Analysing the Implications of a Cost-Channel in a New-Keynesian model

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Abstract

Through making firms' marginal cost dependent on the nominal interest rate, I introduce a cost-channel into an New-Keynesian framework. Including thereby demand and also supply side effects of monetary policy, a monetary authority faces a trade-off between stabilizing inflation and the output gap, when experiencing a shock. I show, that this specification has severe impacts on optimal monetary policy, when the zero lower bound becomes binding. Particularly the economy exits the zero lower bound at a later date when conducting discretionary monetary policy, while it does the opposite when pursuing committing monetary policy compared to a non cost-channel economy.

Key Words: Cost-Channel, Monetary Policy, New-Keynesian Model, Zero Lower Bound

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1 Introduction

In recent decades New-Keynesian DSGE models have been at the centre of monetary theory and policy analysis. These models, based on intertemporal optimization behaviour, rational expectations and temporary price rigidities, are used to derive optimal policy responses when economies are being faced by a shock. Under these simplifications monetary authorities have the tools and ability to perfect counter effects of demand shocks on the economy, as proposed by Clarida, Galí and Gertler (1999), without bearing costs in terms of increased inflation variability.

Since the standard model however lacks the supply side effect of monetary policy, there has been research on incorporating this effect in form of a cost-channel into a new-Keynesian model. Such a channel makes firms' production dependent on in-advance external funding by financial intermediaries, which causes interest rate changes to directly affect marginal costs as well as pricing decisions of firms. Thereby nominal interest rates directly affect the Phillips curve, and domestic inflation, causing monetary authorities to face a realistic trade-off between stabilising the inflation rate and the output gap when the economy is hit by a shock.[2]

Using a VAR model based on industry level data Barth and Ramey (2001) first found evidence for a cost-channel in the US economy, similar to the empirical analysis of Christiano et. al. (2005). The first to establish a New-Keynesian model with a cost-channel were Ravenna and Walsh (2006), who concluded that an active cost-channel has significant effects on the conduct of monetary policy and therefore should not be neglected. Based on an analysis of the financial intermediary sector Chowdnury et. al. (2006) provide evidence, that in market-based countries with highly competitive financial markets, e.g. the US or UK, an immediate pass-through of changes in the monetary policy rate to the costs of working

[2]Ravenna and Walsh(2006) conclude, that this trade-off appears independent of the type of the shock, therefore under demand shocks, supply shocks and cost-push shocks in contrast to the standard New-Kenesian model, where the monetary economy is able to maintain the output-gap and inflation at their steady-state values.

capital occurs and therefore a cost-channel is present.[3] Unlike all other G-7 countries, no significantly cost-channel was found for Japan and Germany, which the authors concluded is due to the countries financial sectors being highly regulated. The relation between the strength of the cost-channel and credit market imperfections can also be seen in Tillmann (2008, 2009a) or more recently in Beaurdry and Portier (2018) who examine the cost-channel in a Real-Keynesian model.

In the aftermath of the financial crisis in 2008 central banks all over the world faced or still face zero lower bounds on nominal interest rates. Eggertsson and Woodford (2003) analysed monetary policy tools like discretionary and committing policy at the zero lower bound in a New-Keynesian model. They showed that under commitment, the nominal interest rate is set equal to zero longer than the natural rate of interest would suggest by monetary authorities in order to create higher inflationary expectations.

Even though there is a vast range of research on the effect of the zero lower bound in general, analysis of a cost-channel at the zero lower bound is still scarce. Chattopadhyay and Ghosh (2016, 2019) and Pathberiya (2016) were the first to analyse monetary policy and its implementations under such a setting and both report similar results to my research.

In my study I show the importance of knowing whether a economy has an active cost-channel for the conduct of monetary policy. When conducting commitment policy the central bank exits the zero lower bound earlier compared to a non cost-channel economy, while under discretionary policy the exit of the zero lower bound is postponed with the strength of the cost-channel, and therefore creates a strong welfare-loss for the economy.

The remainder of the paper is structured as follows. Section 2 states, describes and derives all essential equations of the new Keynesian model with a cost-channel. Section 3 states the optimality conditions of the economy. In Section 4 the effects of a cost-channel on the economy are displayed graphically and section 5 analysis the impact on monetary policy

[3]Following Chowdnury et. al., a cost-channel can also be seen as a possible explanation for the price puzzle, under severe financial frictions, when the cost-channel is stronger than the demand channel and therefore increases inflation.

at the zero lower bound. Section 6 concludes.

2 The Model

The model I use in my paper is an New-Keynesian model based on Ravenna and Walsh (2006) and Wiederholt (2015). Firms need to externally finance their labour costs at the beginning of each period, which forces them to borrow from financial intermediaries in order produce in the economy. That on the other hand leads to nominal interest rates affecting the marginal costs and therefore the Phillips-curve, which introduces a cost-channel.

Households, the firm sector and the monetary authority are the three main blocks of the model economy, in addition to them there is also the fiscal authority, where firms can take out loans. A brief description of the model follows below.

2.1 Households

The economy consist of identical households of mass one, indexed by $i \in [0,1]$. The household i chooses consumption and labor supply in order to maximize its discounted utility, which is stated as

$$E_0^i\left[\sum_{t=0}^{\infty}\beta^t e^{\xi_{i,t}}\left(\frac{C_{i,t}^{1-\gamma}-1}{1-\gamma}-N_{i,t}\right)\right] \tag{1}$$

with $C_{i,t}$ being the consumption of the household in period t, while $N_{i,t}$ is the labor supply chosen in period t, $\xi_{i,t}$ is a preference shock, E_0^i denotes households expectations based on the information it has in period zero. With parameter $\beta \in (0,1)$ being a discount factor and $\gamma > 0$ being the inverse of the intertemporal elasticity of substitution.

Let M_t denote the cash holdings of household i, which whom it enters period t with. The household receives its wage income at the start of the period, which it uses to make deposits D_t at the financial intermediary of the economy. The cash-in-advance constraint of the household i therefore takes the following form

$$P_t C_{i,t} \leq M_{i,t} + W_{i,t} N_{i,t} - D_{i,t}. \tag{2}$$

By the end of the period, household i receives its income profits from the financial intermediary and its returns on deposits made at the intermediary. The flow budget constraint of the household between periods t and $t+1$ reads the following

$$M_{i,t+1} = M_{i,t} + W_{i,t} N_{i,t} - D_{i,t} - P_t C_{i,t} + R_t D_{i,t} + \Pi_{i,t} - T_{i,t}, \tag{3}$$

where the gross nominal interest rate on the deposits at the financial intermediary between periods t and $t-1$ is given by R_t. The nominal wage rate for labour supplied by household i in period t is $W_{i,t}$, while aggregate profits of intermediaries and firms are denoted by $\Pi_{i,t}$. The price of the final good in t is stated by P_t, whereas $P_t C_{i,t}$ states the household's consumption expenditure. Lump-sum taxes are stated by $T_{i,t}$. Households are able to save and borrow from the financial intermediary, furthermore they are not allowed to run a Ponzi scheme. For simplicity I assume same initial cash holdings for all households in period $t-1$.

2.2 Firms

The firm sector consists of two different types of firms, final good producers and intermediate good firms. The technology used by competitive firms to produce the final good reads

$$Y_t = \left(\int_0^1 Y_{j,t}^{\frac{\theta-1}{\theta}} dj \right)^{\frac{\theta}{1-\theta}}, \tag{4}$$

with Y_t being the output of the final good and $Y_{j,t}$ being the input of the intermediate good j, while $\theta > 1$ is the elasticity of substitution between intermediate goods. Prices are fully flexible for final good firms. These type of firms are being faced with the following demand function from households' for good j

$$Y_{j,t} = \left(\frac{P_{j,t}}{P_t}\right)^{-\theta} Y_t, \tag{5}$$

where $P_{j,t}$ stands for the price of the intermediate good j and P_t is the price of the final good. The expression for the price of the final good is given by

$$P_t = \left(\int_0^1 P_{j,t}^{1-\theta} dj\right)^{\frac{1}{1-\theta}}. \tag{6}$$

In order to produce the intermediate good j the firm uses the following production technology

$$Y_{j,t} = N_{j,t}^{\varrho} \qquad with \qquad N_{j,t} = \left(\int_0^1 N_{i,j,t}^{\frac{\eta-1}{\eta}} di\right)^{\frac{\eta}{\eta-1}}. \tag{7}$$

Output is stated by $Y_{j,t}$, the labour input i of monopolist j by $N_{i,j,t}$ and composite labour input by $N_{j,t}$. The elasticity of substitution between types of labour is given by $\eta > 1$, while the parameter $\varrho \in (0, 1]$ denotes the elasticity of output with respect to composite labour.

In contrast to standard New Keynesian literature in my model, firms need to borrow the amount $W_t N_t$ from financial authorities at the gross nominal interest rate R_t, in order to hire labour at the beginning of each period. Therefore the nominal cost of labour is equal to $R_t W_t$. Since profits are being transferred at the end of each period to their owners, firms are relying on external funds to meet their liquidity constraint. Real marginal costs are the same among all firms in the economy. I introduce staggered prices, through a price-setting friction as introduced by Calvo (1983), which states that firms are able to optimize their price each period with the probability of $1 - \alpha$. The fraction α of firms that are not able to optimally adjust their prices in the period, set their price in period t equal to that of the previous period $P_{j,t} = P_{j,t-1}$.

2.2.1 Goods Market

In order for the goods market to be in an equilibrium the following equation must hold

$$Y_t = C_t + G_t, \tag{8}$$

where G_t denotes purchases by the government, which are in the same proportions as that by households. That condition allows to state government purchases as $G_t = (1 - \varsigma_t)Y_t$, with ς_t being stochastic and bound between zero and one. Therefore the aggregate resource constraint can be rewritten as $Y_t = C_t + (1 - \varsigma_t)Y_t$.

