b_t = \frac{B_t}{p_t}$ amount of one period bonds to the intermediate goods producers. The debt contract between households and firms is based on the nominal value. The price for final consumption good is p_t which is being used to bring all variables into real terms. Based on the endowment and flows during the period t, the households budget constraint is given by:

$$\frac{b_{t-1}}{\pi_t} + w_t n_t + d_t = c_t + \frac{b_t}{r_t} + t_t$$

The Lagrange for the same is given by:

$$\begin{aligned} \ell &= E_0 \sum_{t=0}^{t=\infty} \beta^t \left[a_t \left(log(c_t - \gamma c_{t-1}) - \frac{n_t^{(1+1/\eta)}}{1+1/\eta} \right) \right] \\ &+ \beta^t \lambda_t \left(\frac{b_{t-1}}{\pi_t} + w_t n_t + d_t - c_t - \frac{b_t}{r_t} - t_t \right) \end{aligned}$$

Shock to β i.e. time discount factor, a_t follows a stationary autoregressive process is

[17] We use the Stata package Shapley2 for computing R_j^2. See, Florian Chavez Juarez, 2012. "SHAPLEY2: Stata module to compute additive decomposition of estimation statistics by regressors or groups of regressors," Statistical Software Components S457543, Boston College Department of Economics revised 17 Jun 2015.

given by:

$$log(a_t) = \rho_a log(a_{t-1}) + \epsilon_{a,t} \qquad 0 \leq \rho_a < 1 \qquad \epsilon_{a,t} \sim N(0, \sigma_a^2) \tag{E.1}$$

We use a common taste/time discount factor shock for both consumption and labour which is different from using shock to only one of them or using two different shocks for consumption and labour. $\epsilon_{a,t}$ is the taste/preference shock in the model. Household choose c_t, n_t, b_t. First-order conditions (FOCs) are given below:

FOC with respect to c_t:

$$\lambda_t = \frac{a_t}{c_t - \gamma c_{t-1}} - \beta\gamma E_t \left(\frac{a_{t+1}}{c_{t+1} - \gamma c_t} \right) \tag{1}$$

FOC with respect to n_t:

$$n_t^{1/\eta} = \lambda_t w_t \tag{2}$$

FOC with respect to b_t:

$$\frac{\lambda_t}{r_t} = \beta \frac{\lambda_{t+1}}{\pi_{t+1}} \tag{3}$$

FOC with respect to λ_t:

$$\frac{b_{t-1}}{\pi_t} + w_t n_t + d_t = c_t + \frac{b_t}{r_t} + t_t \tag{4}$$

B.2 Final Good Producer

The final good producer aggregates goods produced by intermediate goods producers in a competitive market using the constant returns to scale technology given by:

$$y_t \leq \left[\int_0^1 {y_{i,t}}^{(\theta_t - 1)/\theta_t} di \right]^{\theta_t/(\theta_t - 1)}$$

where θ_t is the time-varying elasticity of substitution between intermediate goods $y_{i,t}$ and $y_{j,t}$ with given prices $p_{i,t}$ and $p_{j,t}$ respectively for $i \neq j$. θ_t is given by the exogenous process (E.2) which brings markup shock, $\epsilon_{\theta,t}$, in the model. Based on the profit maximization condition, the demand for intermediate good, $y_{i,t}$, is given by:

$$y_{it} = \left[\frac{p_{i,t}}{p_t}\right]^{-\theta_t} y_t$$

where

$$p_t = \left[\int_0^1 {p_{i,t}}^{1-\theta_t} di\right]^{1/(1-\theta_t)}$$

$$log\,(\theta_t) = (1-\rho_\theta)log(\theta) + \rho_\theta log(\theta_{t-1}) + \epsilon_{\theta,t} \qquad 0 \leq \rho_\theta < 1 \qquad \epsilon_{\theta,t} \sim N(0, \sigma_\theta^2) \quad \text{(E.2)}$$

