Central Bank of Armenia

Working Paper 21/3/08

Asymmetric Effects of Monetary Policy on the Armenian Economy

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March 2021

WP 21/3/08

CBA Working Paper

Monetary Policy Department

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Abstract

Whether inflation and output respond symmetrically or asymmetrically to contractionary and expansionary monetary policy shock of the same size has important policy implications. This paper shows the presence of asymmetric responses in Armenian inflation and output to positive and negative monetary policy shocks of the same size by employing econometric models. Contractionary policy decreases inflation less than expansionary policy increases it. Output reacts in the opposite way. An estimated small open economy DSGE model with sticky wages and investment adjustment costs explains about half of the asymmetry observed in the monetary policy transmission mechanism. This paper finds that the main part of inflation reaction asymmetry is a result of a highly convex Phillips curve for the importers. The nonlinearities of the internal economy explain the predominant part of the asymmetry in output reaction.

JEL classification: C32, E12, E32, E52
Keywords: nonlinear VAR, New Keynesian Model, monetary policy, asymmetries, business cycle, expansion, recession, asymmetric effects of monetary policy

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The views expressed in this paper are those of the author and do not necessarily represent the views or policies of the Central Bank of Armenia.

The author is grateful to two anonymous reviewers for their great comments and constructive suggestions which have improved the paper.

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Contents

1 Introduction

Do positive and negative interest rate shocks of the same size have asymmetric effects on inflation and output? This is a relevant question from a monetary policy perspective. The size of the asymmetry represents the efficiency of monetary policy in managing inflation, though finding the factors affecting the creation of the asymmetry is important as well.

The literature presents evidence of asymmetric responses of economies to monetary policy shocks in different countries. This paper estimates the size of the asymmetry in Armenia using econometric techniques. Estimated residuals of a forward-looking Taylor rule, which represent the stance of monetary policy, are used as regressors for the estimation of the impact of the policy stance on inflation and output growth. The results report that expansionary policy increases inflation more than contractionary policy decreases it. On the other hand, the decline in output is higher in response to tight policy. Then a nonlinear vector autoregressive (VAR) model is developed and estimated using Armenian data. Impulse response analysis shows the presence of significant asymmetric reactions in the variables to positive and negative monetary policy shocks of the same size.

However, such empirical models do not explain the sources of the asymmetries. Thus, this paper discusses a small open economy dynamic stochastic general equilibrium (DSGE) model with multiple frictions. The model economy is populated by households, which consume domestically produced and imported goods, invest in capital, hold domestic and foreign bonds, supply labor, and choose the utilization rate of capital and lend it out to firms. They pay capital utilization costs. The labor is heterogeneous, and households have the power to reset wages. There are investment adjustment costs in the model. Several types of firms operate in the economy. Prices are set via Calvo mechanism (Calvo, 1983). The model is estimated using 15 macroeconomic time series. The estimation results suggest that the prices of imported consumption goods are less sticky than domestic production.

Linearized DSGE models do not generate asymmetries. Asymmetries arise when nonlinearities are preserved. This paper uses second-order approximation. Simulations of the model show that inflation and output respond asymmetrically to monetary policy shocks. The asymmetry in the theoretical model is about half of the asymmetry in nonlinear VAR. Almost all the real variables react more strongly in response to contractionary policy compared to their reaction during expansionary policy. Then the paper estimates the contribution of specific frictions or model blocks in the creation of asymmetry in the monetary policy transmission mechanism. To show this, we apply a second-order approximation to a particular block and linearize the rest of the model. More than half of the asymmetry in inflation is explained by the nonlinear open economy blocks, which is a result of highly convex Phillips curves for importers. The labor market, the capital market and the nonlinear Phillips curve of domestic producers each explain around 10% of the asymmetry in inflation. On the output side, 20% of the asymmetry in output is created through the nonlinear open economy blocks, while the remaining asymmetry is a result of the nonlinearities of the internal economy.

The paper finds asymmetric reactions of inflation and output during recessions and during growth. Furthermore, asymmetry arises with an increase in the size of the monetary policy shock. Monetary policy is more effective at preventing an inflation acceleration in a demand-driven expansion than at accelerating inflation in a demand-driven recession. When the economy is in a demand-driven expansion, an increase of contractionary monetary policy shock accelerates the decline in output but decreases the relative response of inflation. On the other hand, when the economy is in a demand-driven recession, additional monetary stimulus accelerates inflation and diminishes the recovery of output, because the costs of attracting additional labor and capital increase. The deceleration in inflation is larger in a supply-driven recession compared to a supply-driven expansion. An increase in the size of contractionary monetary policy in a supply-driven expansion does not have a significant impact on inflation.

The rest of this paper is organized as follows. Section 2 provides a review of the literature on the asymmetric effects of monetary policy. Section 3 finds the presence of asymmetric effects of monetary policy on Armenian inflation and output. Section 4 develops the micro-founded theoretical model. Section 5 describes the data and the estimation process of the model. Section 6 discusses the sources of the curvatures in the model. Section 7 discusses the mixed equations approach. Section 8 analyses the asymmetries in the monetary policy transmission mechanism. Section 9 tests the ability of the model to reproduce the asymmetries observed in the Armenian data. Section 10 estimates the efficiency of monetary policy in demand- and supply-driven recessions and expansions. Finally, Section 11 concludes.

2 Literature review

The asymmetric effects of monetary policy have drawn the attention of economists for the past three decades. There is a large empirical literature which estimates the impacts of monetary policy on the economy. DeLong and Summers (1988) show that expansionary monetary policy has a greater effect on U.S. output than a comparable tight policy. Cover (1992), using post-war US data, finds that an increase in the money supply is less effective in stimulating output compared to the effect of a decrease in the money supply. Morgan (1993), using the federal funds rate as the policy instrument, tests the same hypothesis and gets similar results. Ravn and Sola (1997) find no asymmetric impact between positive and negative monetary policy shocks. Instead, the authors find an asymmetry between the relative impacts of small and large shocks. Karras (1996) shows evidence of an asymmetry in the effect of the money supply on output for 18 European countries. Using the methodology of rolling VAR, Wong (2000) finds relatively higher responses in US output and price levels to positive monetary policy shocks. Garcia and Schaller (2002) test the impact of policy on output during recessions and expansions. They use a Markov switching model and find that monetary policy is more effective in recessions. Peersman and Smets (2001) use a multivariate extension of Hamilton's two-state Markov switching model and show that monetary policy is more effective in recessions in the Euro area. Kaufmann (2002) shows the relative efficiency of monetary policy in recessions using Austrian data. Weise (1999) shows the asymmetric reaction of the US economy to monetary policy employing a logistic smooth transition vector autoregressive (LSTVAR) model. Lo and Piger (2005) provide strong evidence of asymmetry in the business cycle by estimating an unobserved components model. Fehr and Tyran (2001) present evidence of asymmetric effects from expansionary and contractionary monetary policies as a result of money illusion.

Most theoretical models are constructed in a partial equilibrium framework. For example, Ball and Mankiw (1994) develop the model of menu costs, which leads to a convex supply curve. General equilibrium models are usually log-linearised, so the nonlinearities are lost, which result in the loss of the model's power to generate asymmetries. Literature related to the asymmetric effects of policy on the economy in general equilibrium is scarce. Wen and Wu (2011) show that first-order approximation of DGSE models results in the inaccurate capture of business cycle properties. Abbritti and Fahr (2011) introduce the mechanism of downward wage rigidities in a DSGE model with search and matching frictions, which enables the reproduction of the business cycle asymmetries observed in OECD countries. Ravn (2014) includes asymmetric monetary policy towards asset prices in a DSGE framework and creates nonlinearities in the economy. Castillo and Montoro (2008) consider intertemporal non-homotheticity in the preferences of agents and induce an asymmetry in the response of the economy to positive and negative monetary policy shocks.

To preserve the nonlinearities of the model, this paper applies second-order approximation. Second-order approximation of the policy function is extensively applied in economics in Judd (1998). Higher order perturbation methods are studied in Collard and Juillard (2001) and Kim et al. (2008). Second-order perturbation methods are widely described in Schmitt-Grohe and Uribe (2004) and Fernández-Villaverde et al. (2016).

3 Empirical evidence of asymmetric effects of monetary policy in Armenia

The main data series used in macroeconomic analysis have asymmetric distribution around their mean values. The skewness of Armenian inflation and the interest rate are positive, and for the economic growth it is negative. The asymmetrical statistics of the main Armenian macroeconomic variables is presented in Table 1. The sample starts at 2004Q1 and ends at 2019Q4.

Inflation, QoQ	0.18
Inflation, YoY	0.2
GDP Growth, QoQ	-1.32
GDP Growth, YoY	-1.49
Interest Rate	0.51

Table 1: Skewness

Log-linearized models, commonly used by macroeconomic policy analysis institutions, generate time series with zero skewness, or symmetric time series. Observed asymmetries are a result of higher order terms, such as price dispersion, investment adjustment costs, wage dispersion, or capital utilization, which are not visible up to the first-order approximation.

3.1 Two stage estimation

This part of the paper tests the presence of asymmetric effects of monetary policy on Armenian economic growth and inflation using the methodology proposed in Cover (1992). The logic of the methodology is as follows. The first stage estimates the Taylor rule to get residuals of the equation or the monetary policy stance. The second stage estimates the impact of policy stance on inflation and economic growth.

The central bank uses a forward-looking Taylor rule. It reacts to expected inflation and output gap with the following reaction function.

$$r_t = \rho r_{t-1} + (1-\rho)(\alpha\pi_{t+k} + \beta y_{t+m}) + \varepsilon_t, \tag{3.1.1}$$

where $\pi_(t+k)$ is the expected inflation, y_{t+m} is the output gap, ρ is the persistence of the interest rate, and α and β are the reaction parameters of the interest rate to inflation expectations and the output gap, respectively. Following Clarida et al. (2000), $\varepsilon_t = -(1-\rho)\{\alpha(\pi_{t+k} - E[\pi_{t+k}|\Omega_t]) + \beta(y_{t+m} - E[y_{t+m}|\Omega_t])\}$. Here E is the expectation operator and Ω_t is the information set at the time the interest rate is set. Hence, the composite error term ε_t is a linear combination of the forecast errors and is orthogonal to the variables in the information set. This provides the basis for the estimation of the parameters using the Generalized

Method of Moments by imposing the orthogonality moment conditions implied by equation (3.1.1) and utilizing instruments from the set of the information of the central bank, Ω_t.

The data are quarterly time series covering the period from 2004Q1 to 2019Q4. The data are obtained from the Statistical Committee of the Republic of Armenia. The interest rate is the Armenian interbank rate. Inflation is expressed as a percentage change in the consumer price index (CPI) and the output gap is calculated running an Hodrick-Prescott (HP) filter ($\lambda = 1600$) on seasonally adjusted quarterly GDP. The instrument set includes lags of the interest rate, inflation, the output gap and the percentage change in real effective exchange rate. The latter is very important for small open economies like Armenia. k is set to 1 to represent one period expected inflation, and m is set to zero to have the output gap at the current time in the Taylor rule. All the variables are demeaned by subtracting a sample average. In case of inflation, sample average is very close (less than 0.12 p.p.) to the Central Bank of Armenia target rate. According to the estimation results (see Table 2), the persistence of the interest rate is high, 0.914. The reactions of the central bank to inflation expectations and the output gap are 1.962 and 0.456, respectively. The results are close to the values observed in the literature.

Interest Rate Persistence, ρ	0.914*** (0.018)
Reaction to inflation expectations, α	1.962 (0.182)
Reaction to output gap, β	0.456*** (0.151)
Durbin-Watson statistic	2.288
J-statistic	8.805
Prob (J-statistic)	0.267

Table 2: Generalized method of moments (GMM) estimation results of forward-looking Taylor rule
Note: Standard errors are in parentheses. The set of instruments includes three lags of inflation, the output gap, the interest rate and the real effective exchange rate.

The next step estimates the responses of economic growth and inflation to expansionary and contractionary monetary policy. Residuals of the estimated Taylor rule represent the stance of monetary policy. The following two equations are estimated using Armenian data:

$$\Delta y_t = a_0 + a_1 \Delta y_{t-1} + \sum_{i=1}^{4} a_{2,i} Policy^{+}_{t-i} + \sum_{i=1}^{4} a_{3,i} Policy^{-}_{t-i} + \varepsilon^{y}_{t}, \qquad (3.1.2)$$

$$\pi_t = b_0 + b_1\pi_{t-1} + \sum_{i=1}^{4} b_{2,i} Policy^{+}_{t-i} + \sum_{i=1}^{4} b_{3,i} Policy^{-}_{t-i} + \varepsilon^{\pi}_t \tag{3.1.3}$$

where Δy_t is economic growth, π_t is inflation, $Policy^{+}_t$ represents contractionary monetary policy (positive residual from the Taylor rule) and $Policy^{-}_t$ expansionary policy (negative residual from the Taylor rule). The inclusion of four lags in the equations enables the smoothing of the volatility of the policy stance between periods, as well as the estimation of both the short- and long-term impacts of policy.

The results of the estimation are presented in Table 3. The cumulative impact of tight monetary policy on output growth (-0.955) is higher compared to the impact of easy policy (0.241). On the other hand, the four-lag cumulative effect of contractionary monetary policy on Armenian inflation is -0.61. The impact of expansionary policy on inflation is 0.905. The net impact of policy on inflation is 0.295, which is statistically significant, and the net impact on economic growth is negative (-0.714).[1]

[1]The growth rates of the estimated variables are de-trended using a local level filter to remove structural breaks from the data.

	Output Growth, QoQ	Inflation, QoQ
$OutputGrowth(-1), QoQ$	0.158^{***} (0.105)	
$Inflation(-1), QoQ$		0.112^{***} (0.038)
$Policy(-1)^{+}$	-0.499^{***} (0.117)	-0.125^{**} (0.059)
$Policy(-2)^{+}$	0.527^{***} (0.094)	0.203^{*} (0.116)
$Policy(-3)^{+}$	-1.261^{***} (0.349)	0.082 (0.056)
$Policy(-4)^{+}$	0.278^{*} (0.156)	-0.770^{***} (0.222)
$Policy(-1)^{-}$	-0.227^{**} (0.104)	0.211^{**} (0.096)
$Policy(-2)^{-}$	-0.921^{***} (0.273)	-0.426^{***} (0.129)
$Policy(-3)^{-}$	0.737^{***} (0.199)	0.455^{***} (0.148)
$Policy(-4)^{-}$	0.652^{*} (0.354)	0.665^{***} (0.177)
Constant	0.948^{***} (0.305)	0.819^{***} (0.279)
$Sum(Policy^{+})^{1}$	-0.955^{***} (0.284)	-0.610^{**} (0.290)
$Sum(Policy^{-})^{2}$	0.241^{*} (0.135)	0.905^{***} (0.244)
$Sum(Policy^{+}) + Sum(Policy^{-})^{3}$	-0.714^{***} (0.244)	0.295^{***} (0.105)
$Policy^{+} = 0^{4}$	94.2^{***}	91.8^{***}
$Policy^{-} = 0^{5}$	62.3	111.4^{***}
$Policy^{+} + Policy^{-} = 0^{6}$	3.1^{***}	2.6^{**}

Table 3: Estimation of the output growth and inflation equations
Notes: Standard errors are in parentheses. *,** and *** are significant at 0.1, 0.05 and 0.01 respectively.
[1] Sum of the coefficients of contractionary monetary policy.
[2]Sum of the coefficients of expansionary monetary policy.
[3]Sum of the net effect of monetary policy.
[4]Wald test of the hypothesis that the sum of the coefficients of contractionary monetary policy equals zero, χ^2
[5]Wald test of the hypothesis that the sum of the coefficients of expansionary monetary policy equals zero, χ^2
[6] t-statistics of the hypothesis that the sum of the coefficients of $Policy^{+}$ and $Policy^{-}$ equals zero

To test the robustness of the results, two other measures of monetary policy stance are used to estimate equations (3.1.2) and (3.1.3). The first measure of policy stance is the quarterly change in the interest rate. [2] The second measure is the percentage deviation of the interest rate from its trend level calculated by the HP filter. The estimation results are given in Table 9 (Appendix A). As can be seen, the impacts of different measures of policy on economic growth and inflation are close to those reported in Table 3.

3.2 Nonlinear VAR model

This section constructs and estimates the nonlinear VAR model, employing the methodology developed in Kilian and Vigfusson (2011). For the estimation of the VAR, we use Armenian data for quarterly economic growth, inflation and interest rates covering the period from 2004Q1 to 2019Q4.[3] Several lag length criteria support the inclusion of two lags.

The system is represented by the following three equations:

$$R_t = f_0 + \sum_{i=1}^{2} f_{1,i} R_{t-i} + \sum_{i=1}^{2} f_{2,i} \Delta y_{t-i} + \sum_{i=1}^{2} b_{3,i} \pi_{t-i} + \varepsilon_t^R \tag{3.2.1}$$

$$\Delta y_t = g_0 + \sum_{i=1}^{2} g_{1,i} R_{t-i} + \sum_{i=1}^{2} g_{2,i} R_{t-i}^{+} + \sum_{i=1}^{2} g_{3,i} \Delta y_{t-i} + \sum_{i=1}^{2} g_{4,i} \pi_{t-i} + \varepsilon_t^y \tag{3.2.2}$$

$$\pi_t = h_0 + \sum_{i=1}^{2} h_{1,i} R_{t-i} + \sum_{i=1}^{2} h_{2,i} R_{t-i}^{-} + \sum_{i=1}^{2} h_{3,i} \Delta y_{t-i} + \sum_{i=1}^{2} h_{4,i} \pi_{t-i} + \varepsilon_t^\pi \tag{3.2.3}$$

The first equation is a standard in VAR. Censored variables R_t^+ and R_t^- are added in the output growth and inflation equations, which add nonlinearities to the system. They are given by:

$$R_t^+ = \begin{cases} R_t, if R_t > 0 \\ 0, if R_t \leq 0, \end{cases} \tag{3.2.4}$$

$$R_t^- = \begin{cases} R_t, if R_t < 0 \\ 0, if R_t \geq 0, \end{cases} \tag{3.2.5}$$

The censored variable in the economic growth equation, R_t^+, equals the interest rate (with subtracted sample average) when the interest rate is positive, and is zero otherwise. The censored variable R_t^- is negative when the interest

[2] See Bernanke (1990) and Laurent (1988).

[3] Growth rates of estimated variables are de-trended using local level filter to remove structural breaks from data.

rate is negative, and is zero otherwise. The censored variable R_t^+ is added in the economic growth equation (3.2.2) based on our previous finding, which shows that expansionary monetary policy increases output less compared to the decline in output as a result of the same size contractionary monetary policy. The same logic is applied to the inclusion of R_t^- in the inflation equation (3.2.3).

Before estimating the whole system and getting the response of the economy to monetary policy shock, the presence of asymmetry is tested. This paper employs the slope-based asymmetry test proposed in Kilian and Vigfusson (2009). The advantage of this test is that it does not require the specification of the complete system. Equations 3.2.2 and 3.2.3 are estimated separately. Then, the hypotheses that coefficients near censored variables are zero are tested:

$$H_0 : g_{2,1} = g_{2,2} = 0 \tag{3.2.6}$$

$$H_0 : h_{2,1} = h_{2,2} = 0 \tag{3.2.7}$$

This can be calculated by a Wald test with χ^2 distribution. Table 4 reports the results of the test. The null hypothesis is rejected, with a significance level of 0.05 for both tests. The results of the slope-based tests support the inclusion of the censored variables in the VAR.