2.3 Monetary Authority

For setting the gross nominal interest rate the monetary authority follows the rule specified below

$$R_t = max\left\{1, R(\Pi_t^{\phi_\pi} + Y_t^{\phi_y})\right\} + e^{\mu_t}, \tag{9}$$

where $R = (\frac{1}{\beta})$ denotes the nominal interest rate in the non-stochastic steady state with zero inflation. While the inflation rate is given by $\Pi_t = (\frac{P_t}{P_{t-1}})$ and Y_t is the deviation of output from its steady state level, wherefore it also can be displayed as $(\frac{Y_t}{Y})$. The parameters ϕ_π and ϕ_y are non-negative and give the sensitivity and severity of the central banks adjustment to changes in Π_t and Y_t, when computing the new nominal interest rate.
The term μ_t^R denotes a monetary-policy shock, which follows an AR(1) process , of the form $\mu_t^R = \rho^R \mu_{t-1}^R + \epsilon_t^R$, where $\epsilon_t^R \overset{\text{iid}}{\sim} (0, \sigma_R^2)$ holds.

2.4 Fiscal Authority

A cash injection X_t is given to the financial intermediary by the monetary authority, these funds are then being lent to the firms in the economy at a gross nominal interest rate R_t. Since financial intermediaries operate costlessly in a competitive market, profits of the industry are given by

$$R_t(D_t + X_t) - R_t D_t = R_t X_t = \Pi_t^i. \tag{10}$$

The gross growth rate of money between the period t and $t+1$ can be expressed as G_{t+1}, which allows to state the cash injection as $X_t = (M_{t+1} - M_t) = (G_{t+1} - 1)M_t$. The equilibrium in the loan market requires $W_T N_t^d = D_t + X_t$ to hold, where N_t^d is the aggregate labor demand by firms.

3 Optimality conditions

In the following section I will state, derive and log-linearise the optimality conditions for the household and firm side of the economy to derive the New-Keynesian Phillips-curve. In the remainder of my paper I will denote log-deviations from the non-stochastic steady state with zero inflation by small letters.

3.1 Household side

Maximizing households utility subject to the budget constraint, the first-order condition for consumption of the household yields

$$C_{i,t}^{-\gamma} = E_t^i \left[\beta \frac{\epsilon^{\xi_{i,t}}}{\epsilon^{\xi_{i,t-1}}} \frac{R_t}{\Pi_{t+1}} C_{i,t+1}^{-\gamma} \right], \tag{11}$$

while the first order condition for real wages is given by

$$\tilde{W}_{i,t} = \frac{\eta}{\eta - 1} C_{i,t}^{\gamma}, \tag{12}$$

where $\tilde{W}_{i,t} = (\frac{W_{i,t}}{P_t})$ stands for the real wage rate for type i labour. When being log-linearised around the non-stochastic steady state, the consumption Euler equation (11) reads

$$c_{i,t} = E_t^i\left[-\frac{1}{\gamma}(r_t - \pi_{t+1}) + c_{i,t+1}\right] + d_t, \tag{13}$$

where $d_t = log(\frac{\xi_t}{\xi_{t-1}})$ is an exogenous preference shock, representing a demand shock. The demand shock follows an AR(1) process with the form of : $d_t = \rho^D d_{t-1} + \epsilon_t^D$, with $\epsilon_t^D \overset{\text{iid}}{\sim} (0, \sigma_D^2)$. While the log-linearised wage setting equation (12) around the non-stochastic steady state is given by

$$\tilde{w}_{i,t} = \gamma c_{i,t}. \tag{14}$$

3.2 Firm side

An intermediate good firm j re-optimising its price in period t, will choose a price maximizing the current market value of the profits generated, while that price remains effective

$$X_{j,t}^i = \underset{Pj,t\in\mathbb{R}++}{arg\,max}\, E_t\left[\textstyle\sum_{s=t}^{\infty} (\alpha\beta)^{s-t} \left(\frac{e^{\xi_{i,s}} C_{i,s}^{-\gamma} P_t}{e^{\xi_{i,t}} C_{i,t}^{-\gamma} P_s}\right) \left(P_{j,t}\left(\frac{P_{j,t}}{P_s}\right)^{-\theta} Y_s - \left((W_s R_s)\left(\left(\frac{P_{j,t}}{P_s}\right)^{-\theta} Y_s\right)^{\frac{1}{\varrho}}\right)\right]\right.$$

The presence of the cost-channel in the equation above can be seen through the presence of the nominal interest rate R_s in the second part of the equation on the right side. By excluding that term, one would get the standard New-Keynesian model maximization.[4] The equation of the adjustment price reads the following after being log-linearised around the non-stochastic steady state

$$x_{j,t}^i = (1-\alpha\beta)E_t\left[\textstyle\sum_{s=t}^{\infty} (\alpha\beta)^{s-t} \left(p_s + \frac{1}{1+\frac{1-\varrho}{\varrho}\theta}(w_s - p_s) + \frac{\frac{1-\varrho}{\varrho}}{1+\frac{1-\varrho}{\varrho}\theta} y_s + \frac{1}{1+\frac{1-\varrho}{\varrho}\theta} r_s \right)\right].$$

Superscript i and j and can be dropped from the log-linearised adjustment price, since it's independent of who owns the firm and is the same for all firms who adjust their price in

[4] For the standard new Keynesian model see Galí (2005, 2008).

period t

$$x_t = (1-\alpha\beta)\left(p_t + \frac{1}{1+\frac{1-\varrho}{\varrho}\theta}(w_t - p_t) + \frac{\frac{1-\varrho}{\varrho}}{1+\frac{1-\varrho}{\varrho}\theta}y_t + r_t\right) + \alpha\beta E_t[x_{t+1}]. \tag{15}$$

3.3 New-Keynesian Phillips-curve

Following the Calvo price-stickiness, that adjusting firms are randomly selected and that the adjustment price is the same for all firms who are able to adjust in period t yields

$$p_t = \int_0^1 p_{j,t} dj = \alpha p_{t-1} + (1-\alpha)x_t$$

Rearranging and substituting the above stated equation for the adjustment prices x_t and x_{t+1} into equation (15) yields

$$\pi_t = \frac{(1-\alpha)(1-\alpha\beta)}{\alpha}\left(\frac{1}{1+\frac{1-\varrho}{\varrho}\theta}(w_t - p_t) + \frac{\frac{1-\varrho}{\varrho}}{1+\frac{1-\varrho}{\varrho}\theta}y_t + \frac{1}{1+\frac{1-\varrho}{\varrho}\theta}r_t\right) + \beta E_t[\pi_{t+1}] \tag{16}$$

Log-linearising the earlier stated equation for the wage index yields

$$w_t = \int_0^1 w_{i,t} di.$$

Using the wage setting equation and $y_t = c_t$, where c_t denotes aggregate consumption of the final good, yields a forward looking New-Keynesian Phillips-curve including a cost-channel

$$\pi_t = \frac{(1-\alpha)(1-\alpha\beta)}{\alpha}\frac{1}{1+\frac{1-\varrho}{\varrho}\theta}\left(\left(\gamma + \frac{1-\varrho}{\varrho}\right)c_t + r_t\right). \tag{17}$$

The New-Keynesian Phillips-curve can be further simplified to

$$\pi_t = \kappa((\gamma+\nu)c_t + \delta r_t) + \beta E_t[\pi_{t+1}] + \mu_t^R, \tag{18}$$

where $\kappa = \frac{(1-\alpha)(1-\alpha\beta)}{\alpha}\frac{1}{1+\frac{1-\varrho}{\varrho}\theta}$ and δ being a coefficient I introduced to denote the strength of the cost-channel. Setting $\delta = 0$ and therefore closing the cost-channel, would yield the standard New-Keynesian Phillips-curve(NKPC).

4 Solutions

In the following section I will present two different methods in order to graphically show and analyses the impact of a cost-channel in a New-Keynesian model. The first one is a non-stochastic closed-form solution for key macroeconomic variables illustrated in an IS-MP and AS-AD graphing.

The second method is a dynamic solution of the model. In order to do so I derive and plot dynamic solutions [5] in form of impulse response functions following an exogenous shock around the steady state. Derivations of the coefficients can be found in the appendix.

The parameters used in order to calibrate the model and produce the plots in Section 4 and 5 are stated in the Appendix. They correspond to standard parameter values frequently used in new Keynesian Literature.

4.1 Non-stochastic Solution

The closed-form solution of the model[6] is derived under the assumption shocks being i.i.d., which allows to set all expected variables equal to zero. The IS-MP schedule consists of two different equations, while the IS-curve is similar to the one in the standard IS-LM set-up, the MP-curve replaces the out-dated LM-curve, through setting the central banks target on the control of the short run nominal interest rate instead of a monetary aggregate as under the LM-setting (Clarida et al. [1999]). The IS-curve, which is the log-linearisation of the Euler-equation can then be stated as follows,

$$y_t = -\frac{1}{\gamma} r_t + d_t, \tag{19}$$

[5] All impulse response function plots were produced using the software Matlab together with Dynare.

[6] There are different ways and approaches to derive closed-form solutions of models, I present another approach in Appendix B.

while the Monetary Policy curve (MP) is given by

$$r_t = \phi_\pi \pi_t + \phi_y y_t + \mu_t, \tag{20}$$

outside the zero lower bound and $r_t = -ln(R) + \mu_t$ when the zero lower bound on nominal interest rates becomes binding.

The lower panels in Figure 1 and 2, plot the so-called AD-PC block combine the AD-curve given by the combination of the dynamic IS-curve and the MP schedule, similar to the standard AS-AD setup. The AS-curve is being replaced through the New-Keynesian Phillips-curve, which relates inflation to the output gap. The AD-curve is stated as follows

$$y_t = -\frac{\phi_\pi}{\gamma + \phi_y}\pi_t - \frac{\mu_t}{\gamma + \phi_y} + \frac{d_t}{\gamma + \phi_y}. \tag{21}$$

The New-Keynesian Phillips-curve (NKPC) is the only equation differing between the economies with and without a cost-channel. In a economy with a cost-channel the NKPC reads

$$\pi_t = \kappa((\sigma + \nu)y_t + \delta r_t), \tag{22}$$

inserting the monetary policy rule the NKPC becomes

$$\pi_t = \frac{\kappa(\sigma + \nu + \delta\phi_y)}{1 - \kappa\delta\phi_\pi} y_t \tag{23}$$

The presence of the nominal costs in the equation displays the trade-off between inflation and the output-gap the monetary authority is confronted with. Setting $\delta = 0$ yields , $\pi_t = \kappa(\sigma + \nu)y_t$ which is equivalent to the standard NKPC without a cost-channel.