B.3 Intermediate Goods Producers

The intermediate goods are produced in a monopolistic product market but the factor market is competitive. Firms use their own accumulated capital and labour from households to produce intermediate goods according to constant returns to scale technology given by:

$$y_{i,t} = z_t k_{i,t-1}^{\alpha} n_{it}^{1-\alpha}$$

Using the demand from final good producer $y_{it} = \left[\frac{p_{i,t}}{p_t}\right]^{-\theta_t} y_t$, one can write the above expression as:

$$\left(\frac{p_{i,t}}{p_t}\right)^{-\theta_t} y_t = z_t k_{i,t-1}^{\alpha} n_{i,t}^{1-\alpha}$$

z_t is a stationary autoregressive neutral technology process given by:

$$log\,(z_t) = \rho_z log\,(z_{t-1}) + \epsilon_{z,t} \quad 0 \leq \rho_z < 1 \qquad \epsilon_{z,t} \sim N(0, \sigma_z^2) \qquad \text{(E.3)}$$

$\epsilon_{z,t}$ is the neutral technology shock in the model. Firms operating profit i.e. earning in the model is given by:

$$e_{i,t} = y_{i,t} - w_{i,t} n_{i,t} = z_t k_{i,t-1}^{\alpha} n_{it}^{1-\alpha} - w_{i,t} n_{i,t}$$

Firms can use earnings as a guarantee for loans. The capital accumulation process is given by:

$$k_{i,t} = (1-\delta)\, k_{i,t-1} + \mu_t \left(1 - S\left(\frac{i_{i,t}}{i_{i,t-1}}\right)\right) i_{i,t}$$

where $S\left(\frac{i_t}{i_{t-1}}\right)$ is the cost of adjusting investment as in Christiano, Eichenbaum and Evans (2005). We assume a convex cost of adjusting investment as given below. In the steady state, the cost and first derivative of the cost are zero.

$$S\left(\frac{i_{i,t}}{i_{i,t-1}}\right) = \frac{S}{2}\left(\frac{i_{i,t}}{i_{i,t-1}} - 1\right)^2$$

μ_t is a stationary autoregressive investment-specific technology process as in Justiniano, Primiceri and Tambalotti (2009).

$$log\left(\mu_t\right) = \rho_\mu log\left(\mu_{t-1}\right) + \epsilon_{\mu,t} \quad 0 \leq \rho_\mu < 1 \qquad \epsilon_{\mu,t} \sim N(0, \sigma_\mu^2) \tag{E.4}$$

$\epsilon_{\mu,t}$ is the investment-specific technology shock in the model. Following Rotemberg (1982, 1987), we assume the convex cost for the adjustment of the nominal price p_{it} given by:

$$\frac{\varphi_p}{2}\left[\frac{p_{i,t}}{\pi_{t-1}^{\tau}\pi^{1-\tau}p_{i,t-1}} - 1\right]^2 y_t$$

where $\varphi_p > 0$ is the parameter influencing price adjustment cost and π is the steady-state inflation or inflation target and $0 \leq \tau \leq 1$. τ determines the persistence in the inflation process. $\tau = 0$ implies a purely forward-looking price setting whereas $\tau = 1$ implies a purely backwards-looking price setting. When $0 < \tau < 1$, the above cost structure ensures that price setting is done keeping in mind both past and expected future inflation. This leads to a new Keynesian Phillips curve which has both backward and expected inflation. Households own the firms and hence firms maximize the present value of the utility from the dividend payment. The period t budget constraint for the firms in real terms is given by:

$$d_{i,t} + i_{i,t} + \frac{b_{i,t-1}}{\pi_t} + \left[\frac{p_{i,t}}{\pi_{t-1}^{\tau}\pi^{1-\tau}p_{i,t-1}} - 1\right]^2 y_t = \frac{p_{i,t}}{p_t} y_{i,t} - w_{i,t}n_{i,t} + \frac{b_{i,t}}{R_t}$$

Substituting the value of $i_{i,t}$ from capital accumulation equation in the above flow budget constraint gives; $d_{it} + \frac{k_{i,t}}{\mu_t} + \frac{b_{i,t-1}}{\pi_t} = \frac{p_{i,t}}{p_t} y_{i,t} - w_{i,t} n_{i,t} + \frac{b_{i,t}}{R_t} + (1-\delta)\frac{k_{i,t-1}}{\mu_t}$. We omit the cost of adjusting investment as it's zero in the steady state. The relative price of capital (relative to final consumption good) is given by $1/\mu_t$. The steady-state value of μ_t is 1 and hence in a steady state, the prices of capital and final consumption goods are the same. A positive shock to μ_t, increases its values above the steady state and decreases the relative price of the capital. This implies that a positive shock to μ_t leads to lower borrowing in the case of assets-based borrowing constraints.