	F-statistic	P-value
Economic Growth (Equation 3.2.2)	3.879	0.023
Inflation (Equation 3.2.3)	3.134	0.044

Table 4: Results of the slope-based tests

Then the system of equations (3.2.1)–(3.2.3) is estimated by the ordinary least squares (OLS) method. Figure 1 shows the response of the economy to a 1% increase and decrease in the interest rate. The responses to negative shock are shown as mirror images to facilitate the comparison. Simulation of the estimated model for Armenia shows that the response of output to contractionary monetary policy is stronger than that to expansionary policy. On the other hand, a low interest rate is more powerful in creating inflation and a high interest rate is less efficient at decreasing inflation. The degree of asymmetry in economic growth is higher than the asymmetry in inflation. Figure 1 shows 90% confidence bands as well. The asymmetric responses of inflation and economic growth to positive and negative monetary policy shocks are statistically significant.

This finding is consistent with the convex Phillips curve theory. A graphical illustration is presented in Figure 2. The equilibrium point of the economy is given by the interaction of the demand and supply curves with the equilibrium levels of output (y^*) and inflation (π^*). In this experiment, we abstract from the nonlinearities of the demand curve. The interest rate, controlled by the central bank, shifts the demand curve. A decrease of the interest rate from R^* to R^1 stimulates demand. Firms, facing growing demand for their production, increase

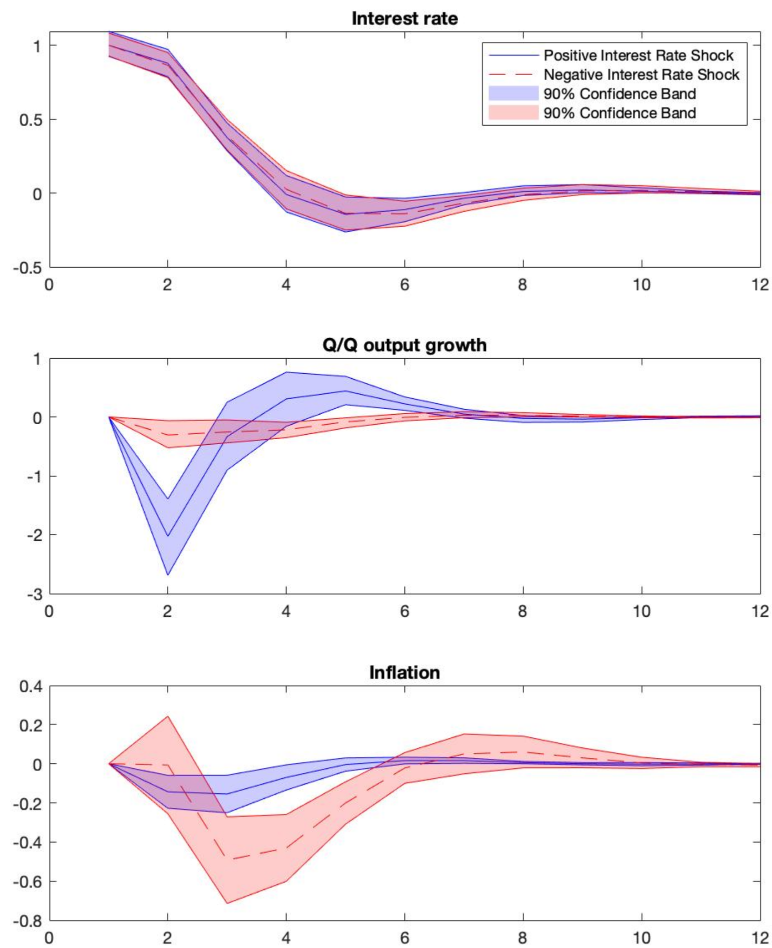

Figure 1: Impulse responses to interest rate shock

their hiring of labor and attraction of capital to produce additional goods. In the short term, the production capacities of the economy are bounded, so firms put more pressure on prices but increase output relatively less. In the opposite case, when the central bank increases the interest rate from R^* to R^2 (the size of interest rate change is symmetric), firms decrease production more than prices, because of downward price rigidities. A graphical illustration of the convex Phillips curve demonstrates that contractionary and expansionary monetary policies of the same magnitude impact output and inflation asymmetrically.

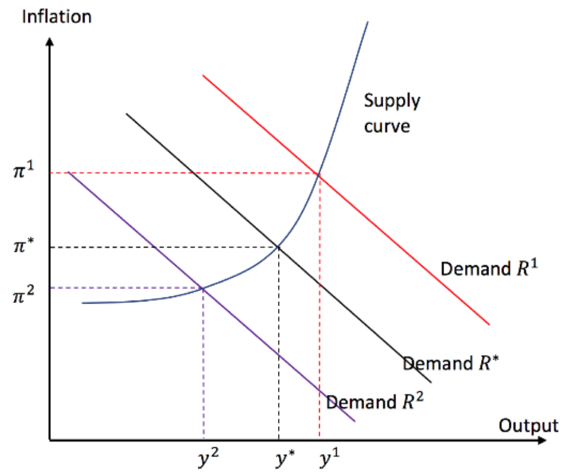

Figure 2: Nonlinear Phillips and Aggregate Demand Curves

On the other hand, with a linear Phillips curve, output and inflation react symmetrically to positive and negative shocks of the same size. This can be graphically illustrated by a simple framework of aggregate supply and demand curves (Figure 3). The only difference from the above example (convex supply curve) is the linear Phillips curve. An increase of the interest rate from R^* to R^2 shifts the aggregate demand to the left and a new equilibrium is reached with output level y^2 and inflation π^2. Expansionary monetary policy of the same magnitude increases output to y^1 and inflation to π^1. In the linear economy, the increase and decrease of output are of equal size. The change in inflation is symmetric as well.

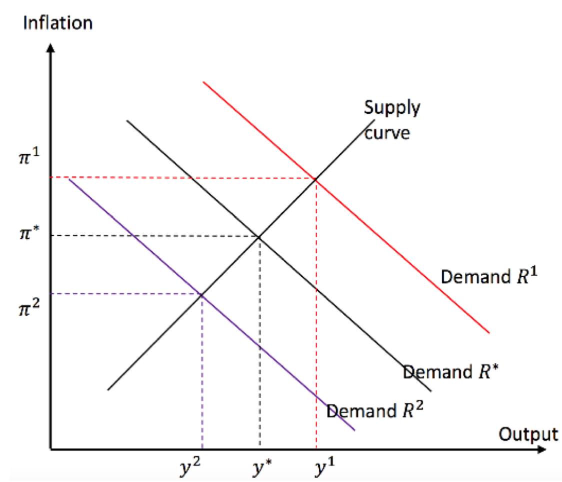

Figure 3: Linear Phillips and Aggregate Demand Curves

4 Small open economy DSGE model

The empirical models discussed in the previous section are quite powerful tools to estimate asymmetries in the data. However, the empirical models are unable to explain the sources of the asymmetries. Theoretical models fill that gap.

This section presents a micro-founded small open economy model. The representative household consumes both domestically produced and imported consumption goods. Each household is specialized in a particular type of labor, has some power to negotiate over wages, and supplies its labor to a labor packager. The labor packager combines heterogeneous labor into a homogeneous package and supplies it to domestic firms, which operate in a monopolistic competitive environment. The discussion of the labor packager is a modeling technique to introduce wage stickiness into the model. Households hold capital stock and invest in capital accumulation by purchasing domestically produced and imported investment goods. Households, choosing the utilization rate of capital, supply it to domestic firms, which produce intermediate goods. They use a Cobb-Douglas production function by combining technology, labor, and capital. The representative firm combines varieties of intermediate inputs into a homogeneous good. Then, the homogeneous good is used in the consumption, investment, government expenditures or export sector. Three types of importer operate in the economy. They import consumption goods, investment goods and goods used in the export sector. Importers import differentiated goods and set prices following the mechanism proposed in Calvo (1983). The central bank operates via the Taylor rule. The domestic economy is small and does not affect the foreign economy, so the external sector's variables are exogenous.

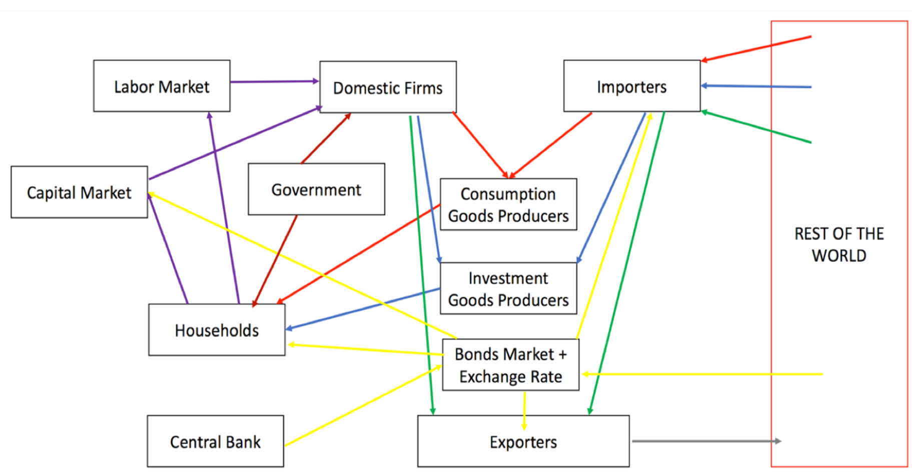

Figure 4: Schematic representation of the model

In contrast with models of this type developed in the literature [4], this paper

[4]See Chang et al. (2007), Christiano et al. (2011), and Schmitt-Grohe and Uribe (2011).

does not discuss the growing path of technology, and the variables are not scaled by unit-root technology. There are two explanations for this. Firstly, the growing path of the model is not a significant feature affecting the asymmetry. Secondly, there is a problem of linking data to the model for developing countries because of deviation from the balanced growth path. A schematic representation of the model is presented in Figure 4.

4.1 Final consumption and investment goods

The consumption basket of the representative household is given by the following functional form:

$$C_t = \left[(1-\gamma_c)^{\frac{1}{\eta_c}} C_{H,t}^{\frac{\eta_c - 1}{\eta_c}} + \gamma_c^{\frac{1}{\eta_c}} C_{F,t}^{\frac{\eta_c - 1}{\eta_c}} \right]^{\frac{\eta_c}{\eta_c - 1}} \tag{4.1.1}$$

where $C_{H,t}$ and $C_{F,t}$ are home-produced and imported consumption goods, respectively, γ_c is the share of imported goods in the household consumption basket, and η_c is the elasticity of substitution between the two groups of goods.

Aggregate investment goods (I_t) are a function of the domestically produced ($I_{H,t}$), imported ($I_{F,t}$) and investment goods used in capital services ($a(u_t)K_t$), given by the following equation:

$$I_t = \left[(1-\gamma_{inv})^{\frac{1}{\eta_{inv}}} I_{H,t}^{\frac{\eta_{inv} - 1}{\eta_{inv}}} + \gamma_{inv}^{\frac{1}{\eta_{inv}}} I_{F,t}^{\frac{\eta_{inv} - 1}{\eta_{inv}}} \right]^{\frac{\eta_{inv}}{\eta_{inv} - 1}} - a(u_t)K_t, \tag{4.1.2}$$

where γ_{inv} is the share of imported investment goods, η_{inv} is the elasticity of substitution between domestic and imported investment goods, K_t is the stock of capital and $a(u_t)$ is the capital utilization cost represented by the following functional form:

$$a(u_t) = \frac{1}{2}\varrho_a \varrho_b u_t^2 + \varrho_b(1-\varrho_a)u_t + \varrho_b(\frac{\varrho_a}{2} - 1), \tag{4.1.3}$$

where u_t is the utilization rate of capital and ϱ_a and ϱ_b are parameters of the function. This function is very convenient for analysis because it goes to zero in a steady state.

4.2 Households

The representative household maximizes its utility function, given by:

$$U_{t+j} = E_t \sum_{j=0}^{\infty} \beta^j \left(\xi_{t+j}^c log(C_{t+j} - habC_{t+j-1}) - \xi_{t+j}^N \frac{n(i)_{t+j}^{(1+\varphi)}}{1+\varphi} \right), \tag{4.2.1}$$

For a detailed description of this type of models, see the working paper versions of the above-mentioned papers.

where E_t is the expectation operator conditional on information available at time t, ξ_t^C and ξ_t^N are consumption preference and labor supply shocks, β denotes the discount factor, hab is the parameter for the habit of consumption, φ is the inverse of the Frisch elasticity of labor supply and $n(i)_t$ represents the i-th type of labor supplied by the household.

The maximization problem is subject to the following budget constraint written in terms of domestic goods:

$$\begin{aligned}\frac{P^C_{t+j}}{P_{t+j}}C_{t+j} + \frac{P^I_{t+j}}{P_{t+j}}I_{t+j} + \frac{B_{t+j}}{P_{t+j}} + \frac{Ex_{t+j}F_{t+j}}{P_{t+j}} + a(u_{t+j})K_{t+j} + T_{t+j} = \\ = \frac{W(i)_{t+j}}{P_{t+j}}N(i)_{t+j} + u_{t+j}K_{t+j-1}R^k_{t+j-1} + \\ + \frac{R_{t+j-1}B_{t+j-1}}{P_{t+j}} + \frac{R^*_{t+j-1}Ex_{t+j}F_{t+j-1}}{P_{t+j}} + \frac{\Pi_{t+j}}{P_{t+j}}\end{aligned} \tag{4.2.2}$$

The left-hand side represents household expenditures. Each period, it purchases consumption goods (C_t), investment goods (I_t), and domestic (B_t) and foreign (F_t) bonds. It also faces capital utilization costs ($a(u_t)$) and pays taxes (T_t). Ex_t denotes the effective nominal exchange rate. The right-hand side of the constraint represent the household's income. The household receives nominal wage $W(i)_t$ for the *i*-th type of labor. R_t^k is the rate of return on installed capital. Households receive interest payments for previously purchased domestic ($R_{t-1}B_{t-1}$) and foreign bonds ($R^*_{t-1}Ex_tF_{t-1}$). Π_t denotes the dividends of firms.

Households hold capital, and its accumulation is represented by the following:

$$K_{t+j+1} = (1-\delta)K_{t+j} + \Psi_{t+j}\left[1 - \Phi\left(\frac{I_{t+j}}{I_{t+j-1}}\right)\right]I_{t+j}, \tag{4.2.3}$$

where δ is the depreciation rate of capital and Ψ_t is the shock to the marginal efficiency of investments. $\Phi\left(\frac{I_t}{I_{t-1}}\right)$ denotes the investment adjustment cost function, which has the following functional form:

$$\Phi\left(\frac{I_t}{I_{t-1}}\right) = 0.5\left\{e^{\sqrt{S''}\left(\frac{I_t}{I_{t-1}}-1\right)} + e^{-\sqrt{S''}\left(\frac{I_t}{I_{t-1}}-1\right)} - 2\right\} \tag{4.2.4}$$

This form of investment adjustment costs is widely used in DSGE literature (see Christiano et al., 2005, Fernández-Villaverde and Rubio-Ramírez, 2006, and Justiniano et al., 2010). There are no costs in a steady state.

The household maximizes its utility subject to the budget constraint and capital accumulation. The first-order conditions of the household problem are given in Appendix B (equations 1, 2, 3, 8, 11 and 12).

4.3 Production

There is a continuum of intermediate goods producers, which use a Cobb-Douglas production function of the form:

$$Y(j)_t = Z_t K^{serv}(j)_t^{\alpha} N(j)_t^{(1-\alpha)} - \Phi, \tag{4.3.1}$$

where $K^{serv}(j)_t$ represents the capital services rented by the j-th firm, $N(j)_t$ is the labour hired by the firm, α represents the share of capital and Z_t is the stationary productivity process available for all firms. Φ denotes the fixed cost of production.[5]

The j-th firm has the monopolistic power to produce a differentiated good. Following Calvo (1983), the firm receives a signal to change the price with probability $(1-\theta^d)$ in each period. Otherwise, it keeps the price unchanged with probability θ^d. The optimal price chosen in the current period is denoted by $P(j)_t^*$. The j-th firm maximizes its expected profit:

$$\max_{\{P(j)_t^*\}} \sum_{j=0}^{\infty} (\beta\theta)^j E_t \left[\Lambda_{t,t+j} \left(\frac{P(j)_t^*}{P_{t+j}} - mc_{t+j}^d \right) Y(j)_{t+j} \right], \tag{4.3.2}$$

subject to the demand function. $\Lambda_{t,t+j}$ denotes the stochastic discount factor. The solution of the optimization problem derives the nonlinear Phillips curve (Appendix B, equations 16–19).

4.4 Importers and exporters

Three types of importers operate in the economy: importers of consumption goods, importers of investment goods, and importers of goods used in the production of final export goods. They have monopolistic power and repackage a homogeneous good from the foreign sector into a specialized good and supply it to domestic retailers. Domestic retailers combine a continuum of specialized goods into a homogeneous imported good using a Dixit-Stiglitz function:

$$Imp_t^i = \left[\int_0^1 Imp_t^i(j)^{\frac{\varepsilon_{i,Imp}-1}{\varepsilon_{i,Imp}}} dj \right]^{\frac{\varepsilon_{i,Imp}}{\varepsilon_{i,Imp}-1}} \tag{4.4.1}$$

where $i \in (C, I, Exp)$ is for consumption, investment, and export sector goods. Imp_t^i is the aggregated import and ε_i is the elasticity of substitution between varieties of goods. The domestic aggregator is competitive and takes the price (P_t^i) of Imp_t^i and price $(P_t^i(j))$ of $Imp_t^i(j)$ as given.

The real marginal cost of importers is given by the expression:

$$mc_t^{i,Imp} = \frac{\tau_t^{i,Imp} Ex_t P_t^*}{P_t^i} \tag{4.4.2}$$

[5] See Christiano et al. (2005).

where $\tau_t^{i,Imp}$ is the mark-up on marginal costs and P_t^* is the foreign price. Importers solve a profit maximization problem similar to the domestic producer's problem. As a result, three nonlinear Phillips curves are derived from these problems (Appendix B, equations 20–23, 26–29, and 32–35). Because of the presence of price dispersion in the model, total imports concentrated for the consumption, investment, and export sectors $i \in (C, I, Exp)$ are the following:

$$Imp_t = Ex_t P_t^* (Imp_t^C (\tilde{p}_t^{c,Imp})^{-\varepsilon_C,Imp} + Imp_t^I (\tilde{p_t}^{Inv,Imp})^{-\varepsilon_I,Imp} + \\ Imp_t^{Exp} (\tilde{p}_t^{Exp,Imp})^{-\varepsilon_{Exp,Imp}}) \quad (4.4.3)$$

Foreign demand for domestically produced goods is represented by the following:

$$Exp_t = \left(\frac{P_t^{Exp}}{Ex_t P_t^*} \right)^{-\eta_f} Y_t^*, \quad (4.4.4)$$

where export is an increasing function of foreign demand Y_t^* and relative prices. η_f is the elasticity of exports and P_t^{Exp} is the export price in domestic currency. Equations describing the export sector are given in Appendix B (38–43).

4.5 Labor market

The representative household supplies labor to the labor packager. The latter combines differentiated labor into a homogeneous labor package via a constant elasticity of substitution (CES) technology

$$N_t = \left[\int_0^1 n(j)_t^{\frac{\varepsilon_w - 1}{\varepsilon_w}} dj \right]^{\frac{\varepsilon_w}{\varepsilon_w - 1}} \quad (4.5.1)$$

A household has the monopolistic power to set wages. Following Calvo (1983), a $(1 - \theta_W)$ share of households is able to optimize wages. A θ_W share of households sets wages looking at inflation, so the non-optimizing household updates its wage according to the following formula:

$$W(j)_{t+s} = \pi_{t,t+s}^c W(j)_t, \quad (4.5.2)$$

where $\pi_{t,t+s}^c$ is cumulative inflation from period t to the period $t + s$. The $j - th$ household chooses optimal wage W_t^* in the current period, considering the flow of future (non-optimized, but updated by (4.5.2)) wages. So, the problem becomes dynamic, which is represented by the following discounted utility function:

$$\sum_{s=0}^{\infty} (\beta \theta_w)^S E_t \left[-\omega_{t+s}^N \frac{n(j)_{t+s}^{(1+\varphi)}}{1 + \varphi} + \lambda_{t+s} W(j)_{t+s} n(i)_{t+s} \right] \quad (4.5.3)$$

The nonlinear Phillips curve of wages is represented by equations 55–60 in Appendix B.