Demand side adjustments in the IS-MP framework are being displayed in the upper panels of Figure 1 and 2 in a (y, r) space, while the lower panel plots the AD-PC curves in a (y, π) space, denoting adjustments of the inflation rate and the output gap.

4.1.1 Outside the ZLB

Panel (a) of Figure 1 displays the standard amplifications in a 3-equation New Keynesian Model following a positive demand shock. Starting from point 1 as the initial equilibrium in the economy, a positive demand shock increases demand and therefore shifts the IS curve upwards to point 2. In order to match the increased demand output increases as well, which leads to a shift of the AD-curve to even above AD'. With output being above its natural rate inflation increases, wherefore the monetary authority increases. This leads to an upward shift of the MP curve, reaching its new Equilibrium at 3. Due to the now higher nominal interest rate the AD-curve is being pushed down to AD'. The shift of the AD-curve combines the initial demand shock as well as the counteraction of the monetary authority through increasing the nominal interest rate.

The dynamics in the IS-MP plot in (b) are similar to the ones stated in (a), since the IS-curve is not affected by the presence of the cost-channel. In contrast to the IS-curve, the NKPC in the lower panel is steeper when a cost-channel is present, due to the direct effect of the nominal interest rate on inflation. Holding everything else equal, that is why such an economy experiences a way more severe increase in inflation following a positive demand shock. Due to the steeper NKPC the shift of the AD-curve is weaker compared to (a), wherefore the output-gap increases to a lower extend, with reaching a lower level in its new equilibrium at point 3.

An increase in the nominal interest rate has two different effects on the NKPC in a cost-channel economy. One being the direct effect on the PC, while the other is an indirect effect through its impact on the IS-curve. As long as the strength of the cost-channel is significantly stronger, meaning that $\delta > (\sigma + \nu)$ holds, the direct effects dominates the indirect effect. The lower panel also illustrates the trade-off between stabilizing the output gap and dampening the increase in inflation, the monetary authority is facing under a cost-channel. It also shows, that the severity of the negative trade-off between employment and inflation variance increases with the strength of the cost-channel.

4.1.2 At the ZLB

The dynamics of an economy hit by a strong negative demand shock, which forces the monetary authority to hit the ZLB[7], are illustrated in Figure 2.

When the ZLB becomes binding, the MP-curve flattens as illustrated in the upper panels, which are similar for both economies. In an economy without a cost-channel the reactions of the economy are those of a standard model. Following a negative demand shock, output decreases and shifts the IS-curve downwards to point 2, where it intersects with the flat and binding MP-curve. Output being below its long-run level causes inflation to decrease, which is illustrated through an downward-shift of the AD-curve to point 2 in the lower panel. At that Equilibrium the PC-curve intersects the downward-sloping AD'-curve, and inflation is therefore not able to stabilize output, compared to the dynamics outside the ZLB, but furthermore even strengthens destabilization.

If the central bank sets the nominal interest rate exactly equal to zero, the cost-channel closes and the amplifications of a negative demand shock in the economy, are equal to those described in panel (a). If the central bank is bound by an effective lower bound, with a nominal interest rate close to zero, the PC-curve in the lower panel of (b) will still be slightly steeper than the one compared to the economy without a cost-channel. Since that significantly diminishes the impact of the cost-channel, the PC-curve differs only marginally between the economies. That is in contrast to the period outside the ZLB in Figure 1, where a significant difference was observable. At the ZLB the steeper NKPC leads to an even lower equilibrium level of inflation and output compared to panel (a). Additional effects which arise due to its presence are illustrated by the dark grey area.

Judging from the graphical analysis the lower panel of (b) suggests, that in the presence of the ZLB, an operating cost-channel has only minor effects on the economy and its dynamics. When howver analysing the conduct of monetary policy at the ZLB, a cost-channel will have

[7] The ZLB, often also referred to as the effective lower bound (ELB), forces the central bank to set nominal interest rate constant at zero, or at an close to zero level, since it is not able to set a negative nominal interest rate.

significantly strong implications on the economy as I will illustrate in Secion 5.

4.2 Dynamic-Simulation

To further analyse the dynamic implications of a cost-channel in a economy following a demand shock, Figure 3 plots dynamic impulsive response functions of key economic variables. The parameter values used for the calibration can be found in the Appendix, the strength of the cost-channel is denoted by the value assigned to δ (the black line, where $\delta = 0$ represents the non cost-channel economy).

Following a positive demand shock, output increases, which causes inflation to increase, with output being above its natural level. Using $\delta = 1.276$[8] as the strength of the cost-channel, causes inflation, being directly effected through the cost-channel and therefore nominal interest rates, to initially increase around 1.2 times stronger compared to the standard economy without a cost-channel ($\delta = 0$). The response of inflation is even more greater for higher values of the interest-rate pass through.

Wherefore the increase in the output-gap is smaller in the economy featuring the cost-channel compared to the scenario of $\delta = 0$, as illustrated in the middle panel of Figure 3. As long as the direct effect of the nominal interest rate dominates the indirect effect, the magnitude of the increase in the nominal interest rate increases with the strength of the cost-channel. Having a strong operating cost-channel can increase the nominal interest rate more than 1.25 times stronger compared to a economy with no cost-channel.

All in all the dynamic solution confirms the graphically analysis done in the section done above.

[8] I follow Ravenna and Walsh(2006), who state $\delta = 1,276$ as an average strength for the cost-channel.

5 Monetary Policy Implications at the ZLB

The loss function in a cost-channel economy I use in my paper, was derived by Ravenna and Walsh (2006) using a second order Taylor approximation[9] of the individual utility function around a inflation steady state. In order to optimal minimize it, the monetary authority needs to find the optimal path for inflation, the nominal interest rate and the output gap simultaneously

$$L_o = \frac{1}{2} E_0 \sum_{t=1}^{\infty} \beta^{t-1} (\pi_t^2 + \lambda y_t^2) \qquad with\ \lambda \in [0, \infty), \tag{24}$$

where $\lambda = \frac{\kappa(\gamma+\nu)}{\vartheta}$ is the weight assigned to the output gap relative to the inflation rate and $\vartheta > 1$ is the own price elasticity of output.[10]

5.1 Discretionary Monetary Policy

When conducting discretionary monetary policy at the zero lower bound, the authority is not committing to future policy actions,in form of solveing sequential optimisation problems every period, independent of future actions.

Following a decrease in the nominal interest rate and the inability of the monetary authority to further lower interest rates, since the ZLB is binding, marginal costs of production are directly negatively affected in a cost-channel economy, causing stronger deflation compared to a non cost-channel economy. This mechanism is increasing with the strength of the cost-channel and therefore driving the severity of the recession, with the output gap decreasing nearly twice the amount in an economy with a strong cost-channel ($\delta = 1.8$), compared to the standard model (solid black line), as displayed in figure 4.

The strong severity of the recession forces the monetary authority to set the nominal interest rates equal to zero for a longer time horizon when a cost-channel is active. While

[9] As done before by Woodford (2003) for a standard new Keynesian model.

[10] I will not show the derivations of the following optimisation problems for the case of commitment and discretion, since it will go beyond the scope of this paper. For detailed derivations see Chattopadhyay and Ghosh(2016) or Pathberiya (2016) who analyse the impact of the ZLB under similar set-ups.

the economy is exiting the ZLB after 4 periods under the standard settings, an economy with a cost-channel exits the zero lower bound more than 1.5 periods later. Inflation, the output gap and the nominal interest rate converge back towards their initial steady state equilibirum levels, the stronger the cost-channel is.

5.2 Commitment Monetary Policy

In contrast to discretionary monetary policy, commitment policy by monetary authorities is taking into account households and agents expectations when minimizing the welfare loss.

Even though both economies initially experience the same drop in the output-gap, as displayed in the middle graph of figure 5, inflation dynamics vary significantly through out the economies. These large differences arise, due to different inflation expectations patterns. Agents in economies with a cost-channel have higher inflation expectations once the economy has excited the zero lower bound, which gives further stimulus to the economy and therefore increases inflation in the medium run, illustrated by all coloured lines being above the solid black line after period 4. This extra stimulus which arises due to the direct impact of the nominal interest rate on the NKPC increases with the degree of the interest-rate pass through.

While the cost-channel economy exited the zero lower bound later compared to a standard economy under discretionary policy, exactly the opposite occurs under commitment. Under the latter policy the monetary authority sets the nominal interest rate at the zero for two more periods in a standard economy compared to a cost-channel economy. In the long-run nominal interest rates take longer to converge back towards their steady state values under a cost-channel compared to modification without a cost-channel. Conducting committing monetary policy allows the authority to more efficiently stable the output-gap, while discretionary monetary policy leads to a way more severe decline in the output gap.

6 Conclusion

In my paper I introduced a cost-channel, which relates firms marginal costs to the nominal interest rate, into a new Keynesian model. My analysis shows, that the presence of a cost-channel forces the monetary authority to face a trade-off between stabilising the output gap and creating inflation rate fluctuations, since nominal interest rate changes directly affect inflation.

When conducting discretionary monetary policy at the zero lower bound, the cost-channel economy, due to its more severe deflation, exits the zero lower bound at a later date compared to a non cost-channel economy. In contrast to that the monetary authority, due to higher inflationary expectations by households, exits the zero lower bound at a earlier date when conducting committing monetary policy, in a cost-channel economy.

Following these different monetary policy patterns studies have shown[11], that the cost-channel also significantly negatively affects the welfare-loss of the economy at the zero lower bound. While I mainly focussed on conventional policy at the zero lower bound in form of commitment and discretion, unconventional policies like forward guidance, which has been conducted by the Federal Reserve Bank (FED) in the past decade need to be analysed in future research as well.