The effective net interest rate for intermediate goods producing firm after tax deductions is $(r_t - 1)(1 - \text{tax rate})$ since r_t is gross interest rate. Thus the gross effective rate for the intermediate goods producing firm is given by:

$$R_t = 1 + (r_t - 1)(1 - \text{tax rate}) \tag{5}$$

Due to tax deduction r_t is higher than R_t. Since firms receive tax deductions on interest payments, they borrow up to their borrowing constraint. Tax deduction for corporates on interest payments exists in many countries. One can bring the borrowing and lending in the model by having firms as a different set of households with lower discount factors as in Iacoviello (2015). The lower discount factor will also make firms impatient and firms will borrow up to their borrowing constraint. Substituting $y_{it} = \left[\frac{p_{i,t}}{p_t}\right]^{-\theta_t} y_t$ in the flow budget constraint gives us:

$$d_{i,t} + i_{i,t} + \frac{b_{i,t-1}}{\pi_t} + \left[\frac{p_{i,t}}{\pi_{t-1}^{\tau}\pi^{1-\tau}p_{i,t-1}} - 1\right]^2 y_t = \left[\frac{p_{i,t}}{p_t}\right]^{1-\theta_t} y_t - w_{i,t}n_{i,t} + \frac{b_{i,t}}{R_t}$$

From above d_{it} is given by:

$$d_{i,t} = \left[\frac{p_{i,t}}{p_t}\right]^{1-\theta_t} y_{i,t} - w_{i,t}n_{i,t} + \frac{b_{i,t}}{R_t} - i_{i,t} - \frac{b_{i,t-1}}{\pi_t} - \left[\frac{p_{i,t}}{\pi_{t-1}^{\tau}\pi^{1-\tau}p_{i,t-1}} - 1\right]^2 y_t$$

Further, firms borrow from households and face a borrowing constraint which is a linear combination of earning and assets-based constraints.

$$\frac{b_{i,t}}{r_t} < \omega \underbrace{\theta_e \left(z_t k_{i,t-1}^{\alpha} n_{i,t}^{1-\alpha} - w_{i,t} n_{i,t} \right)}_{\text{Earning}} + (1-\omega) \underbrace{\theta_k p_{k,t+1} \pi_{t+1} (1-\delta) k_{i,t}}_{\text{Assets}}$$

Firms can borrow $\theta_e \times e_{i,t}$ and $\theta_k \times k_{i,t}$ in case of earnings and assets based constraints respectively. We assume that out of total borrowing ω proportion is due to earning-based constraint. The loan to value ratio is defined as the amount of loan for one unit of assets or earnings. Hence, θ_e and θ_k are respective loan to value ratios. In the baseline model, these loan-to-value ratios are constant. We can allow exogenous variation in them to explore the role of macro-prudential policies. Firms maximize the present value of the utility from the dividend payment. Firm choose n_{it}, b_{it}, k_{it}, i_{it} and p_{it}. The Lagrange for their problem is given by:

$$\begin{aligned}
E_0 \sum_{t=0}^{t=\infty} \beta^t \lambda_t \left(\left[\frac{p_{i,t}}{p_t} \right]^{1-\theta_t} y_t - w_{i,t} n_{i,t} + \frac{b_{i,t}}{R_t} - i_{i,t} - \frac{b_{i,t-1}}{\pi_t} \right) \\
-\beta^t \lambda_t \frac{\varphi_p}{2} \left[\frac{p_{i,t}}{\pi_{t-1}^{\tau} \pi^{1-\tau} p_{i,t-1}} - 1 \right]^2 y_t + \beta^t \lambda_t \Omega_t \left((1-\delta) k_{i,t-1} + \mu_t \left(1 - S\left(\frac{i_{i,t}}{i_{i,t-1}} \right) \right) i_{i,t} - k_{it} \right) \\
+\beta^t \lambda_t \Lambda_t \left(\omega \theta_e \left(z_t k_{i,t-1}^{\alpha} n_{i,t}^{1-\alpha} - w_{i,t} n_{i,t} \right) + (1-\omega) \theta_k p_{k,t+1} \pi_{t+1} (1-\delta) k_{i,t} - \frac{b_{i,t}}{r_t} \right) \\
+\beta^t \lambda_t \mathit{\Pi}_t \left(z_t k_{i,t-1}^{\alpha} n_{i,t}^{1-\alpha} - \left(\frac{p_{i,t}}{p_t} \right)^{-\theta_t} y_t \right)
\end{aligned}$$