4.6 Aggregation

Aggregation of the production function gives the following:

$$Y_t = (\tilde{p}_t)^{\varepsilon_d}(Z_t(K_t^{serv})^{\alpha}(\tilde{w}_t^{\varepsilon_w} n_t)^{1-\alpha} - \Phi) \tag{4.6.1}$$

Price and wage distortions create an inefficient allocation of resource between firms.

On the other hand, production is divided into consumption, investment, government expenditures and exports.

$$Y_t = C_{H,t} + I_{H,t} + G_t + Y_t^{Exp} \tag{4.6.2}$$

4.7 Monetary policy

The central bank follows a Taylor rule of the form:

$$R_t - R^{SS} = \rho_R(R_{t-1} - R^{SS}) + (1-\rho_R)\left(\mu_\pi(\pi_{t+1}^c - \pi^{SS}) + \mu_{gdp} log\left(\frac{GDP_t}{GDP^{SS}}\right)\right) + \sigma_t^R. \tag{4.7.1}$$

The interest rate has some persistence ρ_R and reacts to inflation expectations μ_π and to the deviation of output from its steady state μ_{gdp}.

4.8 Foreign economy

The rest of the world is exogenous to the small open economy. Foreign demand, interest rates and inflation follow first-order autoregressive processes:

$$log\left(\frac{Y_t^*}{Y^{*,ss}}\right) = \rho_{y^*} log\left(\frac{Y_{t-1}^*}{Y^{*,ss}}\right) + \sigma_t^{Y^*} \tag{4.8.1}$$

$$R_t^* - R^{*,ss} = \rho_{R^*}(R_{t-1}^* - R^{*,ss}) + \sigma_t^{R^*}, \tag{4.8.2}$$

$$\pi_t^* - \pi^{*,ss} = \rho_{\pi^*}(\pi_{t-1}^* - \pi^{*,ss}) + \sigma_t^{\pi^*}, \tag{4.8.3}$$

where ρ_{y^*}, ρ_{R^*} and $\rho_{\pi^*} \in (0,1)$ are persistence coefficients and $\sigma_t^{Y^*}$, $\sigma_t^{R^*}$ and $\sigma_t^{\pi^*}$ are independently and identically distributed shocks with zero mean. $Y^{*,ss}$, $R^{*,ss}$ and $\pi^{*,ss}$ are the steady states of foreign demand, foreign $interelog \setminus st$ rates and foreign inflation, respectively.

4.9 Shocks

The model is driven by fifteen structural shocks: consumption preference (ξ_t^c), labor supply (ξ_t^n), marginal efficiency of investments (Ψ_t), government spending (G_t), risk premium (Ω_t), stationary productivity (Z_t), mark-up on domestically produced goods (τ_t^d), mark-up on imported consumption goods ($\tau_t^{c,Imp}$), mark-up on imported investment goods ($\tau_t^{Inv,Imp}$), mark-up on imported goods used

in the export sector ($\tau_t^{Exp,Imp}$), mark-up on exported goods (τ_t^{Exp}), monetary policy (σ_t^R), foreign demand (Y_t^*), foreign inflation (π_t^*) and foreign interest rates (R_t^*).
All the equations of the model are given in Appendix B.

5 Estimation

This section estimates the model developed in the previous section using the Bayesian technique. The first stage determines the approximation modal value of the posterior distribution and the second stage applies the Markov chain Monte Carlo (MCMC) technique to estimate the shape of the posterior parameter distribution near the posterior mode. DSGE literature suggests dividing the parameters into calibrated and estimated. Calibrated parameters are those which are calculated from data or are strictly fixed at some point based on widely used values in the literature. According to Canova (2007) and Fernández-Villaverde et al. (2016), this strategy of estimation leads to more efficient estimation of the non-calibrated parameters.

5.1 Data

For the estimation of the DSGE model, 12 macroeconomic time series for Armenia and three for the foreign economy are used as observables. The sample covers the period from 2004Q1 to 2019Q4. Data for real GDP (GDP_t), private consumption ($Cons_t$), private investment (Inv_t), government expenditures (Gov_t), exports ($Export_t$) and imports ($Import_t$) are from the system of national accounts of the Statistical Committee of the Republic of Armenia. The real effective exchange rate ($REER_t$) is calculated by the Central Bank of Armenia and published on its web site. The real wage ($Wage_t$) is calculated by dividing the nominal wage by the CPI. The interest rate ($IntRate_t$) is the interbank repo rate. Inflation ($dlCPI_t$) is the quarterly percentage change in the CPI. As a proxy for the prices of domestically produced goods, the quarterly percentage change in the GDP deflator ($dlGDPDefl_t$) is used. The price of investment goods ($INVDefl_t$) is the investment deflator from the system of national accounts. Foreign inflation ($dlCPIStar_t$) and GDP ($GDPStar_t$) are calculated as the weighted average of Armenia's trading partners. The foreign interest rate ($IntRateStar_t$) is the average of the USA, Euro Area and Russia's values. All the time series are seasonally adjusted using the X12 algorithm. The corresponding measurement equation is:

$$
Y_t = \begin{bmatrix} dlGDP_t \\ dlCons_t \\ dlInv_t \\ dlExport_t \\ dlImport_t \\ dlGov_t \\ dlWage_t \\ dlREER_t \\ intRate_t \\ dlCPI_t \\ dlGDPDefl_t \\ dlINVDefl_t \\ dlGDPStar_t \\ IntRateStar_t \end{bmatrix} = \begin{bmatrix} GDP_t - GDP_{t-1} \\ C_t - C_{t-1} \\ I_t - I_{t-1} \\ Exp_t - Exp_{t-1} \\ Imp_t - Imp_{t-1} \\ G_t - G_{t-1} \\ w_t - w_{t-1} \\ q_t - q_{t-1} \\ R_t \\ \pi_t^c \\ \pi_t^d \\ \pi_t^{Inv} \\ Y_t^* - Y_{t-1}^* \\ \pi_t^* \\ R_t^* \end{bmatrix} \tag{5.1.1}
$$

where l and dl stand for log and log difference, respectively. Figure 5 in Appendix E presents the model input data.

5.2 Calibration

The discount factor β is calibrated to 0.99, implying a 4% annual real interest rate. Inflation target π^{target} is 1.0097, which corresponds to the quarterly 0.97% inflation. This is the average for the estimation sample. Following a wide range of literature (see, for example, Adolfson et al., 2007, and Christiano et al., 2011, etc.), the elasticities of substitution between varieties of domestically produced (ε_d), imported consumption ($\varepsilon_{c,Imp}$), imported investment ($\varepsilon_{Inv,Imp}$), imported input in the export sector ($\varepsilon_{Exp,Imp}$) and exported (ε_{Exp}) goods are calibrated to 6, which results in a 20% mark-up. The depreciation rate of capital δ is calibrated to 0.025, which is a commonly used value in business cycle literature.

The parameters capturing the shares are calculated from the data. They represent the average of the estimation sample. The share of government expenditures in GDP G^{ss} is 0.165. The share of labor in production $(1 - \alpha)$ is calculated by dividing the nominal wage of all employed by the nominal GDP, which is 0.43. The share of imported goods in the consumption basket is 35% ($\gamma_c = 0.35$). The share of imported investment goods in aggregate investments γ_{Inv} is 0.3. Finally, for the production of final export goods, the sector uses 30% imported goods ($\gamma_{Exp} = 0.3$). Table 10 in Appendix E summarizes the calibration.

5.3 Prior distributions

The rest of the parameters are estimated using the Bayesian technique. Beta distribution is applied to the parameters, which lie between zero and one. The parameters, restricted to be positive, follow a gamma distribution. The means of the standard deviations of structural shocks follow an inverse gamma distribution.

The prior means and standard deviations of the structural parameters are presented in Table 11 (Appendix E). Following much of the literature, all five Calvo price stickiness parameters ($\theta^d, \theta^{c,Imp}, \theta^{Inv,Imp}, \theta^{Exp,Imp}$ and θ^{Exp} and the wage stickiness parameter θ^w have beta distributions with 0.75 prior means and 0.075 standard deviations to match yearly price and wage durations.

The prior mean of the inverse of the Frisch labor supply elasticity parameter φ is calibrated to 2 and has standard deviation 0.3. This calibration of labor supply elasticity is a commonly used value in the literature (see, for example, Gali et al., 2011, Grabek and Kłoset, 2013, etc).

Following Beltran and Draper (2008), the prior means and standard deviations of the elasticities of substitution between home-produced and imported consumption η_c and investment η_{Inv} goods are 2 and 0.45, respectively. The same prior distribution is applied to the elasticity of exports η_f and the elasticity of substitution between domestic and imported goods used in the export sector η_x.

Habit persistence in the utility function has a beta distribution with prior mean 0.5 and standard deviation 0.2, which is the average value used in Chetty and Szeidl (2016). The prior distribution of the investment adjustment costs parameter follows a gamma distribution with mean 9 and standard deviation 2.8. The prior of the parameter in the capital utilization function follows a gamma distribution with mean 0.2 and standard deviation 0.075. This prior is from Smets and Wouters (2007) and Christiano et al. (2011).

The prior mean of persistence in the interest rate ρ_R has a beta distribution with mean 0.7 and standard deviation 0.12. In addition, the responses of the interest rate to inflation expectations μ_π and GDP deviation from its steady state μ_{gdp} follow a gamma distribution with mean values 1.5 and 0.25, respectively.

There is a problem in the identification of the mark-up on wages λ_w parameter, so we take the average of the values used in Smets and Wouters (2007) and Gali et al. (2012). The mark-up on wages parameter follows a gamma distribution and has prior mean 1.3 and standard deviation 0.15.

Following Smets and Wouters (2007), all persistence coefficients of autoregressive processes have beta distributions with identical prior means of 0.8 and standard deviations of 0.085 (see Table 12 in Appendix E).

All the standard errors of structural shocks follow an inverse gamma distribution (see Table 13 in Appendix E). The prior means of the labor supply shock and mark-up shocks are higher compared to the rest of the shocks.

5.4 Posterior estimates

The posterior means and 90% confidence intervals of the estimated parameters are in the fourth, fifth and sixth columns, respectively in Tables 11–13 (see Appendix E). The estimation is obtained by running three parallel chains of the Metropolis-Hastings algorithm with 600,000 draws. The acceptance rates for the three chains are 26.33%, 27.17% and 27.58%. Figure 7 in Appendix

E shows the convergence diagnostics of the model's likelihood function. The blue line captures the 80% interval range based on the pooled draws from all sequences. The red line shows the mean interval range based on the draws of individual sequences. The second (m2) and third (m3) rows show the estimation of the same statistics for the second and third central moments. Convergence is achieved when two lines are stabilized horizontally and should be close to each other. Figure 6 (Appendix E) shows the prior and posterior densities of the estimated parameters. The data are quite informative in obtaining the posterior distribution.[6]

The posterior mean of the price stickiness coefficient of domestically produced goods is 0.91, which corresponds to a price duration of 11 quarters. The price stickiness parameter of exported goods is estimated to be 0.65, capturing a price duration of three quarters. On the other hand, the estimated posterior means of imported consumption goods, investment goods and imported goods used in the export sector are 0.62, 0.52 and 0.45, respectively. The estimation shows that the prices of imported goods are adjusted more frequently compared to domestic prices. Castillo and Montoro (2008) show that the convexity of the second-order approximated Calvo Phillips curve increases with a decrease of price stickiness. The posterior estimation of the Calvo wage stickiness parameter is 0.82, which is a little bit higher than its prior mean. The estimated elasticity of substitution between varieties of labor is 6, reporting a 1.22 mark-up on wages.

The estimated mean of the investment adjustment costs parameter is 5.13. The posterior mean of the parameter in the cost function of capital utilization is estimated to be 0.15, which is smaller compared to its prior mean. The value of this parameter identifies the concavity of the utilization function. The small value of this parameter means less concavity of the utilization function, which decreases the asymmetric adjustment of the utilization rate based on the function's properties.

The persistence parameter in a Taylor rule has posterior mean 0.69. The posterior mean of the reaction to inflation expectations is 1.59. The central bank reacts to deviation of output from its steady state with coefficient 0.18.

5.5 Historical decomposition of output

Figure 8 in Appendix E presents the historical decomposition of Armenian cyclical GDP based on the posteriors of the estimated model. According to the decomposition, the decline in GPD during the financial crisis in 2008–2009 was mostly the result of the marginal efficiency of investment, consumption preference, and productivity shocks. The marginal efficiency of investment represents the transformation of technology investment goods into capital. This transformation decreases during crises and increases in times of high growth. One of the components of this shock is the functioning of financial markets. Models with financial frictions take on the part of the shock. Households increased precau-

[6] The model is estimated within the Dynare software platform.

tionary savings, which is reflected in the negative contribution of consumption preference shock to the GDP decline during the 2008–2009 crisis. The crisis also yields the structural decline in GDP, represented by the fall in productivity. The main positive contribution to Armenian GDP during the crisis was the huge increase in government spending through borrowing. There was some contribution from the monetary policy side to the recovery of the economy.

6 Sources of curvatures in the model

The theoretical model has several sources of asymmetry. The first group of curvatures are the Phillips curves for domestically produced and imported goods. The nonlinear Phillips curve for domestically produced intermediate good is expressed by equations 16–19 in Appendix B. Calvo price setting frictions make the Phillips curve convex, which means that the trade-off between output and prices changes along the supply curve. When the growth of the economy accelerates, more inflation is created. This trade-off decreases when output is below its equilibrium level (see Figure 2 for illustration). First-order approximation or log-linearization of the Phillips curve yields a linear New Keynesian Phillips curve of the following form:

$$\pi_t^d = \beta \pi_{t+1}^d + \frac{(1-\theta^d)(1-\beta\theta^d)}{\theta^d} \tilde{mc}_t^d. \tag{6.0.1}$$

When the economy is described by a linear supply curve, the trade-off between aggregate output and inflation is constant (see Figure 3). This linearization cancels a potential source of the asymmetry in the model. In addition, price dispersion, visible in the second-order approximation, increases the amount of capital and labor needed to produce a given level of output.

The second-order approximated Phillips curve is convex. This creates a nonlinear trade-off between inflation and output. Additionally, the convexity of the Phillips curve with Calvo price setting frictions increases with a decrease in the price stickiness parameter[7]. The estimation of the structural parameters reports that the prices of domestically produced goods are highly sticky. The Calvo parameter of domestically produced goods is 0.91. High price stickiness decreases the convexity of the curve. This is because a higher price stickiness parameter decreases the responsiveness of a firm's prices in optimal equilibrium to its marginal costs.

The next sources of asymmetry are from the import sector's price setting. The estimated Calvo parameters of imported consumption, investment and goods used in the export sector are 0.62, 0.52 and 0.45, respectively, which make the import sector Phillips curves more convex. As a result, the trade-off between prices and imports increases more compared to domestic production.

The next friction is the investment adjustment cost function given by the following:

[7] See Castillo and Montoro (2008).

$$\Phi\left(\frac{I_t}{I_{t-1}}\right) = 0.5\left\{e^{\sqrt{S''}\left(\frac{I_t}{I_{t-1}}-1\right)} + e^{-\sqrt{S''}\left(\frac{I_t}{I_{t-1}}-1\right)} - 2\right\}. \tag{6.0.2}$$

The first-order Taylor approximation of this function around the deterministic steady state is always zero (for more details, see Appendix C). Asymmetry becomes visible in higher order approximations. Actually, the function is symmetric, but it generates asymmetries in the business cycle by accelerating the relative decrease or increase in capital stock.

The next nonlinearity comes from the convex wage curve (Appendix B, equations 55–60). During recessions, households tend to decrease employment rather than nominal wages. When in a growing economy, the wealth effect is dominant over the substitution effect, and households work relatively less, putting pressure on nominal wages to increase. The prior belief about the elasticity of substitution between varieties of labor is 4. The posterior estimated value of this parameter is 6, which results in a higher elasticity of substitution. Castillo et al. (2007) show that an increase in the elasticity of substitution between varieties of goods increases the convexity of the Phillips curve. This high convexity results in the highly asymmetric behavior of the labor market in response to shocks (see Appendix F for graphical illustration).

7 Mixed equations approach and models for simulations

To preserve the nonlinearities of the structural model, this paper uses a second-order approximation of the policy function.[8] This technique is widely used in DSGE literature for studying the nonlinear implications of the model. The presence of nonlinearities enables the determination of the asymmetric responses of the economy to expansionary and contractionary monetary policies of the same magnitude. However, a second-order approximated full model does not allow the estimation of the contribution of specific frictions or specific sectors to the creation of asymmetry.

This paper applies a mixed equations approach to show the contribution of specific frictions in the creation of asymmetric responses of the economy to shocks. To show the relative importance of a specific sector in the creation of asymmetry, we apply second-order approximation to that sector and keep the rest of the model linearized.

To analyze the relative importance of a specific nonlinearity in the creation of asymmetric reactions of the economy to positive and negative monetary policy shocks, the following six specifications of the model are simulated using posterior estimated coefficients for Armenia.

[8] See Collard and Juillard (2001), Kim and Kim (2003), Schmitt-Grohe and Uribe (2004), FernándezFernandez-Villaverde et al. (2016).

Model 1	Second-order approximated model
Model 2	Main non-linear parts are linearized. Second-order approximation is applied to the remaining parts of the model
Model 3	Inclusion of second-order approximated investment adjustment costs and capital utilization costs into Model 2
Model 4	Introduction of second-order approximated Phillips curve of domestically produced goods into Model 2
Model 5	Model 2 with second-order approximated wage setting
Model 6	Model 2 with second-order approximated open economy parts

Table 5: Models for simulations

A second-order perturbation method makes the approximation stable. However, it generates explosive sample paths, which are the result of additional fixed points. The additional fixed points in the system are the result of terms of higher order than 2. This paper uses pruning to avoid the generation of explosive sample paths.[9]

8 Asymmetries in the monetary policy transmission mechanism

This section presents the responses of the economy to positive and negative monetary policy shocks of the same size in six models in steady states.[10] The models are calibrated based on the estimated posterior values of the parameters.

Figure 11 in Appendix G shows the impulse response functions to 1% positive and negative monetary policy shocks in the second-order approximated model. The reaction of inflation to expansionary policy is higher than its reaction to contractionary policy. On the other hand, a 1% contractionary monetary policy decreases GDP by more than a stimulating policy of the same size increases it. The high asymmetry in inflation is created mostly by the imported consumption goods sector. The Phillips curve of imported consumption goods is more convex because the Calvo stickiness coefficient of importers is small, which means that importers tend to increase prices more in response to increasing demand than decrease prices during falling demand. The same tendency is observed in the domestic sector, but the relative size of the asymmetry is less compared to the import sector because the prices of domestically produced goods are stickier, which results in a less convex Phillips curve. Real variables, like consumption, investment, export, and employment, react more to tight policy than to easy policy. The asymmetric reaction of investment creates asymmetries in investment adjustment costs, which further accelerates the asymmetric response of the capital stock. Households react to this by changing the utilization rate asymmetrically and in the opposite direction. When investments decrease and

[9]See Kim et al. (2008).

[10]The simulations are implemented within the Dynare software platform.

price dispersion creates more loss in productivity, households tend to increase the utilization rate of capital. As a result, utilized capital declines relatively less during contractionary monetary policy, preventing further loss in output. Positive monetary policy shock results in more reduction of employment and less fall in nominal wages.