For future studies it will be interesting to further analyse the implementation of such an optimal monetary policy at the zero lower bound.[12] In a second step it will then be interesting to analyse, how dispersed information in form of , not fully credible central banks or irrational households affect an economy, where a cost-channel is operating.

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[11]See Pathberiya (2016) for a detailed derivation of the welfare-loss comparison between a cost-channel and a non cost-channel economy.

[12]Chattopaddyay and Gosh(2019) who analyse the implementation of a T-only policy in a cost-channel economy.

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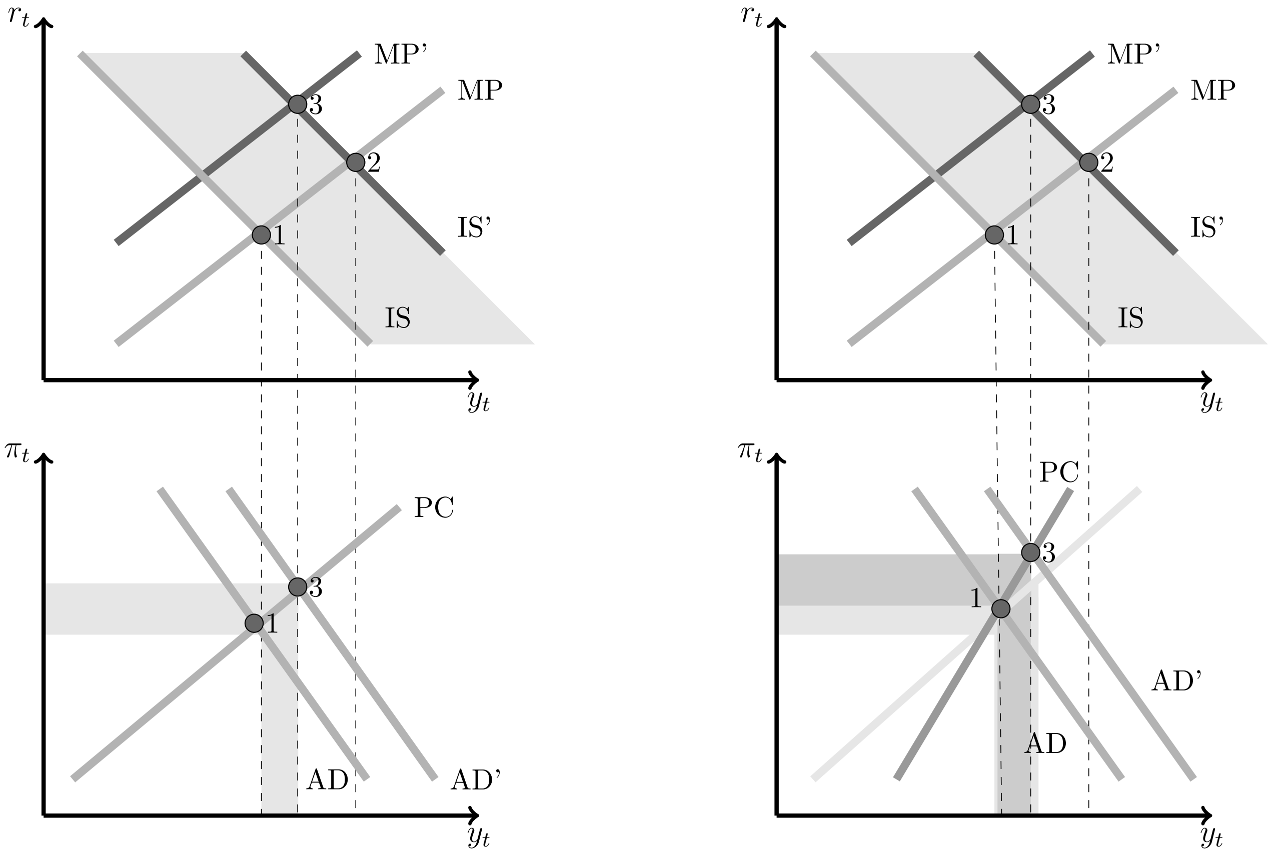
A Appendix

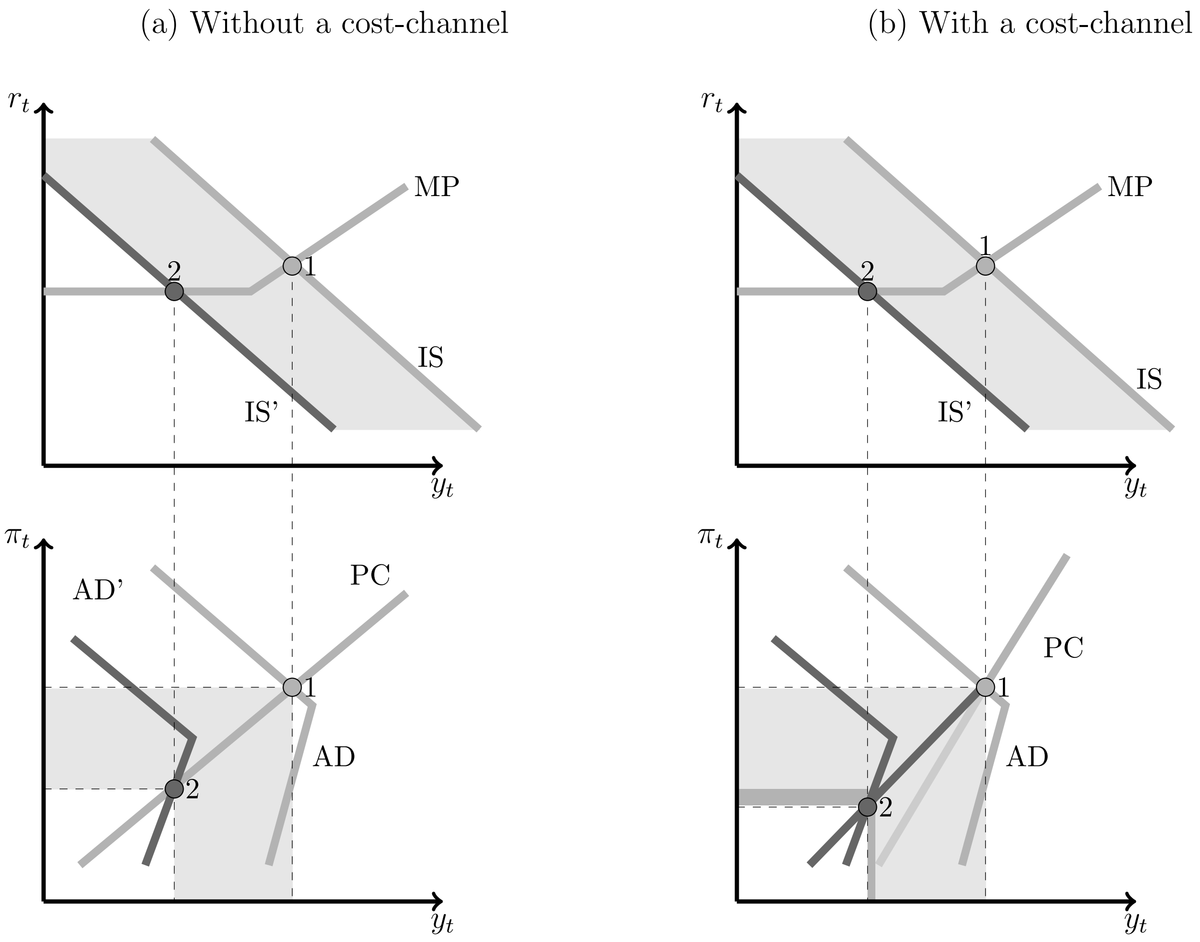
Figure 1: New Keynesian model outside the Effective lower bound, positive demand Shock

(a)Without a cost-channel (b) With a cost-channel



Notes: Fluctuations due to the demand shock are marked by the grey zone, while the dark grey zone shows the fluctuations due to a demand shock in an economy featuring a cost-channel. The slope of the MP-Curve is given by the monetary policy rule $r_t = \max\left\{(\frac{1}{\beta}, \phi_\pi \pi_t + \phi_y y_t\right\} + \mu_t)$ *, the one of the IS-curve is equal to* $y_t = -\gamma r_t + d_t$*, and is equal in both panels. The slope of the AD-Curve is given by inserting* r_t *into the Euler-Equation and solving for* y_t*, which yields the following* $y_t = -\frac{\phi_\pi \gamma}{1+\phi_y \gamma}\pi_t$*. The slope of the PC is the only one being different in the panels. In (a) the slope of the PC-curve is given by* $\pi_t = \kappa(\sigma + \nu)y_t$*, while panel (b) includes a cost-channel and therefore reads the following* $\pi_t = \kappa((\sigma + \nu)y_t + \delta r_t)$

Figure 2: New Keynesian model at the Effective lower bound, negative demand shock



Notes: Fluctuations due to the demand shock are marked by the grey zone, while the dark grey zone shows the fluctuations due to a demand shock in an economy featuring a cost-channel. The slope of the MP-Curve is given by the monetary policy rule $r_t = \max\left\{(\frac{1}{\beta}, \phi_\pi \pi_t + \phi_y y_t\right\} + \mu_t)$ *, the one of the IS-curve is equal to* $y_t = -\gamma r_t + d_t$*, and is equal in both panels. The slope of the AD-Curve is given by inserting* r_t *into the Euler-Equation and solving for* y_t*, which yields the following* $y_t = -\frac{\phi_\pi \gamma}{1+\phi_y \gamma}\pi_t$*. The slope of the PC is the only one being different in the panels. In (a) the slope of the PC-curve is given by* $\pi_t = \kappa(\sigma + \nu)y_t$*, while panel (b) includes a cost-channel and therefore reads the following* $\pi_t = \kappa((\sigma + \nu)y_t + \delta r_t)$

Figure 3: Impulse response functions after a positive demand shock, outside the ZLB