Since these firms are identical, we write the FOCs for symmetric equilibrium below. FOC with respect to k_t:

$$\begin{aligned}
&\lambda_t \Omega_t = \beta \lambda_{t+1} \Omega_{t+1} (1-\delta) + \lambda_t \Lambda_t (1-\omega) \theta_k p_{k,t+1} \pi_{t+1} (1-\delta) \\
&+\beta \lambda_{t+1} \Lambda_{t+1} w \theta_e \alpha z_{t+1} k_t^{\alpha-1} n_{t+1}^{1-\alpha} + \beta \lambda_{t+1} \mathit{\Pi}_{t+1} \alpha z_{t+1} k_t^{\alpha-1} n_{t+1}^{1-\alpha}
\end{aligned} \tag{6}$$

FOC with respect to i_t:

$$\lambda_t = \lambda_t \Omega_t u_t \left(1 - S\left(\frac{i_t}{i_{t-1}}\right)\right) - \lambda_t \Omega_t \mu_t \frac{i_t S}{i_{t-1}} \left(\frac{i_t}{i_{t-1}} - 1\right) + \beta \lambda_{t+1} \Omega_{t+1} \mu_{t+1} \frac{i_{t+1}^2 S}{i_t^2} \left(\frac{i_{t+1}}{i_t} - 1\right) \tag{7}$$

FOC with respect to n_t:

$$w_t n_t = (1-\alpha) \Pi_t y_t + (1-\alpha) \Lambda_t \omega \theta_e y_t - \Lambda_t \omega \theta_e w_t n_t \tag{8}$$

FOC with respect to b_t:

$$\lambda_t \frac{1}{R_t} = \frac{\beta \lambda_{t+1}}{\pi_{t+1}} + \frac{\lambda_t \Lambda_t}{r_t} \tag{9}$$

The price of the capital $p_{k,t}$ is the value of an additional unit of installed capital which is equal to the Lagrange multiplier associated with capital accumulation constraint.

$$p_{k,t} = \frac{\lambda_t \Omega_t}{\lambda_t} \tag{10}$$

FOC with respect to p_{it}:

$$0 = (1-\theta_t) \lambda_t \left[\frac{p_t}{p_t}\right]^{-\theta_t} \frac{y_t}{p_t} + \theta_t \lambda_t \Pi_t \left(\frac{p_t}{p_t}\right)^{-\theta_t - 1} \frac{y_t}{p_t} - \varphi_p \lambda_t \left[\frac{p_t}{\pi_{t-1}^{\alpha} \pi^{1-\tau} p_{t-1}} - 1\right] \left[\frac{1}{\pi_{t-1}^{\tau} \pi^{1-\tau} p_{t-1}}\right] y_t$$

$$+ \beta \varphi_p \lambda_{t+1} \left[\frac{p_{t+1}}{\pi_t^{\tau} \pi^{1-\tau} p_t} - 1\right] \left[\frac{p_{t+1}}{\pi_t^{\tau} \pi^{1-\tau} p_t^2}\right] y_{t+1}$$

Multiplying with p_t and dividing by y_t:

$$0 = (1-\theta_t) \lambda_t \left[\frac{p_t}{p_t}\right]^{-\theta_t} + \theta_t \lambda_t \Pi_t \left(\frac{p_t}{p_t}\right)^{-\theta_t - 1} - \varphi_p \lambda_t \left[\frac{p_t}{\pi_{t-1}^{\alpha} \pi^{1-\tau} p_{t-1}} - 1\right] \left[\frac{p_t}{\pi_{t-1}^{\tau} \pi^{1-\tau} p_{t-1}}\right]$$

$$+ \beta \varphi_p \lambda_{t+1} \left[\frac{p_{t+1}}{\pi_t^{\tau} \pi^{1-\tau} p_t} - 1\right] \left[\frac{p_{t+1}}{\pi_t^{\tau} \pi^{1-\tau} p_t}\right] \left[\frac{y_{t+1}}{y_t}\right] \tag{11}$$