Figure 12 in Appendix G presents the results of the same simulation using Model 2, where the main nonlinearities of the model are linearized. Some standard nonlinear parts are not enough to explain the asymmetries, and we have a symmetric response from the economy to tight and easy policies of the same size.

Figures 13–16 (Appendix G) show the responses of inflation and output from simulations of Models 3, 4, 5 and 6.[11] Table 6 summarizes the contribution of a specific sector or friction in the creation of asymmetry in the monetary policy transmission mechanism. The asymmetry is calculated as follows. We calculate the differences of the responses to positive and negative shocks. Then the absolute value of the sum of the first four quarters of the simulation is taken as the size of the asymmetry. [12]

	Nonlinear VAR	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Inflation, QoQ	0.62	0.28	0	0.03	0.025	0.025	0.17
GDP Growth, QoQ	0.75	0.43	0.002	0.08	0.12	0.105	0.08

Table 6: The decomposition of asymmetry

The asymmetries in inflation and output growth from a nonlinear VAR are 0.62 and 0.75, respectively. The second-order approximated DSGE model explains around half of the asymmetry estimated by the VAR. Most of the asymmetry in inflation is a result of the highly convex Phillips curves of importers (0.17 of 0.28). Both nonlinear labor and capital markets create a 0.025 asymmetry in inflation, while the domestic price setting frictions create 0.03. The sum of the components (0.25) is smaller than the asymmetry from the full second-order approximated model (0.28), because the joint inclusion of parts in the system creates additional asymmetry. The estimated asymmetry in the change of output is mostly a result of the domestic economy's frictions (0.08+0.12+0.105). Open economic parts create a 0.08 asymmetry in GDP growth.

9 Third-order empirical moments of simulated models

As reported in Section 3, economic growth in Armenia is negatively skewed, while the skewness of inflation and interest rates is positive. This section tests

[11]Generalized Impulse Response Functions (GIRFs) of the extended set of variables are available upon request.

[12]Calculations are based on a 0 to 3 period for the DSGE models, and on a 1 to 4 period for VAR.

whether our theoretical model generates the asymmetries observed in the data. Table 7 presents the third-order theoretical moments of inflation, output growth and the interest rate, which are calculated from simulations of 6 models. Skewness is calculated from 25,000 simulations, which are based on the estimated posterior values of the parameters and all the structural shocks.

	Data	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Inflation, QoQ	0.18	0.33	0.00	0.04	0.13	0.21	0.27
GDP Growth, QoQ	-1.32	-0.95	0.04	-0.25	-0.32	-0.49	-0.33
Interest Rate	0.51	0.57	0.02	0.11	0.21	0.25	0.14

Table 7: Skewness of observed and model-generated data

The second-order approximated model generates skewness, the directions and degrees of which are close to those observed in the Armenian data. The skewness of inflation, GDP growth and the interest rate are 0.33, -0.95 and 0.57, respectively. When the main nonlinearities are absent from the model (Model 2), it generates almost symmetrical data. The presence of even one nonlinear block enables a skewed simulation. The high degree of asymmetry in economic growth is a result of internal economy frictions. But even the presence of these nonlinearities in the internal economy results in the generation of skewed inflation very close to the actual data. A nonlinear labor market yields a higher skewness of the interest rate (0.25). Nonlinear specifications of open economy parts generate 0.27 skewness in inflation and negative skewness of economic growth (-0.33).

10 Efficiency of monetary policy in growing economies and recessions

This section estimates the efficiency of monetary policy during expansions and recessions. Both supply and demand shocks are important forces driving Armenian output. This paper divides the 15 structural shocks of the model into demand, supply, and monetary policy shocks. Demand shocks drive inflation and output in the same direction. Inflation and output move in opposite directions in response to supply shocks. This paper then generates supply- and demand-driven expansions and recessions using the posterior values of the structural parameters and the standard deviations of shocks. Here, expansion is defined as a state of the economy where GDP is 5% above the steady state, and recession is a state where GDP is 5% below the steady state level.

Figure 17 in Appendix H shows the reaction of inflation and output to a modest monetary policy shock in demand-driven expansion and recession. In a demand growing economy, firms have attracted additional labor and capital and put pressure on inflation. Aggregate demand intersects aggregate supply in a steeper region. On the other hand, there is unemployment and utilized capital in a recession, and demand intersects the supply curve in a flatter region. So, expansionary policy stimulates more demand in a recession than contractionary policy decreases it in an expansion. Inflation reacts oppositely. In recession, firms react to expansionary policy by producing more goods and put less pressure on prices, because they can easily attract labor and capital. An increase of monetary stimulus in a recession changes the trade-off between output and inflation, which results in a smaller reaction of output and accelerating inflation (Figure 18 in Appendix H). Movement in the direction of equilibrium constrains firms more in finding labor and capital, and they increase prices relatively more. In demand-driven expansion, an increase in the size of contractionary policy accelerates the decline of output and decreases the marginal decline in inflation (Figure 19 in Appendix H).

The next simulations apply contractionary monetary policy shocks in supply-generated expansions and recessions. Tight monetary policy impacts the real economy more strongly in a supply-driven recession, because no additional labor or capital resources are attracted for the expansion of GDP (Figure 20 in Appendix H). On the other hand, the aggregate supply curve intersects aggregate demand in a steeper region in a supply-driven recession. As a result, firms decrease labor and capital inputs less. Instead, they put relatively more pressure on inflation. An increase in the size of monetary policy shock during expansion moves the demand curve into a flatter region of supply and accelerates the decline of output. On the other hand, aggressive policy does not have a significant marginal effect on inflation (Figure 21 in Appendix H). In a supply-driven recession, aggressive monetary policy results in a decrease in the reaction of inflation and an increase in the response of output (Figure 22, Appendix E).

Table 8 summarizes the policy simulations in supply- and demand-driven recessions and expansions. The responses are calculated as the absolute value of the average of the first three periods of the simulation. Responses to aggressive policy are rescaled for comparison.

	Demand shocks				Supply shocks			
	Recession		Expansion		Recession		Expansion	
Variables	Modest response	Aggressive response	Modest response	Aggressive response	Modest response	Aggressive response	Modest response	Aggressive response
Inflation	0.11	0.12	0.14	0.11	0.18	0.1	0.15	0.14
Growth	0.39	0.31	0.31	0.38	0.27	0.34	0.34	0.44

Table 8: Asymmetry in supply- and demand-driven expansions and recessions

11 Conclusion

This paper empirically shows the presence of asymmetries in the monetary policy transmission mechanism in Armenia. Two-stage estimation reports that inflation reacts more strongly to expansionary monetary policy than to contractionary policy. On the other hand, the estimation shows an opposite response from output. To observe the empirically dynamic responses of inflation and output, a nonlinear VAR is constructed and estimated for the Armenian economy. The results show that the economy reacts asymmetrically to positive and negative monetary policy shocks of the same size.

The paper then constructs a small open economy DSGE model to explain the sources of the asymmetries in the monetary policy transmission mechanism. There is a number of nonlinearities in the model, such as the convex Phillips curves of importers, domestic producers and wages, and capital adjustment costs and capital utilization costs. The model is estimated for the Armenian economy using 15 macroeconomic parameters. The estimation's diagnostic measures indicate the good quality of estimation. The estimation reports high stickiness of prices for domestic goods and high flexibility of prices for imported goods. As a result, the Phillips curve of importers is highly convex.

To preserve the nonlinearities of the model, a second-order approximation technique is applied. The theoretical model generates half of the asymmetry in inflation estimated with the empirical model. On the other hand, the DSGE explains more than half of the asymmetry of output estimated with nonlinear VAR. Most of the asymmetry of inflation is a result of the highly convex Phillips curve of importers, but the nonlinearities of the open economy blocks explain around 20% of the asymmetry in output. Much of the asymmetry is a result of the frictions of the internal economy. Policy simulations show that the efficiency of monetary policy in managing inflation in demand-driven recession is high. In addition, the model matches the directions and sizes of the skewness of Armenian inflation and output growth.

A number of extensions of the DSGE model could introduce additional nonlinearities and, as a result, generate more asymmetry, closer to those estimated with empirical models.

References

[1] Abbritti, M. and Fahr, S. (2011). Macroeconomic Implications of Downward Wage Rigidities. European Central Bank Working Paper Series, N 1321.

[2] Adolfson, M., Laseen, S., Linde, J. and Villani, M. (2007). Bayesian Estimation of an Open Economy DSGE Model with Incomplete Pass-Through. Journal of International Economics, 72(2), pp. 481–511. https://doi.org/10.1016/j.jinteco.2007.01.003

[3] Ball, L. and Mankiw, N. G. (1994). Asymmetric Price Adjustment and Economic Fluctuations. Economic Journal, 104(423), pp. 247–261. https://doi.org/10.2307/2234746

[4] Beltran, D. O. and Draper, D. (2008). Estimating the Parameters of a Small Open Economy DSGE Model: Identifiability and Inferential Validity. Board of Governors of the Federal Reserve System International Finance Discussion Papers, N 955. https://doi.org/10.2139/ssrn.1311887

[5] Bernanke, B. (1990). On the Predictive Power of Interest Rates and Interest Rate Spreads. New England Economic Review, November–December, pp. 51–68.

[6] Calvo, G. A. (1983). Staggered Prices in a Utility-Maximizing Framework. Journal of Monetary Economics, 12(3), pp. 383–398. https://doi.org/10.1016/0304-3932(83)90060-0

[7] Canova, F. (2007). Methods for Applied Macroeconomic Research. Princeton; Oxford: Princeton University Press. https://doi.org/10.2307/j.ctvcm4hrv

[8] Castillo, P. and Montoro, C. (2008). The Asymmetric Effects of Monetary Policy in General Equilibrium. Journal of CENTRUM Cathedra, 1(2), pp. 28–46.

[9] Castillo, P., Montoro, C. and Tuesta, V. (2007). Inflation Premium and Oil Price Volatility. LSE Centre for Economic Performance Discussion Paper, N 782.

[10] Chang, Y., Doh, T. and Schorfheide, F. (2007). Non-Stationary Hours in a DSGE Model. Journal of Money, Credit and Banking, 39(6), pp. 1357–1373. https://doi.org/10.1111/j.1538-4616.2007.00070.x

[11] Chetty, R. and Szeidl, A. (2016). Consumption Commitments and Habit Formation. Econometrica, 84(2), pp. 855–890. https://doi.org/10.3982/ECTA9390

[12] 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. https://doi.org/10.1086/426038

[13] Christiano, L. J., Trabandt, M. and Walentin, K. (2011). Introducing Financial Frictions and Unemployment into a Small Open Economy Model. Journal of Economic Dynamics and Control, 35(12), pp. 1999–2041. https://doi.org/10.1016/j.jedc.2011.09.005

[14] Clarida, R., Galí, J. and Gertler, M. (2000). Monetary Policy Rules and Macroeconomic Stability: Evidence and Some Theory. Quarterly Journal of Economics, 115(1), pp. 147–180. https://doi.org/10.1162/003355300554692

[15] Collard, F. and Juillard, M. (2001). Accuracy of Stochastic Perturbation Methods: The Case of Asset Pricing Models. Journal of Economic Dynamics and Control, 25(6–7), pp. 979–999. https://doi.org/10.1016/S0165-1889(00)00064-6

[16] Cover, J. P. (1992). Asymmetric Effects of Positive and Negative Money-Supply Shocks. Quarterly Journal of Economics, 107(4), pp. 1261–1282. https://doi.org/10.2307/2118388

[17] DeLong, J. B. and Summers, L. H. (1988). How Does Macroeconomic Policy Affect Output? Brookings Papers on Economic Activity, 2, pp. 433–494.

[18] Fehr, E. and Tyran, J. R. (2001). Does Money Illusion Matter? American Economic Review, 91(5), pp. 1239–1262. https://doi.org/10.1257/aer.91.5.1239

[19] Fernández-Villaverde, J. and Rubio-Ramírez, J. F. (2006). A Baseline DSGE Model. [Unpublished manuscript]. https://www.sas.upenn.edu/ jesusfv/benchmark_DSGE.pdf [accessed on 24 January 2021].

[20] Fernández-Villaverde, J., Rubio-Ramírez, J. F. and Schorfheide, F. (2016). Solution and Estimation Methods for DSGE Models. In: J. B. Taylor and H. Uhlig, eds. Handbook for Macroeconomics, Vol. 2. Elsevier, pp. 527–724. https://doi.org/10.1016/bs.hesmac.2016.03.006

[21] Gali, J., Smets, F. and Wouters, R. (2012). Unemployment in an Estimated New Keynesian Model. NBER Macroeconomics Annual 2011, 26, pp. 329–360. https://doi.org/10.1086/663994

[22] Garcia, R. and Schaller, H. (2002). Are the Effects of Monetary Policy Asymmetric? Economic Inquiry, 40(1), pp. 102–119. https://doi.org/10.1093/ei/40.1.102

[23] Grabek, G. and Kłos, B. (2013). Unemployment in the Estimated New Keynesian SoePL-2012 DSGE Model. National Bank of Poland Working Paper, N 144.

[24] Judd, K. (1998). Numerical Methods in Economics. Cambridge, MA: MIT Press.

[25] Justiniano, A., Primiceri, G. E. and Tambalotti, A. (2010). Investment Shocks and Business Cycles. Journal of Monetary Economics, 57(2), pp. 132–145. https://doi.org/10.1016/j.jmoneco.2009.12.008

[26] Karras, G. (1996). Are the Output Effects of Monetary Policy Asymmetric? Evidence from a Sample of European Countries. Oxford Bulletin of Economics and Statistics, 58(2), pp. 267–278. https://doi.org/10.1111/j.1468-0084.1996.mp58002004.x

[27] Kaufmann, S. (2002). Is there an Asymmetric Effect of Monetary Policy Over Time? A Bayesian Analysis Using Austrian data. Empirical Economics, 27(2), pp. 277–297. https://doi.org/10.1007/s001810100099

[28] Kilian, L. and Vigfusson, R. J. (2009). Pitfalls in Estimating Asymmetric Effects of Energy Price Shocks. Board of Governors of the Federal Reserve System International Finance Discussion Papers, N 970. https://doi.org/10.2139/ssrn.1420252

[29] Kilian, L. and Vigfusson, R. J. (2011). Are the Responses of the U.S. Economy Asymmetric in Energy Price Increases and Decreases? Quantitative Economics, 2(3), pp. 419–453. https://doi.org/10.3982/QE99

[30] Kim, J. and Kim, S. H. (2003). Spurious Welfare Reversals in International Business Cycle Models. Journal of International Economics, 60, pp. 471–500. https://doi.org/10.1016/S0022-1996(02)00047-8

[31] Kim, J., Kim, S., Schaumburg, E. and Sims, C. A. (2008). Calculating and Using Second-Order Accurate Solutions of Discrete Time Dynamic Equilibrium Models. Journal of Economic Dynamics and Control, 32(11), pp. 3397–3414. https://doi.org/10.1016/j.jedc.2008.02.003

[32] Laurent, R. D. (1988). An Interest Rate-Based Indicator of Monetary Policy. Economic Perspectives, 12(1), pp. 3–14. https://fraser.stlouisfed.org/title/5288/item/552459/toc/521869 [accessed on 24 January 2021].

[33] Lo, M. C. and Piger, J. (2005). Is the Response of Output to Monetary Policy Asymmetric? Evidence from a Regime-Switching Coefficients Model. Journal of Money, Credit and Banking, 37(5), pp. 865–886.

[34] Morgan, D. P. (1993). Asymmetric Effects of Monetary Policy. Federal Reserve Bank of Kansas City Economic Review, 78(2), pp. 21–33.

[35] Peersman, G. and Smets, F. (2001). Are the Effects of Monetary Policy in the Euro Area Greater in Recessions than in Booms? ECB Working Paper, N 52.

[36] Ravn, M. O. and Sola, M. (1997). Asymmetric Effects if Monetary Policy in the US: Positive vs. Negative or Big vs. Small? Universitat Pompeu Fabra Economics Working Papers, N 247.

[37] Ravn, S. H. (2014). Asymmetric Monetary Policy towards the Stock Market: A DSGE Approach. Journal of Macroeconomics, 39(A), pp. 24–41. https://doi.org/10.1016/j.jmacro.2013.11.002

[38] Schmitt-Grohe, S. and Uribe, M. (2004). Solving Dynamic General Equilibrium Models Using a Second-Order Approximation to the Policy Function. Journal of Economic Dynamics and Control, 28(4), pp. 755–775. https://doi.org/10.1016/S0165-1889(03)00043-5

[39] Schmitt-Grohe, S. and Uribe, M. (2011). Business Cycles with a Common Trend in Neutral and Investment-Specific Productivity. Review of Economic Dynamics, 14(1), pp. 122–135. https://doi.org/10.1016/j.red.2010.07.001

[40] Smets, F. and Wouters, R. (2007). Shocks and Frictions in US Business Cycles: A Bayesian DSGE Approach. American Economic Review, 97(3), pp. 586–606. https://doi.org/10.1257/aer.97.3.586

[41] Weise, C. L. (1999). The Asymmetric Effects of Monetary Policy: A Nonlinear Vector Autoregressive Approach. Journal of Money, Credit and Banking, 31(1), pp. 85–108. https://doi.org/10.2307/2601141

[42] Wen, Y. and Wu, H. (2011). Dynamics of Externalities: A Second-Order Perspective. Federal Reserve Bank of St. Louis Review, 93(3), pp. 187–206. https://doi.org/10.20955/r.93.187-206

[43] Wong, K. (2000). Variability in the Effects of Monetary Policy on Economic Activity. Journal of Money, Credit and Banking, 32(2), pp. 179–198.

12 APPENDICES

12.1 Appendix A. Robustness of empirical results

	Output Growth (Interest Rate Gap), QoQ	Output Growth (Change in Interest Rate), QoQ	Inflation (Interest Rate Gap), QoQ	Inflation (Change in Interest Rate), QoQ
Output Growth (-1),QoQ	0.157^{***} (0.052)	0.142^{***} (0.041)		
Inflation (-1),QoQ			0.189^{***} (0.051)	0.143^{***} (0.032)
$Policy(-1)^{+}$	0.258 (0.182)	-0.998^{***} (0.225)	0.228^{**} (0.100)	0.125^{***} (0.032)
$Policy(-2)^{+}$	-0.844^{***} (0.219)	0.462^{*} (0.251)	0.184^{**} (0.082)	-0.379^{***} (0.086)
$Policy(-3)^{+}$	-0.349^{***} (0.085)	-0.481^{***} (0.192)	-0.518^{***} (0.098)	0.068^{***} (0.019)
$Policy(-4)^{+}$	-0.276^{***} (0.072)	-0.165^{**} (0.076)	-0.571^{***} (0.152)	-0.423^{***} (0.131)
$Policy(-1)^{-}$	-1.168^{***} (0.431)	-0.275 (0.163)	0.301^{***} (0.991)	-0.128^{**} (0.609)
$Policy(-2)^{-}$	0.726^{***} (0.215)	-0.503^{*} (0.282)	-0.988^{**} (0.429)	-0.144 (0.365)
$Policy(-3)^{-}$	1.832^{***} (0.523)	0.520^{***} (0.162)	1.008^{***} (0.299)	0.410^{***} (0.122)
$Policy(-4)^{-}$	-0.964^{**} (0.446)	0.659^{***} (0.215)	0.882^{***} (0.153)	0.814^{***} (0.217)
Constant	1.024^{*} (0.575)	1.108^{**} (0.446)	0.809^{**} (0.346)	0.959^{***} (0.305)
$Sum(Policy^{+})^{1}$	-1.211^{***} (0.348)	-1.182^{***} (0.328)	-0.677^{***} (0.241)	-0.609^{***} (0.212)
$Sum(Policy^{-})^{2}$	0.426^{**} (0.201)	0.401^{*} (0.225)	1.203^{***} (0.355)	0.952^{***} (0.209)
$Sum(Policy^{+})+$ $Sum(Policy^{-})^{3}$	-0.785^{***} (0.269)	-0.781^{***} (0.258)	0.526^{**} (0.239)	0.343^{***} (0.110)
$Policy^{+}=0^{4}$	108.2^{***}	86.9^{***}	95.4^{***}	87.1^{***}
$Policy^{-}=0^{5}$	72.1^{**}	75.3^{**}	109.3^{***}	126.6^{***}
$Policy^{+}+Policy^{-}$=0ˆ6	3.2^{***}	3.4^{***}	2.2^{**}	3.3^{***}

Table 9: Estimation of the output growth and inflation equations
Notes: Standard errors are in parentheses. *,** and *** are significant at 0.1, 0.05 and 0.01, respectively. [1] Sum of the coefficients of contractionary monetary policy.
[2] Sum of the coefficients of expansionary monetary policy.
[3] Sum of the net effect of monetary policy.
[4] Wald test of the hypothesis that the sum of the coefficients of contractionary monetary policy equals zero, χ^2.
[5] Wald test of the hypothesis that the sum of the coefficients of expansionary monetary policy equals zero, χ^2.
[6] t-statistics of the hypothesis that the sum of the coefficients of $Policy^{+}$ and $Policy^{-}$ equals zero.