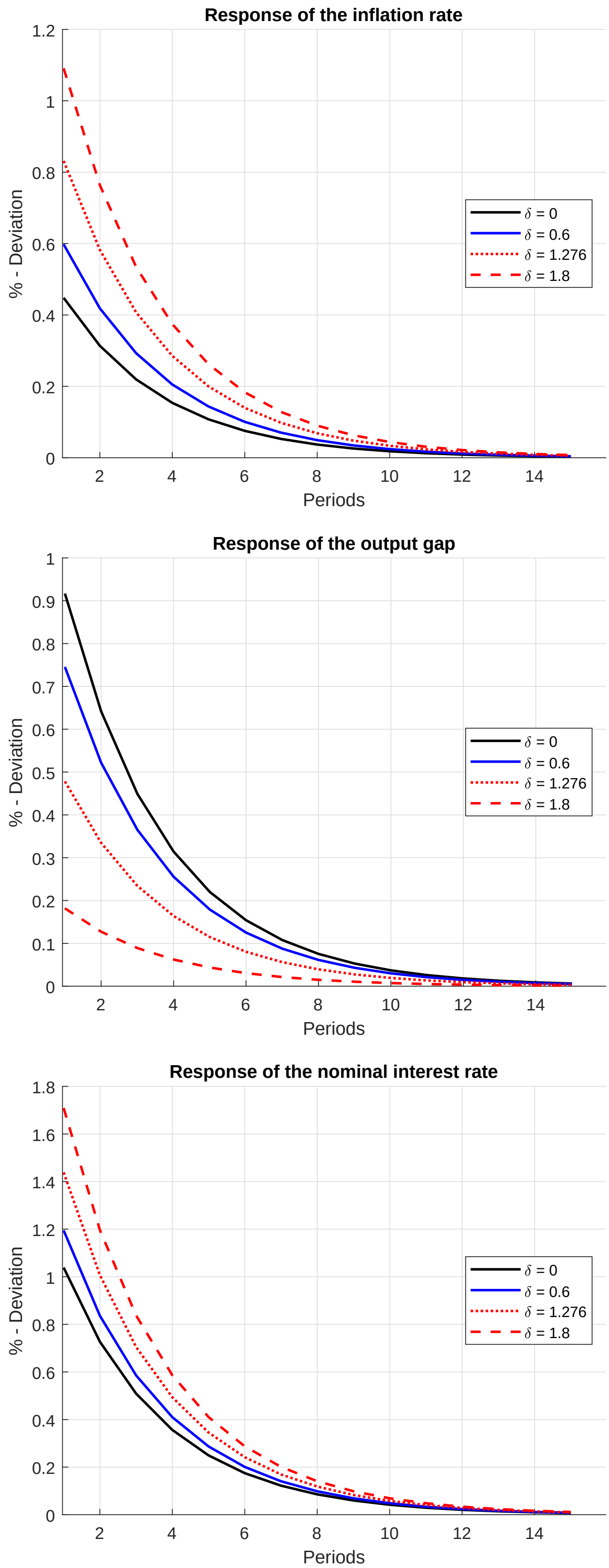


Figure 4: Impulse response functions for discretionary monetary policy at the ZLB

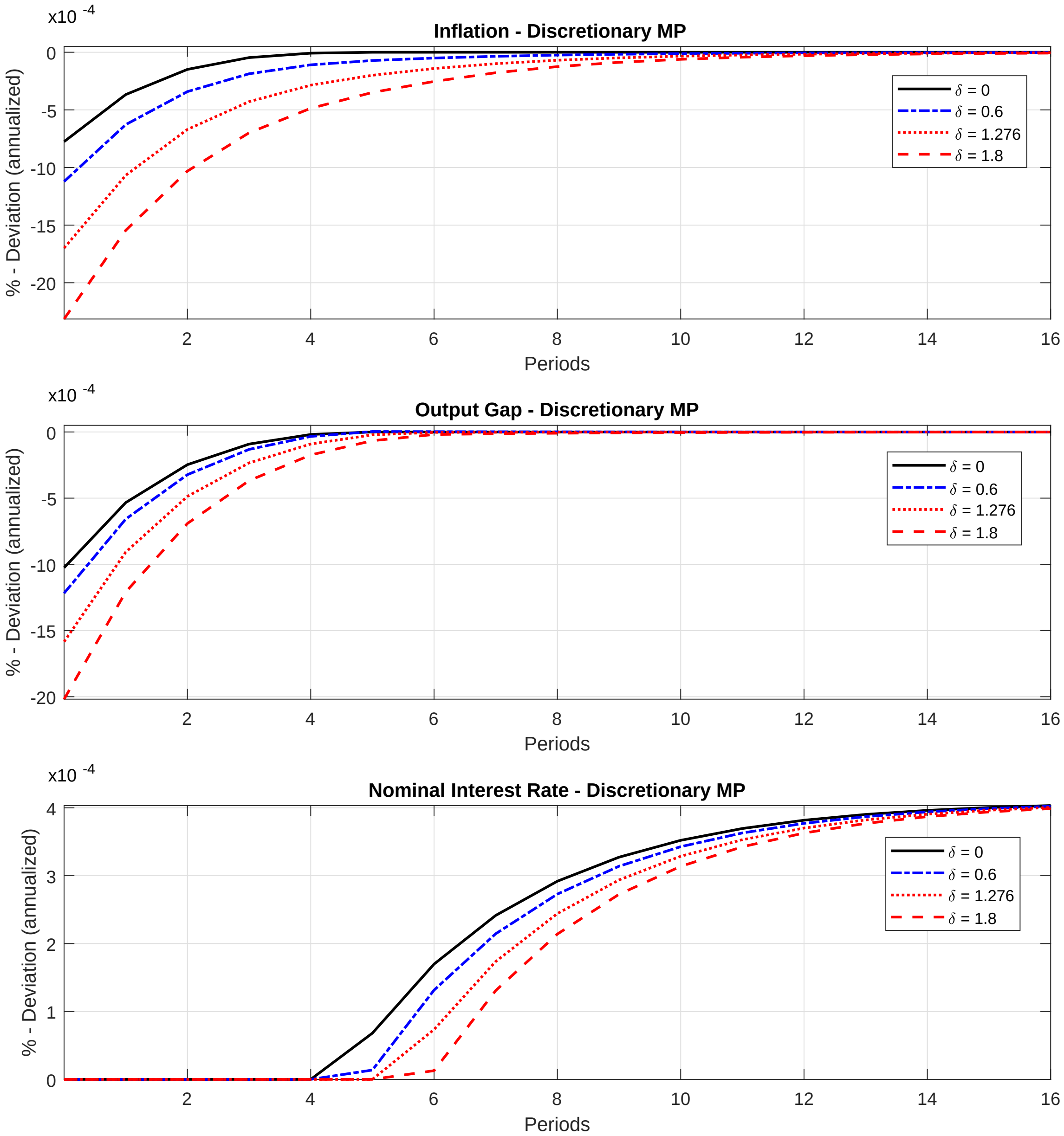
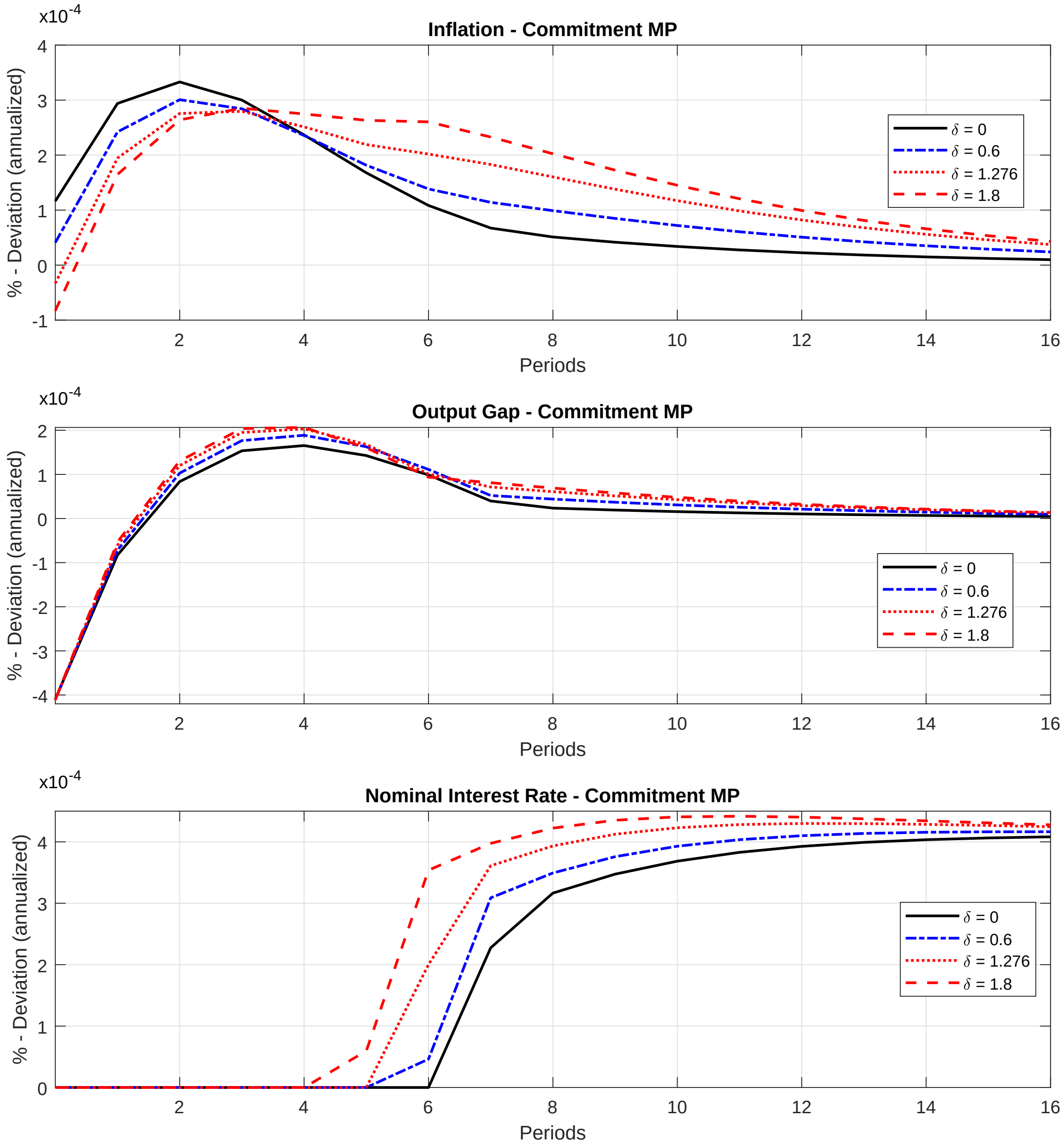