FOC with respect to Ω_t:

$$(1-\delta) k_{t-1} + \mu_t \left(1 - S\left(\frac{i_t}{i_{t-1}}\right)\right) i_t = k_t \tag{12}$$

FOC with respect to Π_t:

$$z_t k_{t-1}^{\alpha} n_t^{1-\alpha} = y_{it} \tag{13}$$

FOC with respect to Λ_t:

$$\omega\theta_e \left(z_t k_{t-1}^{\alpha} n_t^{1-\alpha} - w_t n_t\right) + (1-\omega)\theta_k p_{k,t+1}\pi_{t+1}(1-\delta)k_t = \frac{b_t}{r_t} \tag{14}$$

B.4 Government

Government subsidise the interest cost differential between household and intermediate goods firms to the household. Further, the government makes other real expenditures G_t which evolves exogenously and that gives rise to government expenditure shock $\epsilon_{g,t}$ in the model. Government imposes a lump-sum tax on the households to balance the budget period by period. The nominal lump-sum tax (T) is given by:

$$T_t = \frac{B_t}{R_t} - \frac{B_t}{r_t} + p_t G_t$$

Dividing the above equation by p_t, we obtain the real tax given by:

$$t_t = \frac{b_t}{R_t} - \frac{b_t}{r_t} + G_t \tag{15}$$

Real government expenditure (G_t) is related to real output as given by:

$$G_t = \left(1 - \frac{1}{g_t}\right) y_t \tag{16}$$

where the government spending process, (g_t), follows the stationary autoregressive process given by:

$$log(g_t) = (1-\rho_g)log(g) + \rho_g log(g_{t-1}) + \epsilon_{g,t} \quad 0 \leq \rho_g < 1 \qquad \epsilon_{g,t} \sim N(0, \sigma_g^2) \tag{E.5}$$

$(1 - \frac{1}{g})$ is the steady-state value of government expenditure to output ratio.

B.5 Monetary Authority

The interest rate is set by the central bank using a modified Taylor (1993) rule given by:

$$log\left(\frac{r_t}{r}\right) = \rho_r log\left(\frac{r_{t-1}}{r}\right) + (1-\rho_r)\left[\rho_\pi log\left(\frac{\pi_t}{\pi}\right) + \rho_y log\left(\frac{y_t}{y}\right)\right] + \epsilon_{r,t} \qquad \epsilon_{r,t} \sim N(0, \sigma_r^2) \tag{17}$$

ρ_r denotes the persistence in the interest rate. Monetary authority responds to deviation of inflation (π_t) from inflation target or steady-state inflation (π). It also responds to the output gap i.e. the deviation of output (y_t) from the steady-state output (y). The weights attached to inflation and output gap are allowed to be different. $\epsilon_{r,t}$ is the interest rate shock in the model.

B.6 Aggregate Resource Constraints

Market clearing condition ignoring the adjustment costs is given by:

$$c_t + i_t + G_t = y_t \tag{18}$$

The dividend payment in the model is given by:

$$d_t = y_t - w_t n_t + \frac{b_t}{R_t} - i_t - \frac{b_{t-1}}{\pi_t} \tag{19}$$

We have 19 equations for 18 endogenous variables ($c_t, n_t, b_t, d_t, k_t, i_t, G_t, t_t, y_t, R_t, r_t,$ $\pi_t, \lambda_t, \Omega_t, \Lambda_t, \mathit{\Pi}_t, p_{k,t}, w_t,$) in the model. One of the equations out of (4), (18), and (19) is redundant due to Walras law. Thereafter, we solve for 18 endogenous variables using the remaining 18 equations and obtain a steady state. Exogenous variables $a_t, \theta_t, z_t, \mu_t, g_t$ are given by (E.1-E.5). We use Dynare to estimate the model and obtain smoothed estimates of six shocks.