12.2 Appendix B. Model equations

1. Household first order condition (FOC) with respect to consumption:

$$p_t^c \lambda_c = \frac{\xi_t^c}{C_t - hC_{t-1}} - \frac{\beta h \xi_{t+1}^c}{C_{t+1} - hC_t} \tag{12.2.1}$$

2. Household FOC with respect to capital:

$$\lambda_t = \beta \lambda_{t+1} \frac{R_{t+1}^k}{\pi_{t+1}^d} \tag{12.2.2}$$

3. Household FOC with respect to capital utilization:

$$r_t^k = p_t^{Inv}(\varrho^a \varrho^b u_t + \varrho^b(1 - \varrho^a)) \tag{12.2.3}$$

4. Investment adjustment costs function:

$$\Phi\left(\frac{I_t}{I_{t-1}}\right) = 0.5\left\{e^{\sqrt{S''}\left(\frac{I_t}{I_{t-1}}-1\right)} + e^{-\sqrt{S''}\left(\frac{I_t}{I_{t-1}}-1\right)} - 2\right\} \tag{12.2.4}$$

5. Derivative of investment adjustment costs function with respect to $\frac{I_t}{I_{t-1}}$

$$\Phi'\left(\frac{I_t}{I_{t-1}}\right) = 0.5\sqrt{S''}\left\{e^{\sqrt{S''}\left(\frac{I_t}{I_{t-1}}-1\right)} - e^{-\sqrt{S''}\left(\frac{I_t}{I_{t-1}}-1\right)}\right\} \tag{12.2.5}$$

6. Capital utilization costs:

$$a(u_t) = \frac{1}{2}\varrho_a \varrho_b u_t^2 + \varrho_b(1 - \varrho_a)u_t + \varrho_b(\frac{\varrho_a}{2} - 1), \tag{12.2.6}$$

7. Real return on capital

$$R_{t+1}^k = \frac{\pi_{t+1}^d}{p_t^k}[u_{t+1} r_{t+1}^k - p_{t+1}^{Inv} a(u_{t+1}) + (1 - \delta)p_{t+1}^k] \tag{12.2.7}$$

8. Household FOC with respect to investment:

$$\begin{aligned}\lambda_t p_t^{Inv} = \lambda_t p_t^k \Psi_t \left[1 - \Phi\left(\frac{I_t}{I_{t-1}}\right) - \Phi'\left(\frac{I_t}{I_{t-1}}\right)\frac{I_t}{I_{t-1}}\right] + \\ \beta \lambda_{t+1} p_{t+1}^k \Psi_{t+1} \Phi'\left(\frac{I_{t+1}}{I_t}\right)\left[\frac{I_{t+1}}{I_t}\right]^2\end{aligned} \tag{12.2.8}$$

9. Capital accumulation equation:

$$\bar{K}_{t+1} = (1 - \delta)\bar{K}_t + \Psi_t\left[1 - \Phi\left(\frac{I_t}{I_{t-1}}\right)\right] I_t \tag{12.2.9}$$

10. Utilized capital:
$$K_t = u_t \bar{K}_t \tag{12.2.10}$$

11. Household FOC with respect to domestic bonds:
$$\lambda_t = \beta \lambda_{t+1} \frac{R_t}{\pi^d_{t+1}} \tag{12.2.11}$$

12. Household FOC with respect to foreign bonds:
$$\lambda_t = \beta \lambda_{t+1} \frac{\Delta E_{t+1} R^*_t \Omega_t}{\pi^d_{t+1}} \tag{12.2.12}$$

13. Production function:
$$Y_t = \tilde{p}_t^{d^{\varepsilon_d}} (Z_t K_t^\alpha N_t^{(1-\alpha)} - X) \tag{12.2.13}$$

14. Marginal costs in the domestic intermediate good production sector:
$$mc^d_t = \frac{\tau^d_t}{Z_t} \left(\frac{1}{\alpha}\right)^\alpha \left(\frac{1}{1-\alpha}\right)^{1-\alpha} (r^k_t)^\alpha (w_t)^{1-\alpha} \tag{12.2.14}$$

15. Capital-labor ratio equation:
$$mc^d_t = \frac{\tau^d_t w_t}{(1-\alpha) Z_t \left(\frac{K_t}{N_t}\right)^\alpha} \tag{12.2.15}$$

16. First auxiliary variable of the intermediate good Phillips curve:
$$X^d_{2,t} = \lambda_t Y_t + \beta \theta^d (\pi_{t+1})^{\varepsilon_d - 1} X^d_{2,t+1} \tag{12.2.16}$$

17. Second auxiliary variable of the intermediate good Phillips curve:
$$X^d_{1,t} = \frac{\varepsilon_d}{\varepsilon_d - 1} \lambda_t Y_t mc^d_t + \beta \theta^d (\pi_{t+1})^{\varepsilon_d} X^d_{1,t+1} \tag{12.2.17}$$

18. Optimal ratio in the price setting of intermediate goods:
$$\frac{X^d_{1,t}}{X^d_{2,t}} = \left[\frac{1 - \theta^d (\pi_t)^{1-\varepsilon_d}}{1 - \theta^d}\right]^{\frac{1}{1-\varepsilon_d}} \tag{12.2.18}$$

19. Price distortion in the intermediate good production sector:
$$\tilde{p}_t = \left[(1-\theta^d)\left(\frac{1 - \theta^d (\pi_t)^{\varepsilon_d - 1}}{1 - \theta^d}\right)^{\frac{\varepsilon_d}{\varepsilon_d - 1}} + \theta^d \left(\frac{\tilde{p}_{t-1}}{\pi_t}\right)^{-\varepsilon_d}\right]^{-\frac{1}{\varepsilon_d}} \tag{12.2.19}$$

20. First auxiliary variable of imported consumption good Phillips curve:

$$X_{2,t}^{c,Imp} = \lambda_t C_t^{Imp} p_t^{c,Imp} + \beta \theta^{c,Imp} (\pi_{t+1}^{c,Imp})^{\varepsilon_{c,Imp}-1} X_{2,t+1}^{c,Imp} \tag{12.2.20}$$

21. Second auxiliary variable of imported consumption good Phillips curve:

$$X_{1,t}^{c,Imp} = \frac{\varepsilon_{c,Imp}}{\varepsilon_{c,Imp}-1} \lambda_t C_t^{Imp} p_t^{c,Imp} mc_t^{c,Imp} + \beta \theta^{c,Imp} (\pi_{t+1}^{c,Imp})^{\varepsilon_{c,Imp}} X_{1,t+1}^{c,Imp} \tag{12.2.21}$$

22. Optimal ratio in the price setting of imported consumption goods:

$$\frac{X_{1,t}^{c,Imp}}{X_{2,t}^{c,Imp}} = \left[\frac{1 - \theta^{c,Imp} (\pi_t^{c,Imp})^{1-\varepsilon_{c,Imp}}}{1 - \theta^{c,Imp}} \right]^{\frac{1}{1-\varepsilon_{c,Imp}}} \tag{12.2.22}$$

23. Price distortion of imported consumption goods:

$$\tilde{p}_t^{c,Imp} = \left[(1 - \theta^{c,Imp}) \left(\frac{1 - \theta^{c,Imp} (\pi_t^{c,Imp})^{\varepsilon_{c,Imp}-1}}{1 - \theta^{c,Imp}} \right)^{\frac{\varepsilon_{c,Imp}}{\varepsilon_{c,Imp}-1}} + \theta^{c,Imp} \left(\frac{\tilde{p}_{t-1}^{c,Imp}}{\pi_t^{c,Imp}} \right)^{-\varepsilon_{c,Imp}} \right]^{-\frac{1}{\varepsilon_{c,Imp}}} \tag{12.2.23}$$

24. Import of consumption goods:

$$C_t^{Imp} = \gamma_c \left(\frac{p_t^c}{p_t^{c,Imp}} \right)^{\eta_c} C_t \tag{12.2.24}$$

25. Marginal cost of imported consumption goods:

$$mc_t^{c,Imp} = \frac{\tau_t^{c,Imp} q_t p_t^c}{p_t^{c,Imp}} \tag{12.2.25}$$

26. First auxiliary variable of imported investment good Phillips curve:

$$X_{2,t}^{Inv,Imp} = \lambda_t I_t^{Imp} p_t^{c,Imp} + \beta \theta^{Inv,Imp} (\pi_{t+1}^{Inv,Imp})^{\varepsilon_{Inv,Imp}-1} X_{2,t+1}^{Inv,Imp} \tag{12.2.26}$$

27. Second auxiliary variable of imported investment good Phillips curve:

$$X_{1,t}^{Inv,Imp} = \frac{\varepsilon_{Inv,Imp}}{\varepsilon_{Inv,Imp}-1} \lambda_t I_t^{Imp} p_t^{Inv,Imp} mc_t^{Inv,Imp} + \beta \theta^{Inv,Imp} (\pi_{t+1}^{Inv,Imp})^{\varepsilon_{Inv,Imp}} X_{1,t+1}^{Inv,Imp} \tag{12.2.27}$$

28. Price distortion of imported investment goods:

$$\tilde{p}_t^{Inv,Imp} = \left[(1 - \theta^{Inv,Imp}) \left(\frac{1 - \theta^{Inv,Imp} (\pi_t^{Inv,Imp})^{\varepsilon_{Inv,Imp}-1}}{1 - \theta^{Inv,Imp}} \right)^{\frac{\varepsilon_{Inv,Imp}}{\varepsilon_{Inv,Imp}-1}} + \theta^{Inv,Imp} \left(\frac{\tilde{p}_{t-1}^{Inv,Imp}}{\pi_t^{Inv,Imp}} \right)^{-\varepsilon_{Inv,Imp}} \right]^{-\frac{1}{\varepsilon_{Inv,Imp}}} \tag{12.2.28}$$

29. Optimal ratio in the price setting of imported investment goods:

$$\frac{X_{1,t}^{Inv,Imp}}{X_{2,t}^{Inv,Imp}} = \left[\frac{1-\theta^{Inv,Imp}(\pi_t^{Inv,Imp})^{1-\varepsilon_{Inv,Imp}}}{1-\theta^{Inv,Imp}}\right]^{\frac{1}{1-\varepsilon_{Inv,Imp}}} \tag{12.2.29}$$

30. Marginal cost of imported investment goods:

$$mc_t^{Inv,Imp} = \frac{\tau_t^{Inv,Imp} q_t p_t^c}{p_t^{Inv,Imp}} \tag{12.2.30}$$

31. Import of investment goods:

$$I_t^{Imp} = \gamma_{Inv}\left(\frac{p_t^{Inv}}{p_t^{Inv,Imp}}\right)^{\eta_{Imp}}[I_t + a(u_t)\bar{K}_t] \tag{12.2.31}$$

32. First auxiliary variable of the imported goods used in the export sector Phillips curve:

$$X_{2,t}^{Exp,Imp} = \lambda_t Exp_t^{Imp} p_t^{Exp,Imp} + \beta\theta^{Exp,Imp}(\pi_{t+1}^{Exp,Imp})^{\varepsilon_{Exp,Imp}-1} X_{2,t+1}^{Exp,Imp} \tag{12.2.32}$$

33. Second auxiliary variable of the imported goods used in the export sector Phillips curve:

$$X_{1,t}^{Exp,Imp} = \frac{\varepsilon_{Exp,Imp}}{\varepsilon_{Exp,Imp}-1}\lambda_t Exp_t^{Imp} p_t^{Exp,Imp} mc_t^{Exp,Imp} + \beta\theta^{Exp,Imp}(\pi_{t+1}^{Exp,Imp})^{\varepsilon_{Exp,Imp}} X_{1,t+1}^{Exp,Imp} \tag{12.2.33}$$

34. Optimal ratio in price setting of imported goods used in the export sector:

$$\frac{X_{1,t}^{Exp,Imp}}{X_{2,t}^{Exp,Imp}} = \left[\frac{1-\theta^{Exp,Imp}(\pi_t^{Exp,Imp})^{\varepsilon_{Exp,Imp}}}{1-\theta^{Exp,Imp}}\right]^{\frac{1}{1-\varepsilon_{Exp,Imp}}} \tag{12.2.34}$$

35. Price distortion of imported goods used in the export sector:

$$\tilde{p}_t^{Exp,Imp} = \left[(1-\theta^{Exp,Imp})\left(\frac{1-\theta^{Exp,Imp}(\pi_t^{Exp,Imp})^{\varepsilon_{Exp,Imp}-1}}{1-\theta^{Exp,Imp}}\right)^{\frac{\varepsilon_{Exp,Imp}}{\varepsilon_{Exp,Imp}-1}} + \theta^{Exp,Imp}\left(\frac{\tilde{p}_{t-1}^{Exp,Imp}}{\pi_t^{Exp,Imp}}\right)^{-\varepsilon_{Exp,Imp}}\right]^{-\frac{1}{\varepsilon_{Exp,Imp}}} \tag{12.2.35}$$

36. Marginal cost of imported goods used in the export sector:

$$mc_t^{Exp,Imp} = \frac{\tau_t^{Exp,Imp} q_t p_t^c}{p_t^{Exp,Imp}} \tag{12.2.36}$$

37. Import of goods used in the export sector:

$$Imp_t^{Exp} = \gamma_{Exp}\left[\frac{(\gamma_{Exp}(p_t^{Exp,Imp})^{(1-\eta_{Exp})}+1-\gamma_{Exp})^{\frac{1}{1-\eta_{Exp}}}}{p_t^{Exp,Imp}}\right]^{\eta_{Exp}}(\tilde{p}_t^{Exp})^{-\varepsilon_{Exp}}(p_t^{Exp})^{-\eta_f}Y_t^* \quad (12.2.37)$$

38. First auxiliary variable of export Phillips curve:

$$X_{2,t}^{Exp} = \lambda_t q_t p_t^c p_t^x Exp_t + \beta\theta^{Exp}(\pi_{t+1}^{Exp})^{\varepsilon_{Exp}-1}X_{2,t+1}^{Exp} \quad (12.2.38)$$

39. Second auxiliary variable of export Phillips curve:

$$X_{1,t}^{Exp} = \frac{\varepsilon_{Exp}}{\varepsilon_{Exp}-1}\lambda_t q_t p_t^c p_t^x Exp_t mc_t^{Exp} + \beta\theta^{Exp}(\pi_{t+1}^{Exp})^{\varepsilon_{Exp}}X_{1,t+1}^{Exp} \quad (12.2.39)$$

40. Optimal ratio in price setting of the export sector:

$$\frac{X_{1,t}^{Exp}}{X_{2,t}^{Exp}} = \left[\frac{1-\theta^{Exp}(\pi_t^{Exp})^{\varepsilon_{Exp}}}{1-\theta^{Exp}}\right]^{\frac{1}{1-\varepsilon_{Exp}}} \quad (12.2.40)$$

41. Price distortion of imported goods used in the export sector:

$$\tilde{p}_t^{Exp} = \left[(1-\theta^{Exp})\left(\frac{1-\theta^{Exp}(\pi_t^{Exp})^{\varepsilon_{Exp}-1}}{1-\theta^{Exp}}\right)^{\frac{\varepsilon_{Exp}}{\varepsilon_{Exp}-1}} + \right.$$
$$\left. +\theta^{Exp}\left(\frac{\tilde{p}_{t-1}^{Exp}}{\pi_t^{Exp}}\right)^{-\varepsilon_{Exp}}\right]^{-\frac{1}{\varepsilon_{Exp}}} \quad (12.2.41)$$

42. Marginal cost of exporters:

$$mc_t^{Exp,Imp} = \frac{\tau_t^{Exp}}{q_t p_t^c p_t^x}[\gamma_{Exp}(p_t^{Exp,Imp})^{1-\eta_x}+1-\gamma_{Exp}]^{\frac{1}{1-\eta_x}} \quad (12.2.42)$$

43. Foreign demand for domestic exports:

$$Exp_t = (p_t^x)^{-\eta_f}Y_t^* \quad (12.2.43)$$

44. Market clearing condition:

$$Y_t = (1-\gamma_c)(p_t^c)^{\eta_c}C_t + (1-\gamma_{Inv})(p_t^{Inv})^{\eta_{Imp}}[I_c + a(u_t)\bar{K}_t] + G_t$$
$$+(1-\gamma_{Exp})[\gamma_{Exp}(p_t^{Exp,Imp})^{1-\eta_x}+1-\gamma_{Exp}]^{\frac{\eta_x}{1-\eta_x}}(\tilde{p}_t^{Exp})^{-\varepsilon_{Exp}}(p_t^x)^{-\eta_f}Y_t^* \quad (12.2.44)$$

45. Definition of GDP:

$$GDP_t = Y_t - (1-\gamma_{Inv})(p_t^{Inv})^{\eta_{Imp}} a(u_t)\bar{K}_t \tag{12.2.45}$$

46. Relative price of imported consumption goods:

$$\frac{p_t^{c,Imp}}{p_{t-1}^{c,Imp}} = \frac{\pi_t^{c,Imp}}{\pi_t^d} \tag{12.2.46}$$

47. Relative price of imported investment goods:

$$\frac{p_t^{Inv,Imp}}{p_{t-1}^{Inv,Imp}} = \frac{\pi_t^{Inv,Imp}}{\pi_t^d} \tag{12.2.47}$$

48. Relative price of imported goods used in the export sector:

$$\frac{p_t^{Exp,Imp}}{p_{t-1}^{Exp,Imp}} = \frac{\pi_t^{Exp,Imp}}{\pi_t^d} \tag{12.2.48}$$

49. Relative price of exported goods:

$$\frac{p_t^{Exp}}{p_{t-1}^{Exp}} = \frac{\pi_t^{Exp}}{\Delta E_t \pi_t^*} \tag{12.2.49}$$

50. Definition of real exchange rate:

$$\frac{q_t}{q_{t-1}} = \frac{\Delta E_t \pi_t^*}{\pi_t^c} \tag{12.2.50}$$

51. Relative price of final consumption goods:

$$p_t^c = [1-\gamma_c + \gamma_c (p_t^{c,Imp})^{1-\eta_c}]^{\frac{1}{1-\eta_c}} \tag{12.2.51}$$

52. Relative price of investment goods:

$$p_t^{Inv} = [1-\gamma_{Inv} + \gamma_{Inv} (p_t^{Inv,Imp})^{1-\eta_{Inv}}]^{\frac{1}{1-\eta_{Inv}}} \tag{12.2.52}$$