Figure 5: Impulse response functions for committing monetary policy at the ZLB



B Appendix B

B.1 Tables

Table 1: Calibration of parameters

Parameter	Description	Value
α	probability of setting old price	0.75
β	discount factor of households	0.99
δ	strength of the cost-channel	[0,1.8]
γ	relative risk aversion	1
ν	elasticity of labour supply	0.5
ϕ_y	influence of the output gap in on the nominal interest rate	0.4
ϕ_π	influence of the inflation rate on the nominal interest rate	1.5
ρ_r	persistency of demand shock	0.9
ρ_d	persistency of monetary policy shock	0.4
θ	elasticity of substitution between intermediate goods	10
ϱ	elasticity of output with respect to labour	2/3
λ	weight associated to output in the loss function	0.25

Notes: The table states the parameter values I used to calibrate my model and plot the impulse response functions.

B.2 Derivations

In the following I will state a different approach to derive the IS-MP and AD-PC equations compared to the one I am using in my paper.

The New-Kenyesian Phillips-curve, the IS-curve and the MP-curve initially all look the same.

NKPC:

$$\pi_t = \kappa((\gamma + \nu)y_t + \delta r_t) + \beta E_t[\pi_{t+1}] + \mu_t^{CP} \tag{25}$$

IS-curve:

$$y_t = E_t[-\frac{1}{\gamma}(r_t - \pi_{t+1}) + y_{t+1}] + d_t \tag{26}$$

The Monetary Policy-curve :

$$r_t = \phi_\pi \pi_t + \phi_y y_t + \mu_t^R \tag{27}$$

In order to derive the static solution for the model two assumptions need to be make. The first is, that the authority is fully credible, which allows to set $E_t\ [\pi_{t+1}] = \pi_0$, where the latter represents the long-run target rate of infation. The second assumption which needs to be taken is, that the economy in equilibrium is close to full employment, wherefore the output-gap is $E_t[y_{t+1}] = y_0$. Due to that the gap between the real interest rate and natural interest rate disappears from the IS-curve. This leads to the above stated equation simplifying to the following:

$$\pi = \pi_0 + \kappa(\gamma + \nu)y + \delta\kappa r + \mu^{CP} \tag{28}$$

$$y = y_0 - \frac{1}{\gamma}r + d \tag{29}$$

$$r = \phi_\pi(\pi - \pi_0) + \phi_y y + \mu^R \tag{30}$$

Combining equations (5) and (6) yields the AD-curve:

$$y = \frac{y_0}{1+\gamma\phi_y} - \frac{\gamma\phi_\pi}{1+\gamma\phi_y}(\pi - \pi_0) + \frac{1}{d\gamma\phi_y}, \tag{31}$$

while the NKPC can be re-written as:

$$(\pi - \pi_0) = \frac{\kappa((\gamma+\nu) + \delta\phi_y)}{1 - \delta\kappa\phi_\pi} + \frac{\mu^{CP}}{1 - \delta\kappa\phi_\pi}. \tag{32}$$

The IS-curve is equal to Equation (5) and the MP-curve equal to (6).

B.3 Guess and Verify

The following section contains the Guess and Verify approach in order to derive the coefficients of the impulse response functions.

$$\pi_t = \beta E_t \pi_{t+1} + \kappa\big((\sigma+\nu)y_t + \delta i_t\big) + \mu_t^{CP} \tag{33}$$

$$y_t = E_t y_{t+1} - \frac{1}{\gamma}(r_t - E_t \pi_{t+1}) + d_t \tag{34}$$

$$r_t = \phi_\pi \pi_t + \phi_y y_t + \mu_t^R \tag{35}$$

In the following a cost-push shock will be denoted as e_t, while an demand shock euals u_t and a monetary policy shock m_t. The guess is, that π_t and y_t respond to shocks the following way:

$\pi_t = \psi_{\pi,e} e_t + \psi_{\pi,u} u_t + \psi_{\pi,m} m_t$

$y_t = \psi_{y,e} e_t + \psi_{y,u} u_t + \psi_{y,m} m_t$

1) Cost-Push Shock

$e_t : \pi_t = \psi_{\pi,e} e_t \quad \& \quad y_t = \psi_{y,e} e_t$

$E_t \pi_{t+1} = \psi_{\pi,e} E_t e_{t+1} = \psi_{\pi,e} \rho_e e_t + E_t e_t = \psi_{\pi,e} \rho_e e_t$

$E_t y_{t+1} = \psi_{y,e} E_t e_{t+1} = \psi_{y,e} \rho_e e_t + E_t e_t = \psi_{y,e} \rho_e e_t$

$\psi_{y,e} e_t = \psi_{y,e} \rho_e e_t - \frac{1}{\gamma}[(\phi_\pi \psi_{\pi,e} e_t + \phi_y \psi_{y,e} e_t) - \psi_{\pi,e} \rho_e e_t]$

$\psi_{y,e} = \psi_{y,e} \rho_e - \frac{1}{\gamma}[(\phi_\pi \psi_{\pi,e} + \phi_y \psi_{y,e}) - \psi_{\pi,e} \rho_e]$

$\psi_{y,e} - \psi_{y,e} \rho_e + \frac{1}{\gamma} \phi_y \psi_{y,e} = \frac{1}{\gamma} \phi_\pi \psi_{\pi,e} + \frac{1}{\gamma} \psi_{\pi,e} \rho_e$

$\psi_{y,e}(1 - \rho_e + \frac{1}{\gamma}\phi_y) = \psi_{\pi,e}(\frac{1}{\sigma}\rho_e - \frac{1}{\gamma}\phi_\pi)$

$\psi_{y,e} \frac{(1-\rho_e+\frac{1}{\gamma}\phi_y)}{(\frac{1}{\gamma}\rho_e - \frac{1}{\gamma})} = \psi_{\pi,e}$

$\psi_{\pi,e} e_t = \beta \psi_{\pi,e} \rho_e e_t + \kappa[(\sigma+\nu)\psi_{y,e} e_t + \delta(\phi_\pi \psi_{\pi,e} e_t + \phi_y \psi_{y,e} e_t] + e_t$

$$\psi_{\pi,e} = \beta\psi_{\pi,e}\rho_e + \kappa[(\sigma+\nu)\psi_{y,e} + \delta(\phi_\pi\psi_{\pi,e} + \phi_y\psi_{y,e}] + 1$$

$$\psi_{\pi,e} - \beta\psi_{\pi,e}\rho_e - \kappa\delta\phi_\pi\psi_{\pi,e} = \kappa(\sigma+\nu)\psi_{y,e} + \kappa\delta\phi_y\psi_{y,e} + 1$$

$$\frac{(1-\rho_e+\frac{1}{\gamma}\phi_y)}{(\frac{1}{\gamma}\rho_e-\frac{1}{\gamma}\phi_\pi)}\psi_{y,e} = \psi_{y,e}\frac{(\kappa(\sigma+\nu)+\kappa\delta\phi_y)}{(1-\beta\rho_e-\kappa\delta\phi_\pi)} + \frac{1}{(1-\beta\rho_e-\kappa\delta\phi_\pi)}$$

$$\psi_{y,e}\left(\left(\frac{1-\rho_e+\frac{1}{\gamma}\phi_y}{\frac{1}{\gamma}\rho_e-\frac{1}{\gamma}\phi_\pi}\right) - \left(\frac{\kappa(\sigma+\nu)+\kappa\delta\phi_y}{(1-\beta\rho_e-\kappa\delta\phi_\pi)}\right)\right) = \frac{1}{(1-\beta\rho_e-\kappa\delta\phi_\pi)}$$

$$\psi_{y,e} = \frac{1}{(1-\beta\rho_e-\kappa\delta\phi_\pi)}\frac{1}{D_e}$$

$$\psi_{\pi,e} = \psi_{y,e}\frac{(1-\rho_e+\frac{1}{\gamma}\phi_y)}{(\frac{1}{\gamma}\rho_e-\frac{1}{\gamma})}$$

$$D_e = \left(\left(\frac{1-\rho_e+\frac{1}{\gamma}\phi_y}{\frac{1}{\gamma}\rho_e-\frac{1}{\gamma}\phi_\pi}\right) - \left(\frac{\kappa(\sigma+\nu)+\kappa\delta\phi_y}{(1-\beta\rho_e-\kappa\delta\phi_\pi)}\right)\right)$$

2) Demand Shock

$u_t : \pi_t = \psi_{\pi,u}u_t \quad \& \quad y_t = \psi_{y,u}u_t$

$$E_t\pi_{t+1} = \psi_{\pi,u}E_tu_{t+1} = \psi_{\pi,u}\rho_u u_t + E_tu_t = \psi_{\pi,u}\rho_u u_t$$

$$E_ty_{t+1} = \psi_{y,u}E_tu_{t+1} = \psi_{y,u}\rho_u u_t + E_tu_t = \psi_{y,u}\rho_u u_t$$

$$\psi_{\pi,u}u_t = \beta\psi_{\pi,u}\rho_u u_t + \kappa[(\sigma+\nu)\psi_{y,u}u_t + \delta(\phi_\pi\psi_{\pi,u}u_t + \phi_y\psi_{y,u}u_t]$$

$$\psi_{\pi,u} - \beta\psi_{\pi,u}\rho_u - \kappa\delta\phi_\pi\psi_{\pi,u} = \kappa(\sigma+\nu)\psi_{y,u} + \kappa\delta\phi_y\psi_{y,u}$$

$$\psi_{\pi,u}(1-\beta\rho_u-\kappa\delta\phi_\pi) = \psi_{y,u} + (\kappa(\sigma+\nu)+\kappa\delta\phi_y)$$

$$\psi_{\pi,u} = \psi_{y,u}\frac{\kappa(\sigma+\nu)+\kappa\delta\phi_y}{(1-\beta\rho_u-\kappa\delta\phi_\pi)}$$

$$\psi_{y,u}u_t = \psi_{y,u}\rho_u u_t - \frac{1}{\gamma}(\phi_\pi\psi_{\pi,u}u_t + \phi_y\psi_{y,u}u_t) - \psi_{\pi,u}\rho_u u_t) + u_t$$

$$\psi_{y,u}(1-\rho_u+\frac{1}{\gamma}\phi_y) = \psi_{\pi,u}\frac{1}{\gamma}(\rho_u - \ phi_\pi) + 1$$

$$\psi_{y,u} = \psi_{\pi,u}\frac{(\frac{1}{\gamma}\rho_u-\frac{1}{\gamma}\phi_\pi)}{(1-\rho_u+\frac{1}{\gamma}\phi_y)} + \frac{1}{(1-\rho_u+\frac{1}{\gamma}\phi_y)}$$

$$\psi_{\pi,u}\Bigg(\big(\frac{(1-\beta\rho_u-\kappa\delta\phi_\pi)}{\kappa[\sigma+\nu)+\kappa\delta\phi_y}\big)-\big(\frac{\frac{1}{\gamma}(\rho_u-\phi_\pi)}{(1-\rho_u+\frac{1}{\gamma}\phi_y)}\big)\Bigg)=\frac{1}{(1-\rho_u+\frac{1}{\gamma}\phi_y)}$$

$$\psi_{\pi,u}=\frac{1}{1-\rho_u+\frac{1}{\gamma}\phi_y}\frac{1}{D_u}$$

$$\psi_{y,u}=\psi_{\pi,u}\frac{(1-\beta\rho_u-\kappa\delta\phi_\pi)}{\kappa(\sigma+\nu)+\kappa\delta\phi_y)}$$

$$D_u=\Bigg(\big(\frac{(1-\beta\rho_u-\kappa\delta\phi_\pi)}{\kappa[\sigma+\nu)+\kappa\delta\phi_y}\big)-\big(\frac{\frac{1}{\gamma}(\rho_u-\phi_\pi)}{(1-\rho_u+\frac{1}{\gamma}\phi_y y)}\big)\Bigg)$$

3) Monetary Policy Shock

$$m_t:\pi_t=\psi_{\pi,m}m_t \quad \& \quad y_t=\psi_{y,m}m_t$$

$$E_t\pi_{t+1}=\psi_{\pi,m}E_tm_{t+1}=\psi_{\pi,m}\rho_m m_t+E_tm_t=\psi_{\pi,m}\rho_m m_t$$

$$E_ty_{t+1}=\psi_{y,u}E_tm_{t+1}=\psi_{y,m}\rho_m m_t+E_tm_t=\psi_{y,m}\rho_m m_t$$

$$\psi_{\pi,m}m_t=\beta\psi_{\pi,m}\rho_m m_t+\kappa((\sigma+\nu)\psi_{y,m}m_t+\delta(\phi_\pi\psi_{\pi,m}m_t+\phi_y\psi_{y,m}m_t+m_t)$$

$$\psi_{\pi,m}-\beta\psi_{\pi,m}\rho_m-\kappa\delta\phi_\pi\psi_{\pi,m}=\kappa(\sigma+\nu)\psi_{y,m}+\kappa\delta\phi_y\psi_{y,m}+\kappa\delta$$

$$\psi_{\pi,m}(1-\beta\rho_m-\kappa\delta\phi_\pi)=\psi_{y,m}(\kappa(\sigma+\nu)+\kappa\delta\phi_y)+\kappa\delta$$

$$\psi_{\pi,m}=\psi_{y,m}\frac{(\kappa(\sigma+\nu)+\kappa\delta\phi_y)}{(1-\beta\rho_m-\kappa\delta\phi_\pi)}+\frac{\kappa\delta}{(1-\beta\rho_m-\kappa\delta\phi_\pi)}$$

$$\psi_{y,m}m_t=\psi_{y,m}\rho_m m_t-\frac{1}{\gamma}\Bigg((\phi_\pi\psi_{\pi,m}m_t+\phi_y\psi_{y,m}m_t+m_t)-\psi_{\pi.m}m_t\rho_m\Bigg)$$

$$\psi_{y,m}(1-\rho_m+\frac{1}{\gamma}\phi_y)=\psi_{\pi,m}(\frac{1}{\gamma}\rho_m-\phi_\pi\frac{1}{\gamma})-\frac{1}{\gamma}$$

$$\psi_{y,m}=\psi_{\pi,m}\frac{(\frac{1}{\gamma}\rho_m-\phi_\pi\frac{1}{\gamma})}{(1-\rho_m+\frac{1}{\gamma}\phi_y)}-\frac{\frac{1}{\gamma}}{(1-\rho_m+\frac{1}{\gamma}\phi_y)}$$

$$\psi_{\pi,m}\Bigg(\big(\frac{1-\beta\rho_m-\kappa\delta\phi_\pi}{\kappa(\sigma+\nu)+\kappa\delta\phi_y}\big)-\big(\frac{\frac{1}{\gamma}(\rho_m-\phi_\pi)}{1-\rho_m+\frac{1}{\gamma}\rho_y}\big)\Bigg)=-\frac{\frac{1}{\gamma}}{(1-\rho_m+\frac{1}{\gamma}\phi_y)}+\frac{\kappa\delta}{(1-\beta\rho_m-\kappa\delta\phi_\pi)}\big(\frac{1-\beta\rho_m-\kappa\delta\phi_\pi}{\kappa(\sigma+\nu)+\kappa\delta\phi_y}\big)$$

$$\psi_{\pi,m}=\Bigg(-\frac{\frac{1}{\gamma}}{(1-\rho_m+\frac{1}{\gamma}\phi_y)}+\frac{\kappa\delta}{(1-\beta\rho_m-\kappa\delta\phi_\pi)}\big(\frac{1-\beta\rho_m-\kappa\delta\phi_\pi}{\kappa(\sigma+\nu)+\kappa\delta\phi_y}\big)\Bigg)\frac{1}{D_m}$$

$$\psi_{y,m} = \psi_{\pi,m} \frac{(\frac{1}{\gamma}\rho_m - \phi_\pi \frac{1}{\gamma})}{(1-\rho_m+\frac{1}{\gamma}\phi_y)} - \frac{\frac{1}{\gamma}}{(1-\rho_m+\frac{1}{\gamma}\phi_y)}$$

$$D_m = \left(\left(\frac{1-\beta\rho_m-\kappa\delta\phi_\pi}{\kappa(\sigma+\nu)+\kappa\delta\phi_y}\right) - \left(\frac{\frac{1}{\gamma}(\rho_m-\phi_\pi)}{1-\rho_m+\frac{1}{\gamma}\rho_y}\right) \right)$$

B.4 Impulse Response Functions

The following section contains impulse response functions following different type of shocks which hit the economy. The shock value is equal to one, whch is an one percent shock or equal to one std. deviation.

Figure 6: Impulse response functions after a negate demand shock, outside the ZLB