53. Inflation of consumption goods:

$$\pi_t^c = \pi_t^d \left[\frac{1-\gamma_c + \gamma_c (p_t^{c,Imp})^{1-\eta_c}}{1-\gamma_c + \gamma_c (p_{t-1}^{c,Imp})^{1-\eta_c}}\right]^{\frac{1}{1-\eta_c}} \tag{12.2.53}$$

54. Inflation of investment goods:

$$\pi_t^{Inv} = \pi_t^d \left[\frac{1-\gamma_{Inv} + \gamma_{Inv} (p_t^{Inv,Imp})^{1-\eta_{Inv}}}{1-\gamma_{Inv} + \gamma_{Inv} (p_{t-1}^{Inv,Imp})^{1-\eta_{Inv}}}\right]^{\frac{1}{1-\eta_{Inv}}} \tag{12.2.54}$$

55. First auxiliary variable of wage Phillips curve:

$$X_{2,t}^{w} = \frac{\lambda_t}{\lambda_w}(\tilde{w}_t)^{\varepsilon_w} n_t + \beta\theta^w X_{2,t+1}^{w}\left(\frac{w_{t+1}}{w_t}\right)(\pi_{t+1}^{w})^{\varepsilon_w - 1} \tag{12.2.55}$$

56. Second auxiliary variable of wage Phillips curve:

$$X_{1,t}^{w} = \xi_t^n((\tilde{w}_t)^{\varepsilon_w} n_t)^{1+\varphi} + \beta\theta^w X_{1,t+1}^{w}(\pi_{t+1}^{w})^{\varepsilon_w(1+\varphi)} \tag{12.2.56}$$

57. Optimal ratio in wage setting:

$$\frac{X_{1,t}^{w}}{X_{2,t}^{w}} = w_t\left[\frac{1-\theta^w(\pi_t^w)^{1-\varepsilon_w}}{1-\theta^w}\right]^{1-\frac{\varepsilon_w}{\varepsilon_w - 1}(1+\varphi)} \tag{12.2.57}$$

58. Wage distortion in labour market:

$$\tilde{w}_t = \left[(1-\theta^w)\left(\frac{1-\theta^w(\pi_t^w)^{\varepsilon_w - 1}}{1-\theta^w}\right)^{\frac{\varepsilon_w}{\varepsilon_w - 1}} + \theta^w\left(\frac{\tilde{w}_{t-1}}{\pi_t^w}\right)^{-\varepsilon_w}\right]^{-\frac{1}{\varepsilon_w}} \tag{12.2.58}$$

59. Change of the nominal wage:

$$\pi_t^W = \frac{w_t\pi_t^d}{w_{t-1}} \tag{12.2.59}$$

60. Relationship between labour supply and labour input in the production function:

$$N_t = (\tilde{w}_t)^{\varepsilon_W} n_t \tag{12.2.60}$$

61. Aggregate Import equation:

$$\begin{aligned} Imp_t = q_t p_t^c (C_t^{Imp}(\tilde{p}^{C,Imp})^{-\varepsilon_{C,Imp}} + I_t^{Imp}(\tilde{p}_t^{Inv,Imp})^{-\varepsilon_{Inv,Imp}} + \\ Exp_t^{Imp}(\tilde{p}_t^{Exp,Imp})^{-\varepsilon_{Exp,Imp}}) \end{aligned} \tag{12.2.61}$$

62. Taylor rule:

$$\frac{R_t}{R^{ss}} = \rho_R\frac{R_{t-1}}{R^{ss}} + (1-\rho_R)\left[\mu_\pi\frac{\pi_{t+1}^c}{\pi^{target}} + \mu_{gdp}\frac{GDP_t}{GDP^{ss}}\right] + \sigma_t^R \tag{12.2.62}$$

63. Price mark-up shock of domestic intermediate goods:

$$\tau_t^d = \rho_{\tau^d}\tau_{t-1}^d + \sigma_t^{\tau^d} \tag{12.2.63}$$

64. Price mark-up shock of imported consumption goods:

$$\tau_t^{c,Imp} = \rho_{\tau^{c,Imp}}\tau_{t-1}^{c,Imp} + \sigma_t^{\tau^{c,Imp}} \tag{12.2.64}$$

65. Price mark-up shock of imported investment goods:

$$\tau_t^{Inv,Imp} = \rho_{\tau^{Inv,Imp}} \tau_{t-1}^{Inv,Imp} + \sigma_t^{\tau^{Inv,Imp}} \tag{12.2.65}$$

66. Price mark-up shock of imported goods used in the export sector:

$$\tau_t^{Exp,Imp} = \rho_{\tau^{Exp,Imp}} \tau_{t-1}^{Exp,Imp} + \sigma_t^{\tau^{Exp,Imp}} \tag{12.2.66}$$

67. Price mark-up shock of exported goods:

$$\tau_t^{Exp} = \rho_{\tau^{Exp}} \tau_{t-1}^{Exp} + \sigma_t^{\tau^{Exp}} \tag{12.2.67}$$

68. AR(1) process for productivity:

$$Z_t = \rho_Z Z_{t-1} + \sigma_t^Z \tag{12.2.68}$$

69. Consumption preference shock:

$$\xi_t^c = \rho_{\xi^c} \xi_{t-1}^c + \sigma_t^{\xi^c} \tag{12.2.69}$$

70. Labour supply shock:

$$\xi_t^n = \rho_{\xi^n} \xi_{t-1}^n + \sigma_t^{\xi^n} \tag{12.2.70}$$

71. Government spending:

$$G_t = \rho_G G_{t-1} + (1 - \rho_G) G^{ss} + \sigma_t^G \tag{12.2.71}$$

72. Marginal efficiency of investment:

$$\Psi_t = \rho_\Psi \Psi_{t-1} + \sigma_t^\Psi \tag{12.2.72}$$

73. Risk premium shock:

$$\Omega_t = \rho_\Omega \Omega_{t-1} + \sigma_t^\Omega \tag{12.2.73}$$

74. Foreign inflation:

$$\pi_t^* = \rho_{\pi^*} \pi_{t-1}^* + \sigma_t^{\pi^*} \tag{12.2.74}$$

75. Foreign demand:

$$Y_t^* = \rho_{Y^*} Y_{t-1}^* + (1 - \rho_{Y^*}) Y^{*,ss} + \sigma_t^{Y^*} \tag{12.2.75}$$

76. Foreign interest rate:

$$R_t^* = \rho_{R^*} R_{t-1}^* + (1 - \rho_{R^*}) R^{*,ss} + \sigma_t^{R^*} \tag{12.2.76}$$

Linking observables to the model equations (77–91):

77. GDP:

$$dlGDP_t = GDP_t - GDP_{t-1} \tag{12.2.77}$$

78. Real private consumption:

$$dlCons_t = C_t - C_{t-1} \tag{12.2.78}$$

79. Real private invesmtent:

$$dlInv_t = I_t - I_{t-1} \tag{12.2.79}$$

80. Real exports:

$$dlExport_t = Exp_t - Exp_{t-1} \tag{12.2.80}$$

81. Real imports:

$$dlImport_t = Imp_t - Imp_{t-1} \tag{12.2.81}$$

82. Government spending:

$$dlGov_t = G_t - G_{t-1} \tag{12.2.82}$$

83. Real wages:

$$dlWage_t = w_t - w_{t-1} \tag{12.2.83}$$

84. Real effective exchange rate:

$$dlREER_t = q_t - q_{t-1} \tag{12.2.84}$$

85. Interest rate:

$$IntRate_t = R_t \tag{12.2.85}$$

86. Inflation:

$$dlCPI_t = \pi_t^c + \pi^{target} - 1 \tag{12.2.86}$$

87. GDP deflator:

$$dlGDPDefl_t = \pi_t^d \tag{12.2.87}$$

88. Investment deflator:

$$dlINVDefl_t = \pi_t^{Inv} \tag{12.2.88}$$

89. Foreign demand:

$$dlGDPStar_t = Y_t^* - Y_{t-1}^* \tag{12.2.89}$$

90. Foreign inflation:

$$dlCPIStar_t = \pi_t^* \tag{12.2.90}$$

91. Foreign interest rate:

$$IntRateStar_t = R_t^* \tag{12.2.91}$$

12.3 Appendix C. First-order approximation of investment adjustment cost

The investment adjustment cost function is given in the following form:

$$\Phi\left(\frac{I_t}{I_{t-1}}\right) = 0.5\left\{e^{\sqrt{S''}\left(\frac{I_t}{I_{t-1}}-1\right)} + e^{-\sqrt{S''}\left(\frac{I_t}{I_{t-1}}-1\right)} - 2\right\}. \tag{12.3.1}$$

The first-order approximation of the $f(I_t, I_{t-1})$ function is calculated by the following:

$$f(I_t, I_{t-1}) = f(I^{ss}, I^{ss}) + f_{I_t}(I^{ss}, I^{ss})(I_t - I^{ss}) + f_{I_{t-1}}(I^{ss}, I^{ss})(I_{t-1} - I^{ss}) + [O^2] \tag{12.3.2}$$

where $f(I^{ss}, I^{ss})$ is the value of the function in a steady state, $f_{I_t}(I^{ss}, I^{ss})$ is the first-order derivative of function $f(I_t, I_{t-1})$ with respect to I_t at $I_t = I^{ss}$ and $I_{t-1} = I^{ss}$. $f_{t-1}(I^{ss}, I^{ss})$ is the derivative of $f(I_t, I_{t-1})$ with respect to I_{t-1}. $[O^2]$ includes second and higher order terms. At the first order, we assume that the higher order terms are zero.

We apply the above formula of the first order Taylor approximation to the investment adjustment cost function used in the model.

$$\begin{aligned}\Phi\left(\frac{I_t}{I_{t-1}}\right) &= 0.5e^{\sqrt{S''}\left(\frac{I^{ss}}{I^{ss}}-1\right)} + 0.5e^{-\sqrt{S''}\left(\frac{I^{ss}}{I^{ss}}-1\right)} - 1 + 0.5e^{\sqrt{S''}\left(\frac{I^{ss}}{I^{ss}}-1\right)} + \\ &+0.5e^{\sqrt{S''}\left(\frac{I^{ss}}{I^{ss}}-1\right)}\frac{\sqrt{S''}}{I^{ss}}(I_t - I^{ss}) + 0.5e^{\sqrt{S''}\left(\frac{I^{ss}}{I^{ss}}-1\right)}\left(-\frac{\sqrt{S''}I^{ss}}{((I^{ss})^2}\right)(I_{t-1} - I^{ss}) + \\ &+0.5e^{-\sqrt{S''}\left(\frac{I^{ss}}{I^{ss}}-1\right)}\left(-\frac{\sqrt{S''}}{I^{ss}}\right)(I_t - I^{ss}) + 0.5e^{-\sqrt{S''}\left(\frac{I^{ss}}{I^{ss}}-1\right)}\left(\frac{\sqrt{S''}I^{ss}}{(I^{ss})^2}\right)(I_{t-1} - I^{ss})\end{aligned}$$

Some simplification yields the following:

$$\begin{aligned}\Phi\left(\frac{I_t}{I_{t-1}}\right) &= 0.5e^0 + 0.5e^0 - 1 + 0.5e^0\sqrt{S''}\left(\frac{I_t - I^{ss}}{I^{ss}}\right) - 0.5e^0\sqrt{S''}\left(\frac{I_{t-1} - I^{ss}}{I^{ss}}\right) - \\ &-0.5e^0\sqrt{S''}\left(\frac{I_t - I^{ss}}{I^{ss}}\right) + 0.5e^0\sqrt{S''}\left(\frac{I_{t-1} - I^{ss}}{I^{ss}}\right)\end{aligned}$$

Further simplification gives:

$$\begin{aligned}\Phi\left(\frac{I_t}{I_{t-1}}\right) &= 0.5 + 0.5 - 1 + 0.5\sqrt{S''}\left(\frac{I_t - I^{ss}}{I^{ss}}\right) - 0.5\sqrt{S''}\left(\frac{I_t - I^{ss}}{I^{ss}}\right) + \\ &+0.5\sqrt{S''}\left(\frac{I_{t-1} - I^{ss}}{I^{ss}}\right) - 0.5\sqrt{S''}\left(\frac{I_{t-1} - I^{ss}}{I^{ss}}\right)\end{aligned}$$

All terms cancel each other, and we have zero value of investment adjustment costs by applying the first order approximation.

$$\Phi\left(\frac{I_t}{I_{t-1}}\right) = 0$$

12.4 Appendix D. Input data for the estimation of DSGE

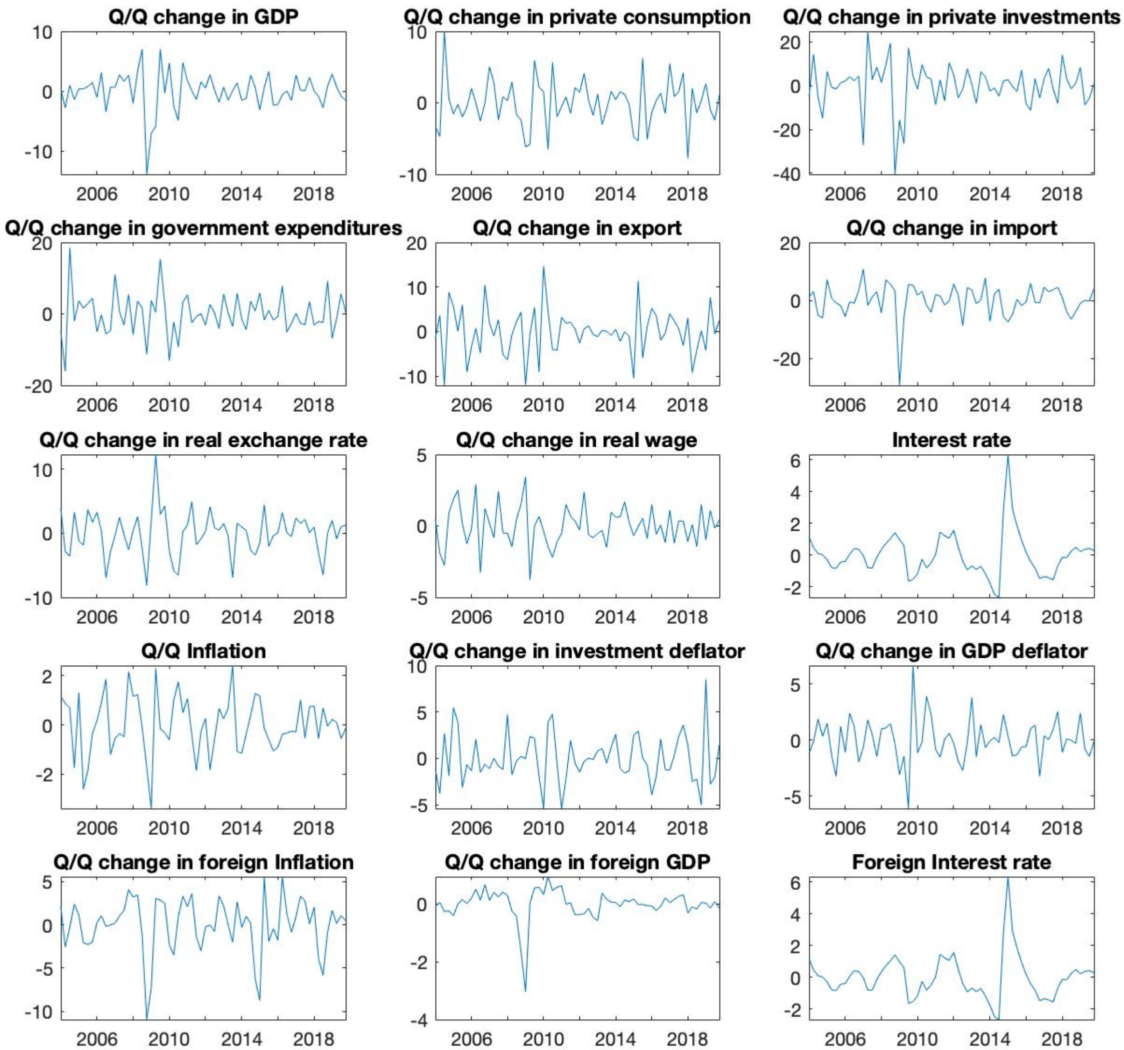

Figure 5: Model input data

12.5 Appendix E. Calibration and estimation results

Parameters	Description	Values
β	Discount factor	0.99
γ_c	Share of imported goods in consumption	0.35
γ_{Inv}	Share of imported goods in investment	0.3
γ_{Exp}	Share of imported inputs in exports	0.3
ε_d	Elasticity of substitution between varieties of domestically produced goods	6.0
$\varepsilon_{c,Imp}$	Elasticity of substitution between varieties of imported consumption goods	6.0
$\varepsilon_{Inv,Imp}$	Elasticity of substitution between varieties of imported investment goods	6.0
$\varepsilon_{Exp,Imp}$	Elasticity of substitution between varieties of imported goods used in export sector	6.0
ε_{Exp}	Elasticity of substitution between varieties of exported goods	6.0
δ	Depreciation rate of capital	0.025
α	Share of capital in production function	0.57
G^{ss}	Share of government expenditures in GDP	0.165
π^{target}	Inflation target	1.0097

Table 10: Calibrated parameters

	Description	Prior mean	Posterior mean	5%	95%	Prior distribution	Prior standard deviation
θ^{d}	Price stickiness coefficient of home-produced goods	0.75	0.91	0.88	0.93	Beta	0.075
$\theta^{c,Imp}$	Price stickiness coefficient of imported consumption	0.75	0.62	0.51	0.73	Beta	0.075
$\theta^{Inv,Imp}$	Price stickiness coefficient of imported investment goods	0.75	0.52	0.41	0.65	Beta	0.075
$\theta^{Exp,Imp}$	Price stickiness coefficient of imported goods used in export sector	0.75	0.45	0.33	0.57	Beta	0.075
θ^{Exp}	Price stickiness coefficient of exported goods	0.75	0.65	0.56	0.76	Beta	0.075
θ^{w}	Wage stickiness coefficient	0.75	0.82	0.74	0.89	Beta	0.075
η_c	Elasticity of substitution between domestic and imported consumption goods	2.0	0.76	0.51	1.00	Gamma	0.45
η_{Inv}	Elasticity of substitution between domestic and imported investment goods	2.0	0.71	0.48	0.92	Gamma	0.45
η_f	Elasticity of exports	2.0	1.01	0.69	1.32	Gamma	0.45
η_x	Elasticity of substitution between domestic and imported inputs in export sector	2.0	1.56	1.13	1.98	Gamma	0.45
φ	Inverse elasticity of labor supply	2.0	1.84	1.38	2.29	Gamma	0.3
hab	Habit parameter	0.5	0.42	0.31	0.52	Beta	0.1
$S^{''}$	Investment adjustment costs parameter	9.0	5.13	1.53	8.52	Gamma	2.8
ϱ^{a}	Parameter in capital utilization	0.2	0.15	0.06	0.24	Gamma	0.075
$\lambda_w = \frac{\varepsilon_w}{\varepsilon_w - 1}$	Mark-up on wages	1.3	1.22	1.04	1.39	Gamma	0.15
ρ_R	Persistence coefficient in Taylor rule	0.7	0.69	0.61	0.76	Beta	0.12
μ_π	Reaction of interest rate to inflation expectations in Taylor rule	1.5	1.59	1.20	1.97	Gamma	0.25
μ_{gdp}	Reaction of interest rate to deviation of output from steady state	0.25	0.18	0.13	0.24	Gamma	0.05

Table 11: Prior and posterior distributions of structural parameters

	Description	Prior mean	Posterior mean	5%	95%	Prior distribution	Prior standard deviation
ρ_{ξ^c}	Consumption preference	0.80	0.59	0.45	0.73	Beta	0.085
ρ_{ξ^n}	Labor supply	0.80	0.53	0.36	0.69	Beta	0.085
ρ_z	Productivity	0.80	0.39	0.29	0.49	Beta	0.085
ρ_ψ	Marginal efficiency of investment	0.80	0.36	0.26	0.46	Beta	0.085
ρ_G	Government spending	0.80	0.62	0.49	0.76	Beta	0.085
ρ_Ω	Risk premium	0.80	0.68	0.55	0.81	Beta	0.085
ρ_{τ^d}	Price mark-up of domestic intermediate goods	0.80	0.44	0.33	0.56	Beta	0.085
$\rho_{\tau^{c,Imp}}$	Price mark-up of imported consumption goods	0.80	0.52	0.37	0.67	Beta	0.085
$\rho_{\tau^{Inv,Imp}}$	Price mark-up of imported investment goods	0.80	0.51	0.38	0.65	Beta	0.085
$\rho_{\tau^{Exp,Imp}}$	Price mark-up of imported goods used in export sector	0.80	0.45	0.30	0.59	Beta	0.085
$\rho_{\tau^{Exp}}$	Price mark-up of exported goods	0.80	0.56	0.40	0.72	Beta	0.085
ρ_{Y^*}	Foreign demand	0.80	0.84	0.77	0.92	Beta	0.085
ρ_{π^*}	Foreign inflation	0.80	0.28	0.21	0.36	Beta	0.085
ρ_{R^*}	Foreign interest rate	0.80	0.62	0.51	0.73	Beta	0.085

Table 12: Prior and posterior distribution of shocks' autoregressive parameters

	Description	Prior mean	Posterior mean	5%	95%	Prior distribution	Prior standard deviation
σ^{ξ^c}	Consumption preference	0.4	5.94	4.61	7.28	Inverse gamma	5.0
σ^{ξ^n}	Labour supply	2.4	264.21	118.05	406.07	Inverse gamma	10.0
σ^{Z}	Productivity	0.4	31.63	26.42	36.76	Inverse gamma	5.0
σ^{ψ}	Marginal efficiency of Investment	0.4	44.76	15.08	73.91	Inverse gamma	5.0
σ^{G}	Government spending	0.4	5.02	4.27	5.75	Inverse gamma	5.0
σ^{Ω}	Risk premium	0.4	1.48	0.89	2.05	Inverse gamma	5.0
σ^{R}	Monetary policy	0.4	0.96	0.82	1.09	Inverse gamma	5.0
σ^{τ^d}	Price mark-up of domestic intermediate goods	2.4	151.61	71.43	221.62	Inverse gamma	10.0
$\sigma^{\tau^{c,Imp}}$	Price mark-up of imported consumption goods	2.4	19.54	9.28	29.66	Inverse gamma	10.0
$\sigma^{\tau^{Inv,Imp}}$	Price mark-up of imported investment goods	2.4	32.84	17.92	48.32	Inverse gamma	10.0
$\sigma^{\tau^{Exp,Imp}}$	Price mark-up of imported goods used in export sector	2.4	83.97	43.52	124.72	Inverse gamma	10.0
$\sigma^{\tau^{Exp}}$	Price mark-up of exported goods	2.4	35.94	17.39	54.27	Inverse gamma	10.0
σ^{Y^*}	Foreign demand	0.4	0.52	0.44	0.59	Inverse gamma	5.0
ρ_{π^*}	Foreign inflation	0.4	3.00	2.56	3.43	Inverse gamma	5.0
σ^{R^*}	Foreign interest rate	0.4	0.42	0.36	0.48	Inverse gamma	5.0

Table 13: Prior and posterior distribution of shocks' standard errors

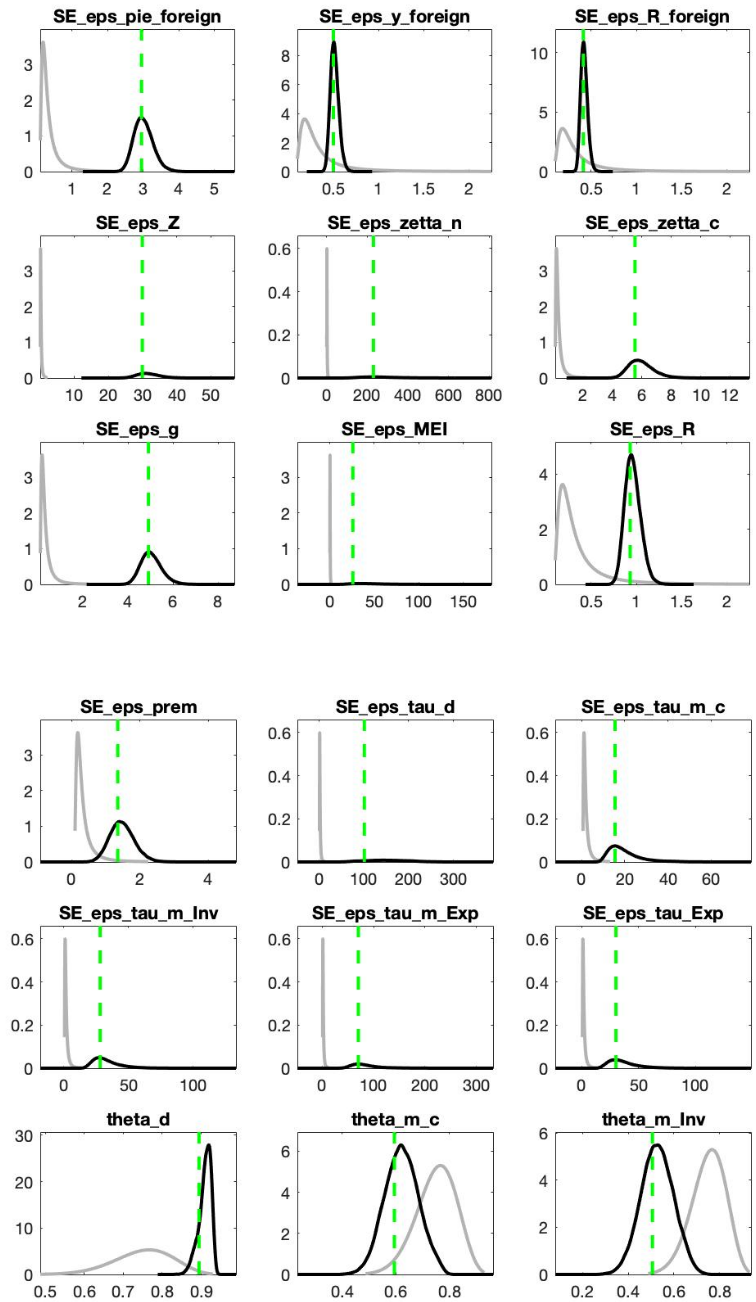

Figure 6: Prior and posterior distributions

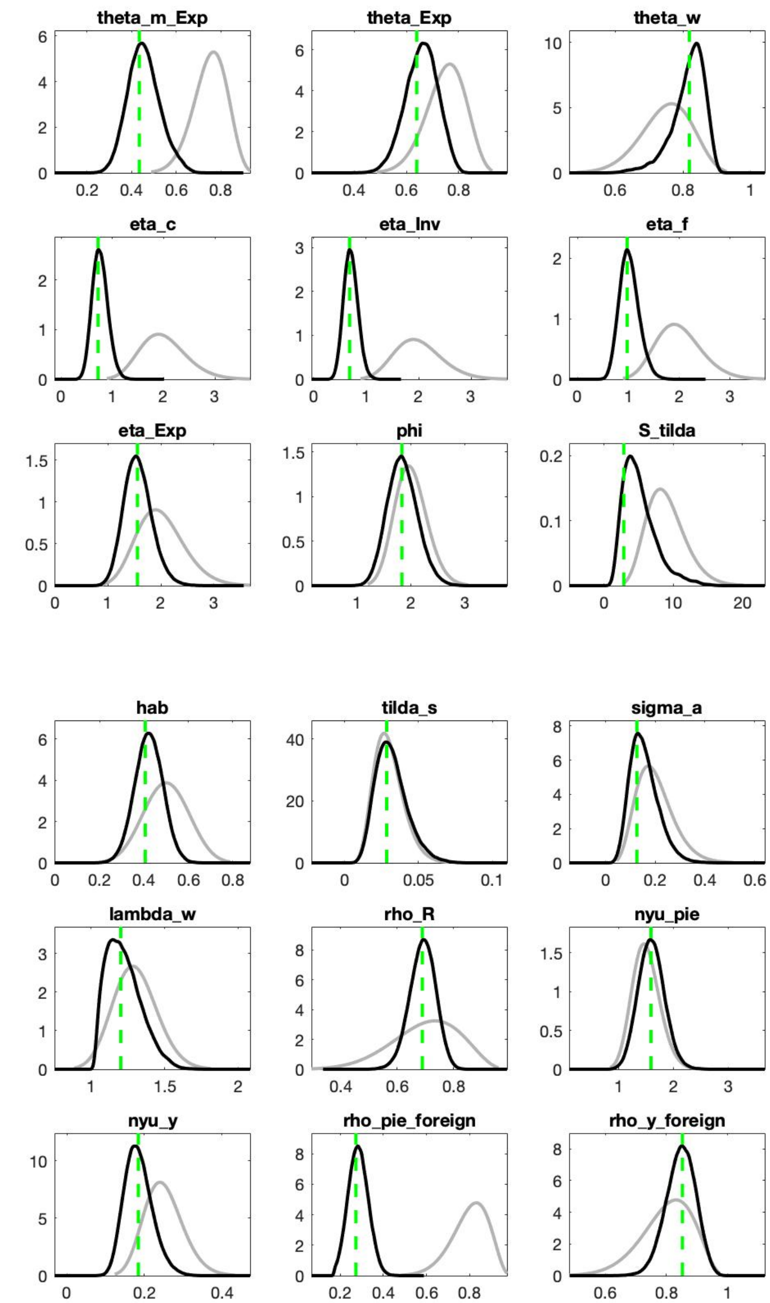

Figure 6: Prior and posterior distributions

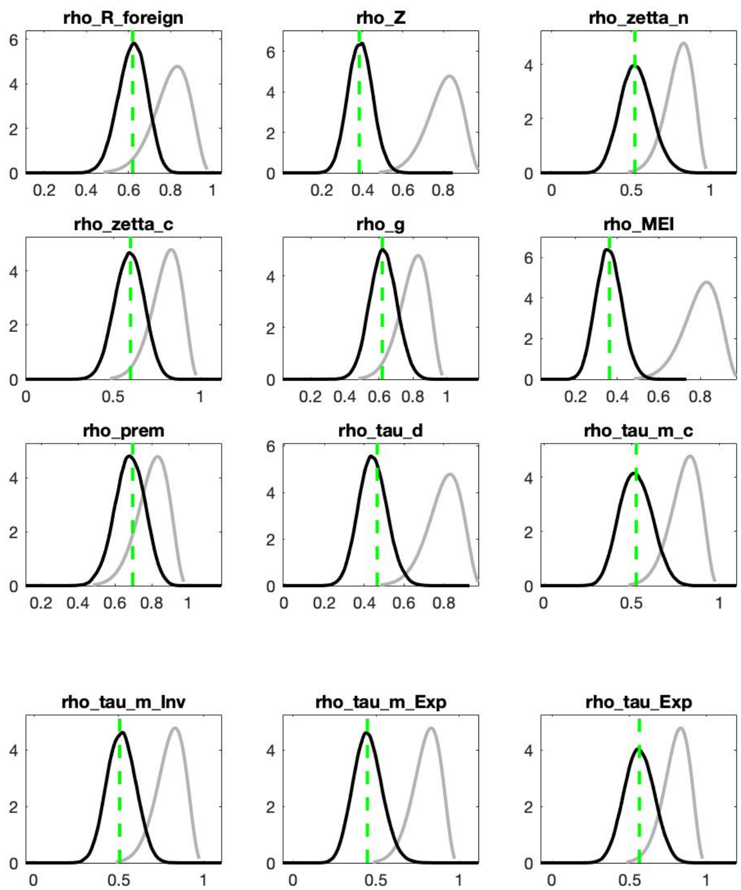

Figure 6: Prior and posterior distributions

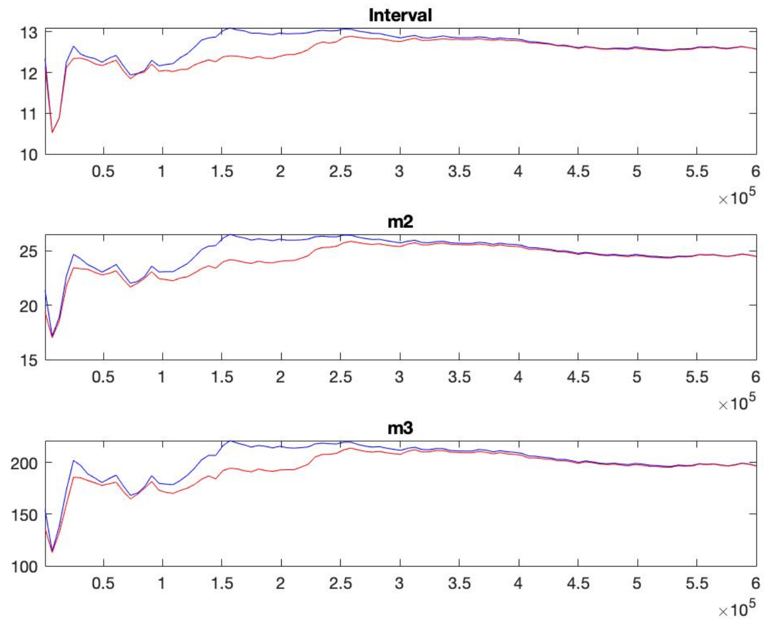

Figure 7: Multivariate convergence diagnostics

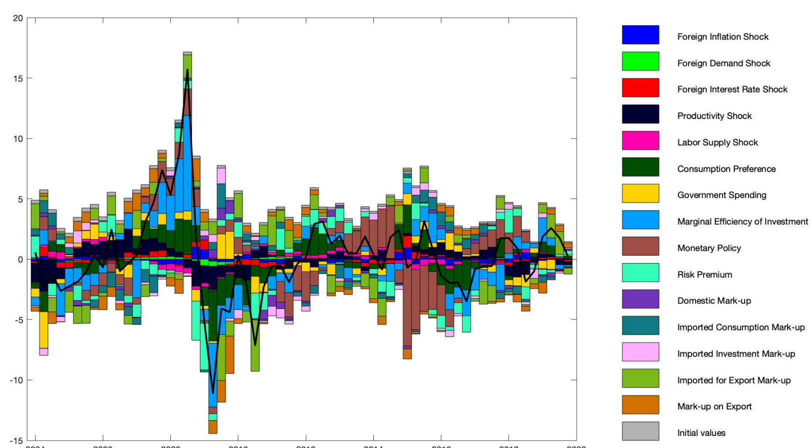

Figure 8: Historical decomposition of GDP

12.6 Appendix F. Graphical illustration of labor market

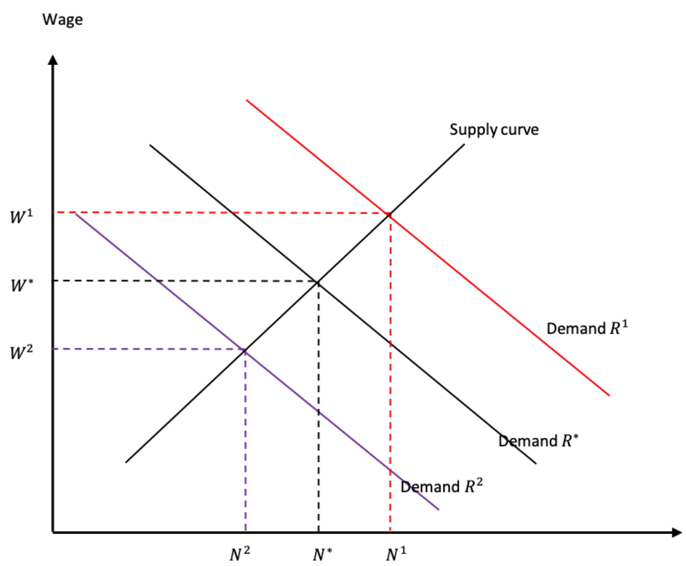

Figure 9: Linear labor supply and demand

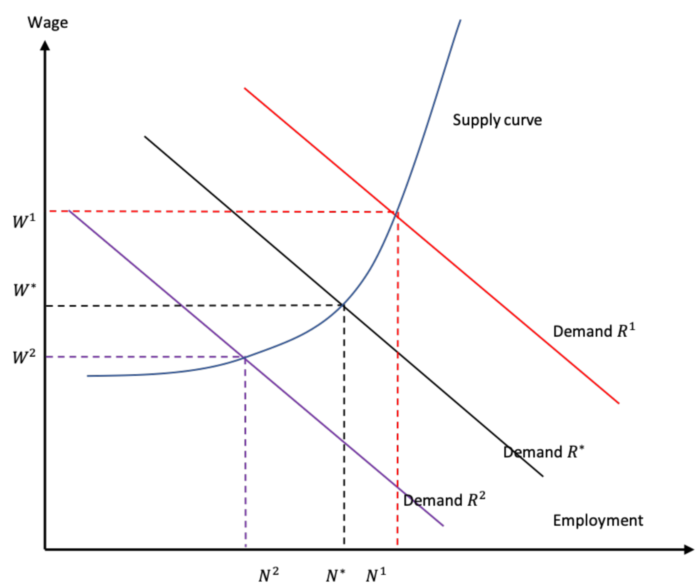

Figure 10: Nonlinear labor supply and linear demand

12.7 Appendix G. Asymmetries in the monetary policy transmission mechanism

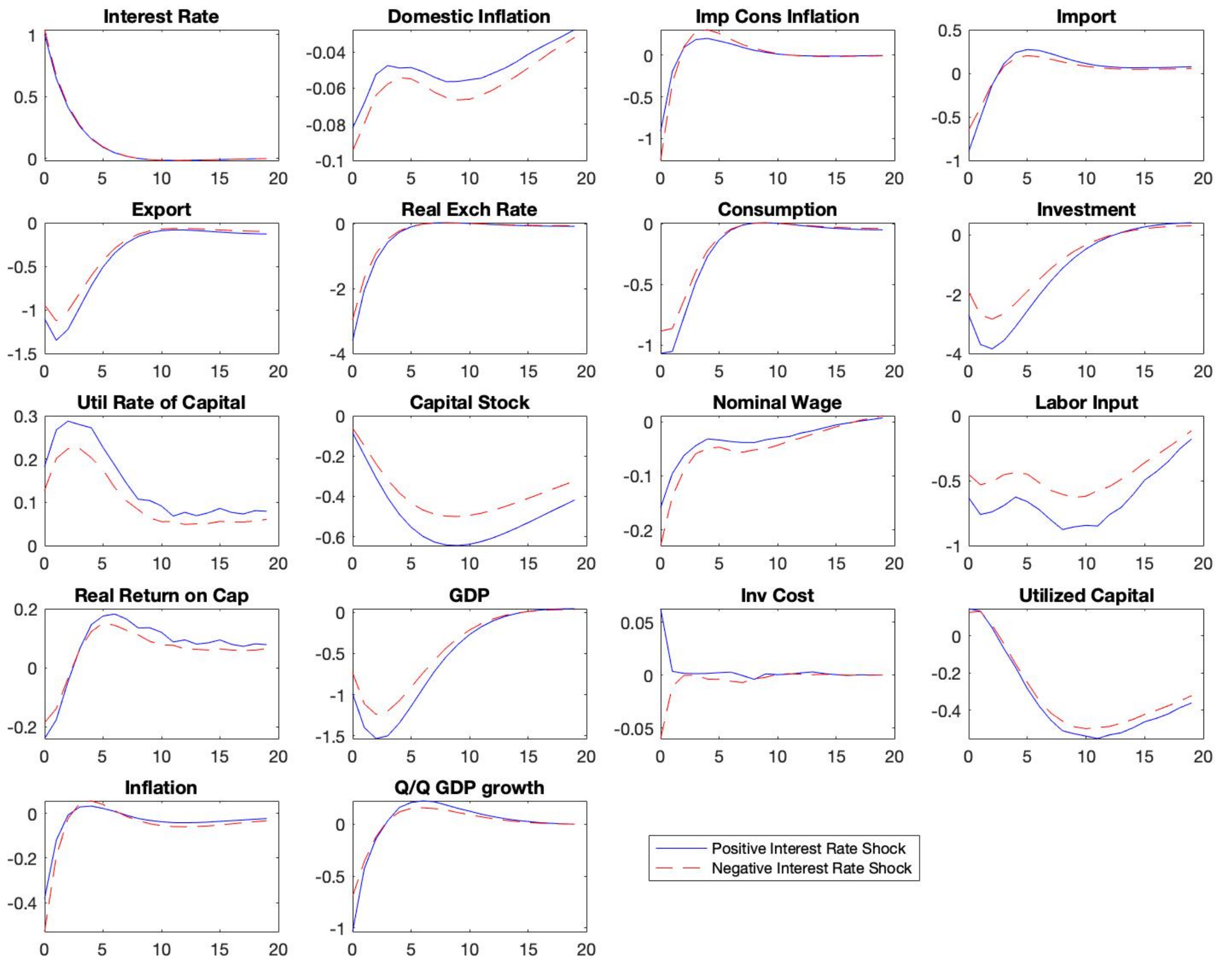

Figure 11: Monetary policy shock in the second-order approximated model (Model 1)
Note: Generalized impulse response functions at ergodic mean based on the average of 25,000 simulations. 1,000 periods in simulation are dropped as burn-in. The responses to negative shock are shown as mirror images to facilitate comparison