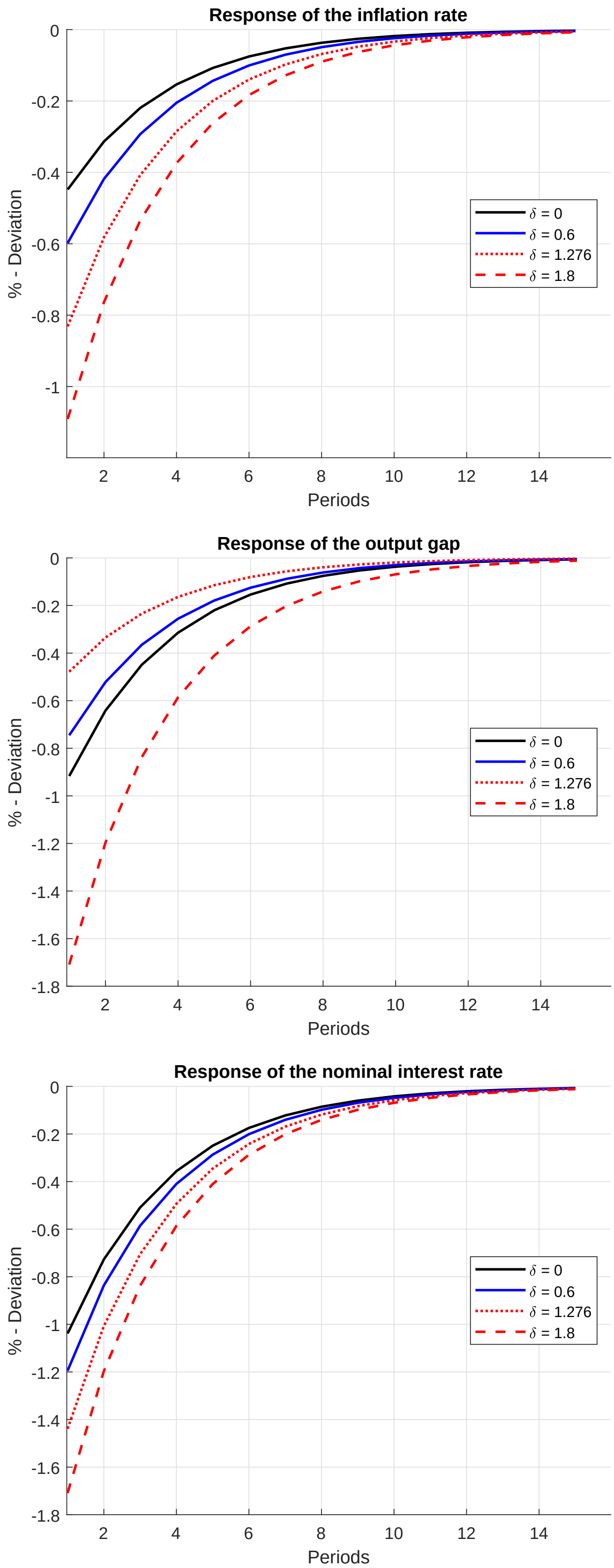


Figure 7: Impulse response functions after a cost-push shock, outside the ZLB

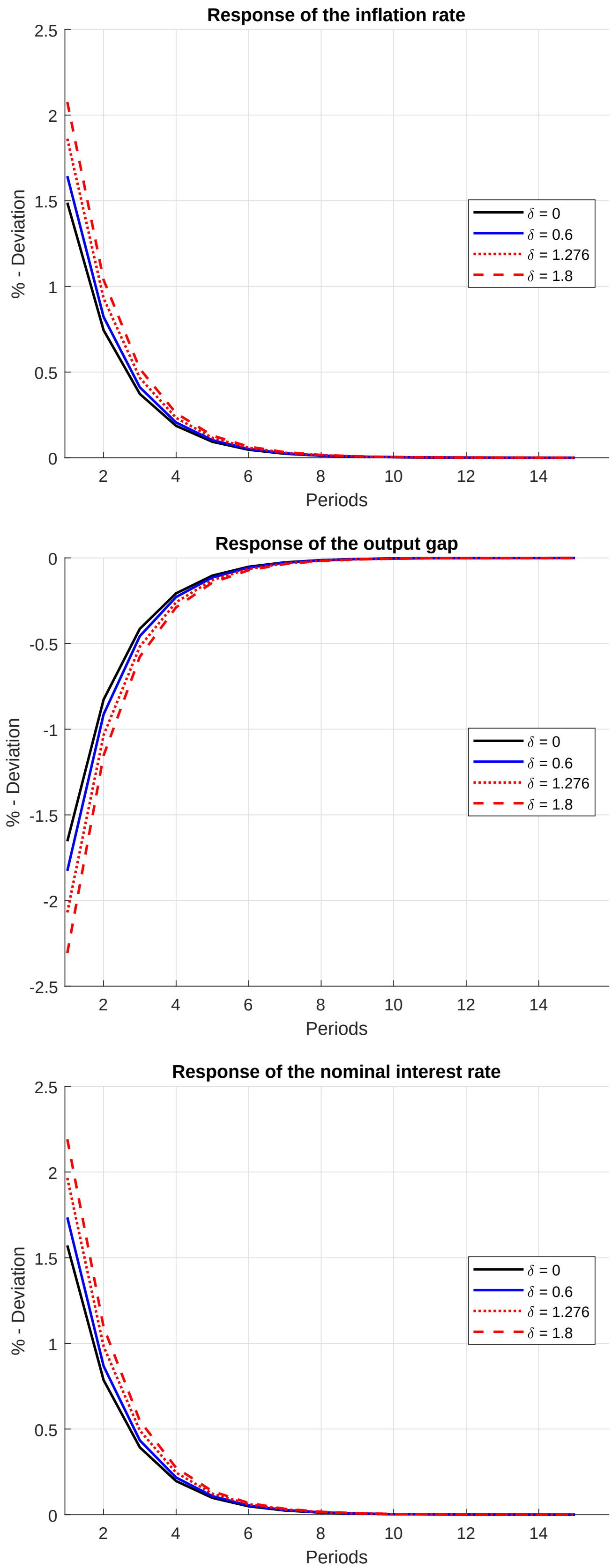


Figure 8: Impulse response functions after a negative cost-push shock, outside the ZLB

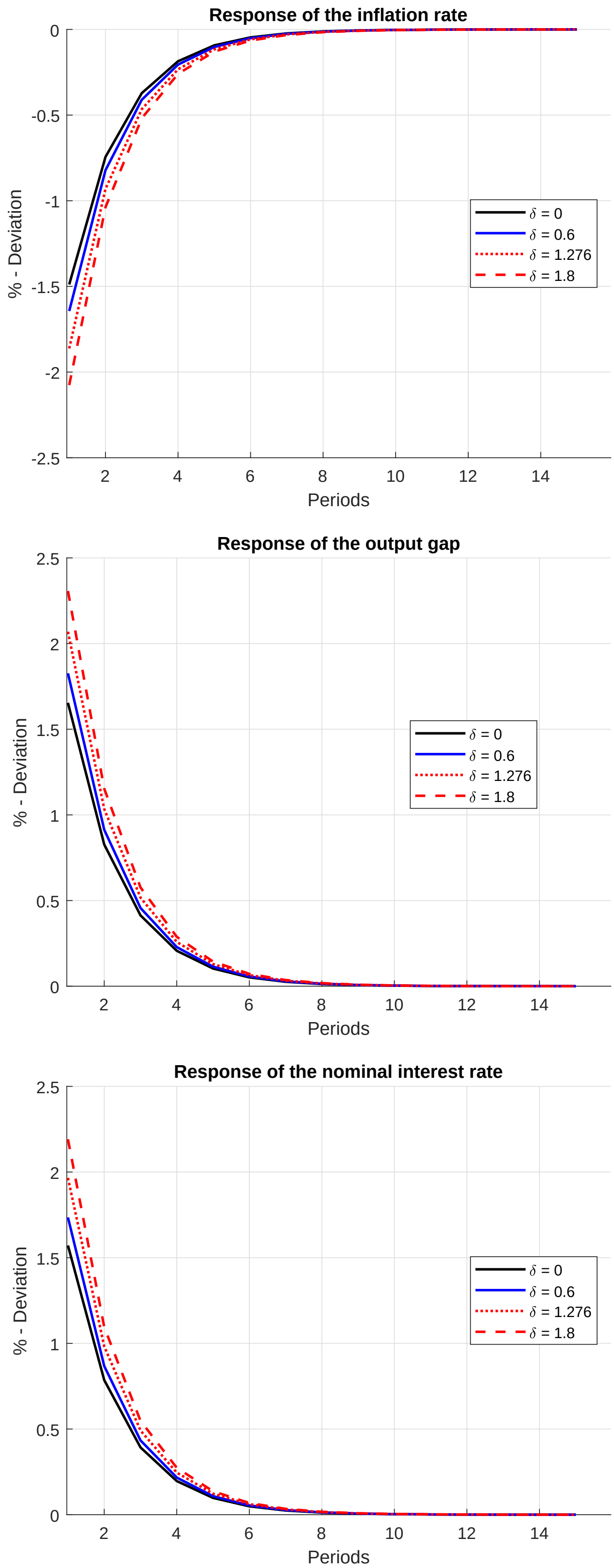


Figure 9: Impulse response functions after a positive monetary policyshock, outside the ZLB

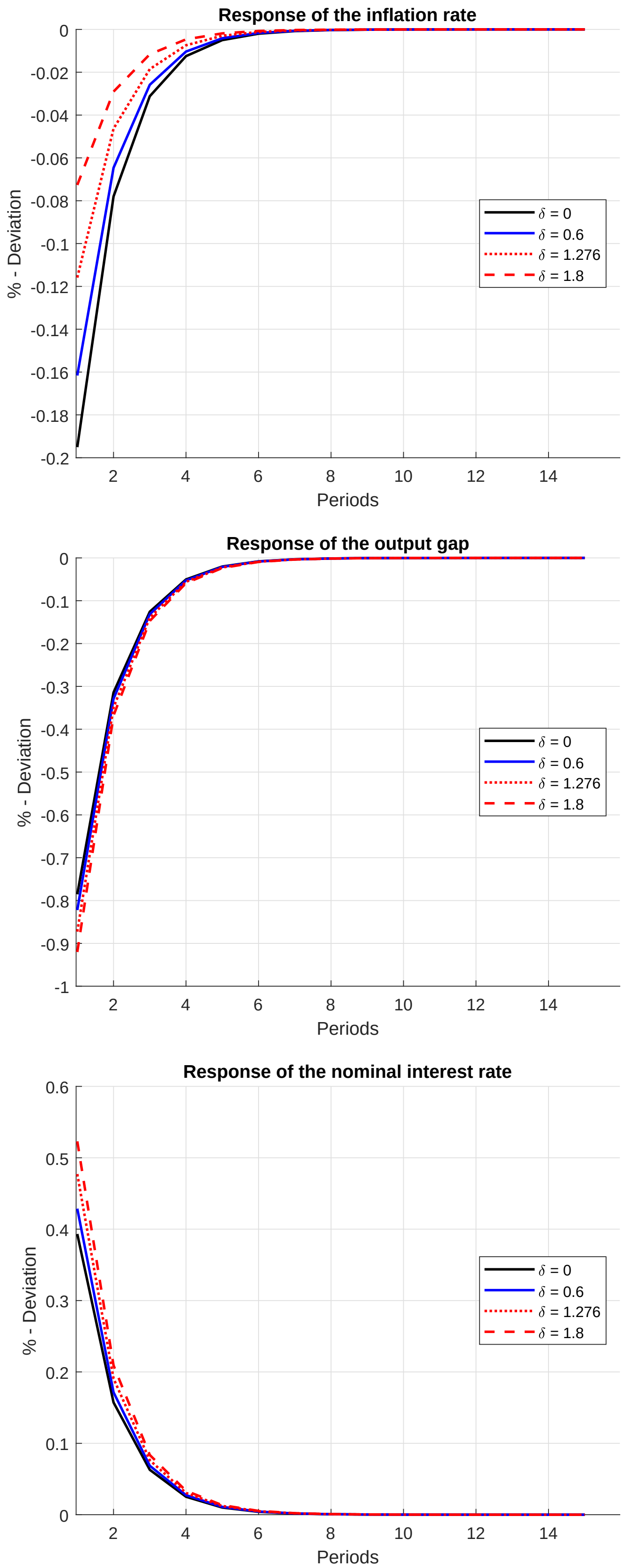


Figure 10: Impulse response functions after a negative monetary policyshock, outside the ZLB