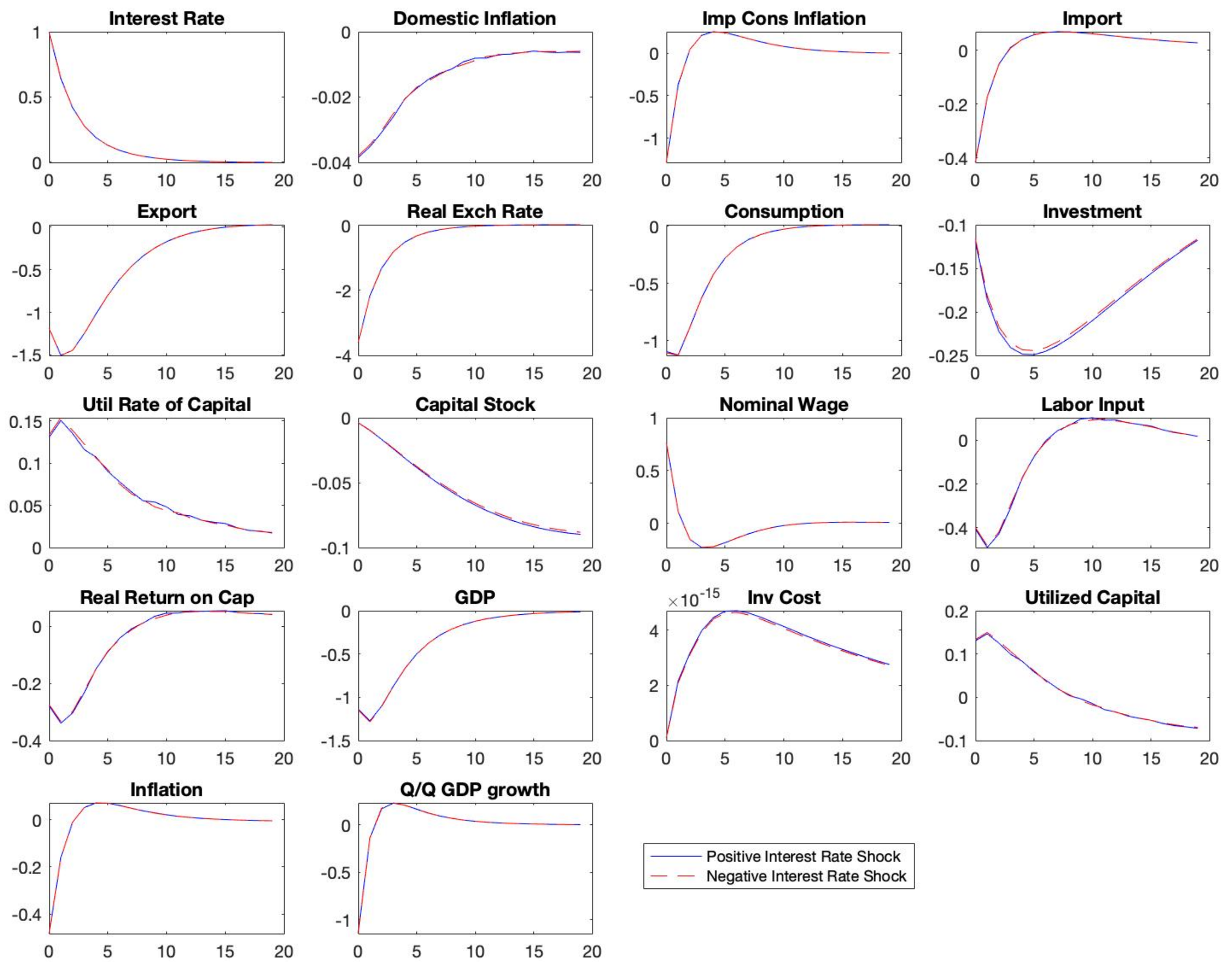

Figure 12: Monetary policy shock in the log-linearized model. Standard assumptions are kept non-linear (Model 2)
Note: Generalized impulse response functions at ergodic mean based on the average of 25,000 simulations. 1,000 periods in simulation are dropped as burn-in. The responses to negative shock are shown as mirror images to facilitate comparison

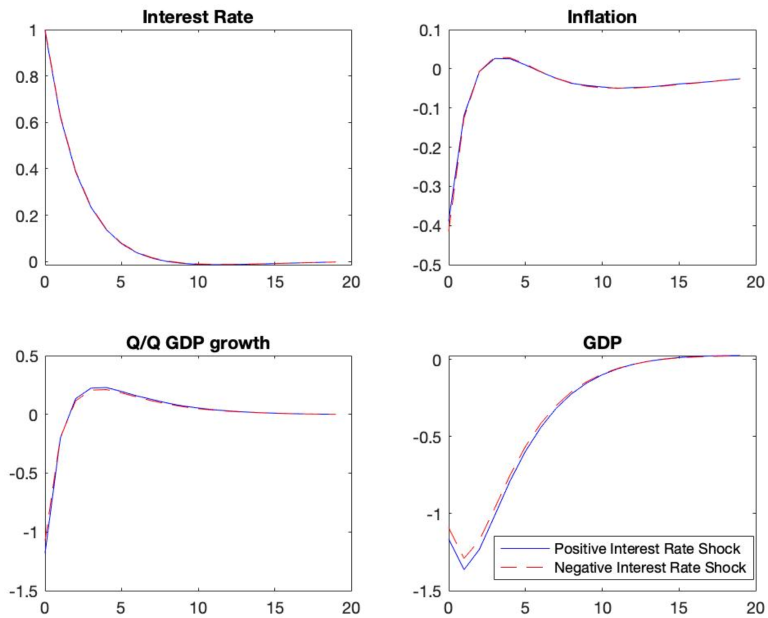

Figure 13: Monetary policy shock in the model with second-order approximated capital market (Model 3)
Note: Generalized impulse response functions at ergodic mean based on the average of 25000 simulations. 1000 periods in simulation are dropped as burn-in. The responses to negative shock are shown as mirror images to facilitate the comparison.

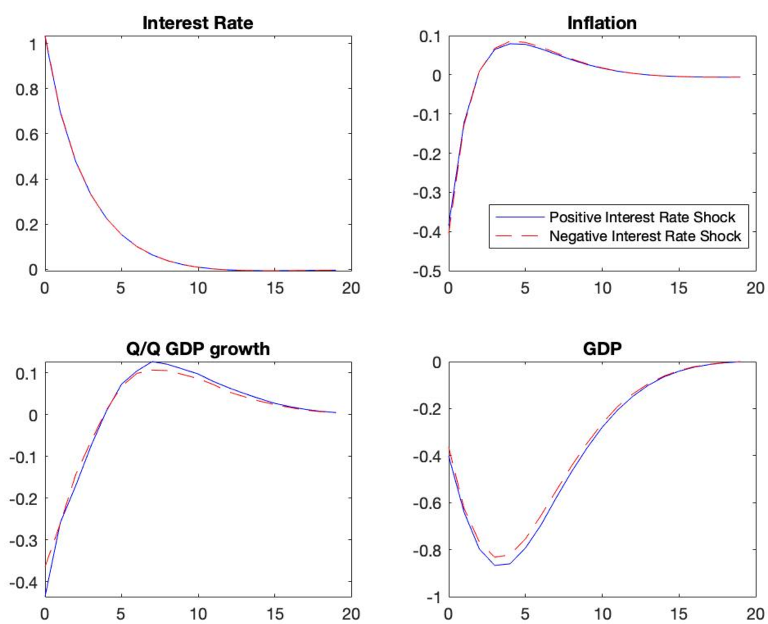

Figure 14: . Monetary policy shock in the model with second-order approximated internal economy Phillips curves (Model 4)
Note: Generalized impulse response functions at ergodic mean based on the average of 25,000 simulations. 1,000 periods in simulation are dropped as burn-in. The responses to negative shock are shown as mirror images to facilitate comparison.

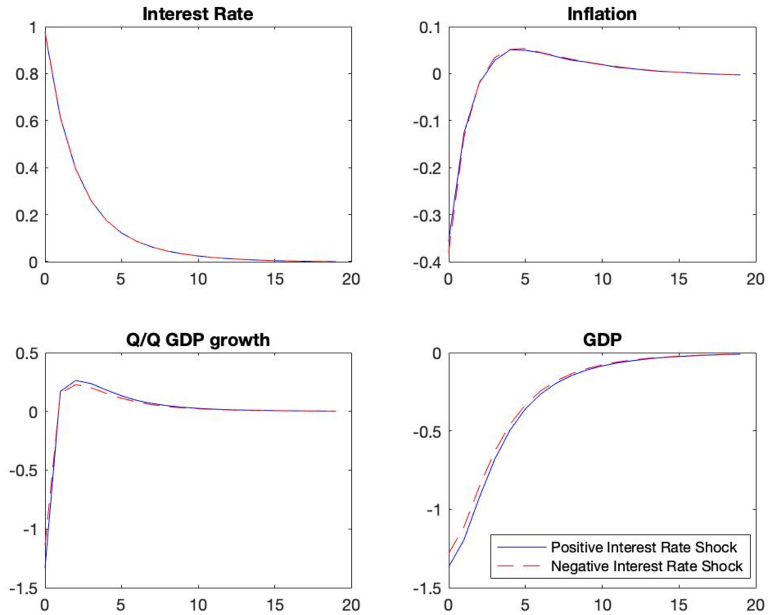

Figure 15: Monetary policy shock in the model with second-order approximated labour market frictions (Model 5)
Note: Generalized impulse response functions at ergodic mean based on the average of 25000 simulations. 1000 periods in simulation are dropped as burn-in. The responses to negative shock are shown as mirror images to facilitate the comparison.

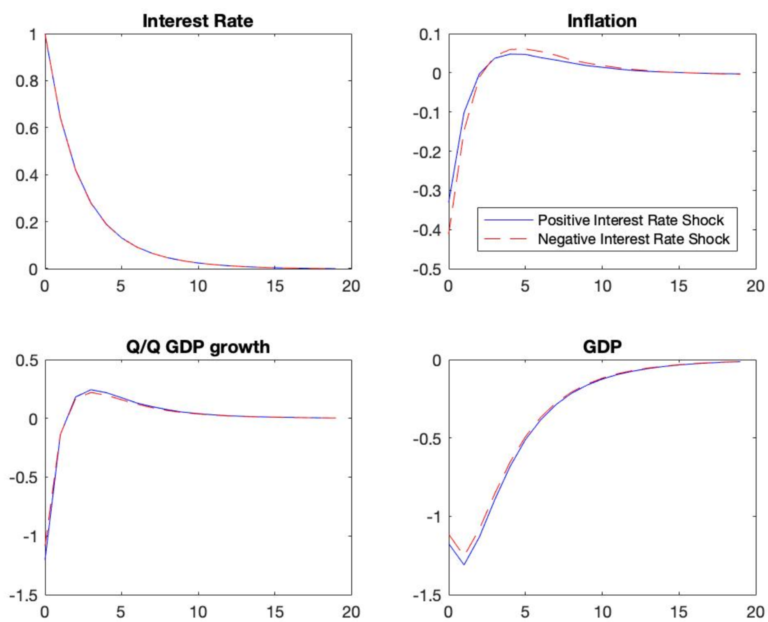

Figure 16: Monetary policy shock in the log-linearized internal economy and second-order approximated external sector model (Model 6)
Note: Generalized impulse response functions at ergodic mean based on the average of 25,000 simulations. 1,000 periods in simulation are dropped as burn-in. The responses to negative shock are shown as mirror images to facilitate comparison.

12.8 Appendix H. Monetary policy in growing economies and recessions

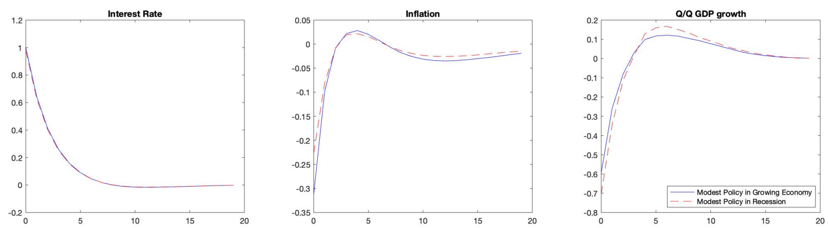

Figure 17: Modest monetary policy shock in demand-driven growing economy and recession

Note: The recession graphs are shown as mirror images to facilitate comparison. Generalized impulse response functions at 5% above and below (driven by the model supply side shocks) steady state level of GDP based on the average of 25000 simulations. 1000 periods in simulations are dropped as burn-in. Modest response is 1% interest rate shock. Aggressive response is 2% monetary policy shock.

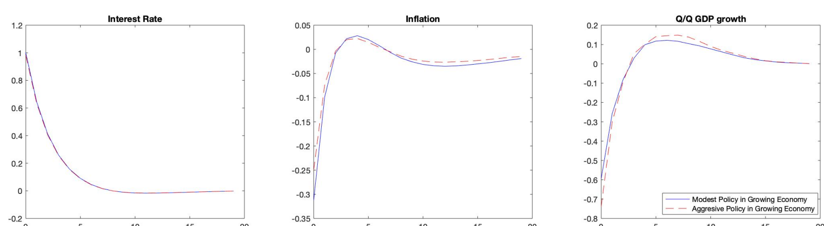

Figure 18: Modest and aggressive monetary policy shocks in demand-driven growing economy

Note: The aggressive response is rescaled to facilitate comparison. Generalized impulse response functions at 5% above and below (driven by the model supply side shocks) steady state level of GDP based on the average of 25000 simulations. 1000 periods in simulations are dropped as burn-in. Modest response is 1% interest rate shock. Aggressive response is 2% monetary policy shock.

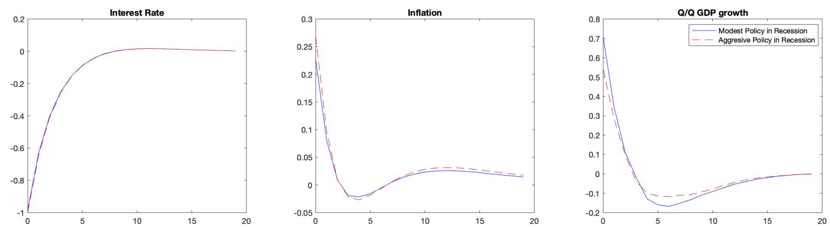

Figure 19: Modest and aggressive monetary policy shocks in demand-driven recession
Note: The aggressive response is rescaled to facilitate comparison. Generalized impulse response functions at 5% above and below (driven by model demand-side shocks) steady state level of GDP based on the average of 25,000 simulations. 1,000 periods in simulation are dropped as burn-in. A modest response is a 1% interest rate shock. An aggressive response is a 2% monetary policy shock.

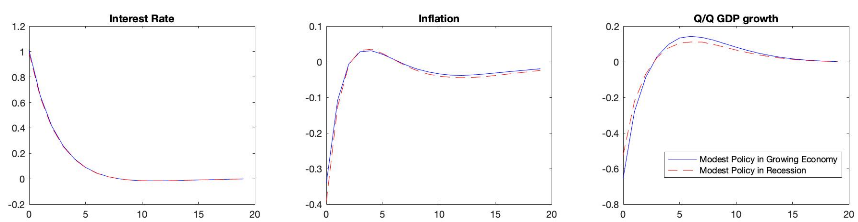

Figure 20: Modest monetary policy shock in supply-driven growing economy and recession
Note: Generalized impulse response functions at 5% above and below (driven by the model supply side shocks) steady state level of GDP based on the average of 25000 simulations. 1000 periods in simulations are dropped as burn-in. Modest response is 1% interest rate shock. Aggressive response is 2% monetary policy shock.

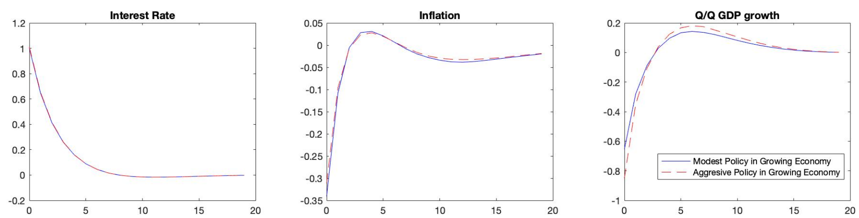

Figure 21: Modest and aggressive monetary policy shocks in supply-driven growing economy
Note: The aggressive response is rescaled to facilitate comparison. Generalized impulse response functions at 5% above and below (driven by the model supply side shocks) steady state level of GDP based on the average of 25000 simulations. 1000 periods in simulations are dropped as burn-in. Modest response is 1% interest rate shock. Aggressive response is 2% monetary policy shock.

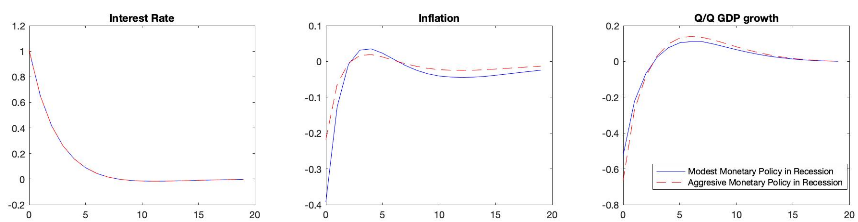

Figure 22: Modest and aggressive monetary policy shocks in supply-driven recession
Note: The aggressive response is rescaled to facilitate comparison. Generalized impulse response functions at 5% above and below (driven by model supply-side shocks) steady state level of GDP based on the average of 25,000 simulations. 1,000 periods in simulation are dropped as burn-in. A modest response is a 1% interest rate shock. An aggressive response is a 2% monetary policy shock.