Persistent Monetary Policy in a Model with Labor Market Frictions*

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Abstract

In a basic New Keynesian DSGE model with involuntary unemployment and inflation target shocks, we study the role of labor markets in the transmission of persistent monetary policy shocks that increase households' inflation expectations. The model predicts that labor market conditions can play important role in the transmission channel of the persistent inflation target shock: quantitatively realistic labor market frictions increase the expansionary effect of inflation target shock on output by around a half compared to that under the model without labor market frictions. Using a VAR analysis, we further provide empirical evidence consistent with the predictions of our theoretical model.

JEL classification: E32, E24, E52, E58

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1. INTRODUCTION

Central banks' effort to stimulate economies during the Great Recession pushed policy rates to zero. Consequently, this limited the central banks' capacity to raise excessively low inflation using the conventional monetary policy tools. As such, central banks had to employ alternative monetary policy instruments that instead target the households' long-term inflation expectations.[1] In this paper, we study the transmission of persistent monetary policy shocks, which target long-term inflation expectations, using a New Keynesian (NK) model with labor market frictions. We show that labor market frictions play important role in the transmission of persistent monetary policy shocks and, thus, should be taken into account by policymakers. We further provide empirical evidence consistent with the predictions of our theoretical model.

Empirical studies find that highly persistent monetary policy shocks that increase inflation in the long run boost production already in the short-run (Mumtaz and Theodoridis (2018), Uribe (2020), Lukmanova and Rabitsch (2020)). Intuitively, when economic agents expect higher prices in the future they optimally increase current consumption at prices lower relative to the future, which consequently stimulates aggregate demand and improves economic activity. However, to sustain output increase, production inputs must increase as well. Firms' ability to increase labor input, however, depends on the underlying labor market conditions. In a standard NK model, labor markets are frictionless and, thus, readily accommodate the increased demand for labor. Thus, to fully understand the transmission of persistent monetary shocks to output it is important to account for labor market imperfections that could either limit or increase the firm production capacity and, thus, affect the transmission of the shock.

We begin our analysis by constructing a stylized NK model with unemployment and persistent monetary policy shocks. We employ the model from Galí (2010), who introduces search and matching frictions, similar to those found in the Diamond-Mortensen-Pissarides search and matching model of unemployment, into otherwise standard basic NK model. We model persistent monetary policy shocks as shocks to the time-varying inflation target (Ireland (2007), Cogley et al.

[1] There have been several indications by the Federal Reserve (Fed) to employ long-term monetary policy measures: for example, in 2011 it has officially adopted a 2% inflation target, and in August 2020 the Fed has explicitly announced a course to increase long-run inflation expectations aiming to achieve inflation moderately above the 2% target for some time (Powell, 2020).

(2010), Lukmanova and Rabitsch (2020)).[2] The model is calibrated to the U.S. data.

Our analysis predicts that labor market conditions, which are shaped by labor market frictions, play important role in the transmission channel of the persistent inflation target shock. The inflation target shock transmits primarily through the demand channel (Lukmanova and Rabitsch (2020)). Upon the positive inflation target shock, households adjust their inflation expectations upwards leading to a fall in the real interest rate and a consequent increase in the current consumption relative to savings, which in turn creates an expansionary effect on output. The expansionary effect on output, however, depends on the firm's capacity to increase the production input, which is labor in our analysis. A priori the effect of labor market friction on the transmission of inflation target shock is not obvious. On the one hand, because of the persistent nature of the inflation target shock firms would want to maintain their increased production for multiple periods. This, however, sustaining a high level of employment for an extended period of time could be costly in the frictional labor market environment. On the other hand, the frictional labor market environment implies the presence of a pool of unemployed which can be readily used to extend production. Our model predicts that under the realistic value of labor market frictions the second effect dominates so that the expansionary effect of inflation target shock on output is around 40-50% larger in the model with labor market frictions than in the model without.

While we do find that labor market frictions are important for the transmission of the inflation target shock in the model, they do not appear so for the transmission of the standard temporary nominal interest rate shock. As in Galí (2010), at least quantitatively, the presence of labor market frictions has little impact on the economy's response to a standard temporary nominal interest rate shock. Because of the short-term nature of the nominal interest rate shock, quantitatively realistic labor market frictions are not sufficiently large to have a significant effect on the response of the real variables. Intuitively, following expansionary nominal interest shock firms increase their production only for a few periods, which is not long enough for the labor market frictions to have a meaningful effect. In contrast, due to the persistency of the inflation target shock even moderate firms need to increase their production for many periods to accommodate increased demand.

Results from the NK model indicate that: (i) quantitatively reasonable labor market frictions

[2] Alternatively, more recent contributions explicitly include permanent nominal interest rate shocks in the theoretical model framework (Uribe (2020); Cochrane (2018)).

amplify the real effect of the inflation target shock, (ii) increasing the pool of unemployed further increases the real effect of the inflation target shock, while (iii) more restricted access to the labor (e.g., higher hiring costs) leads to a smaller reaction of real output but a higher reaction of inflation. Equipped with these results, we turn to the empirical analysis of the transmission of a persistent monetary shock using U.S. data. Our objective here is to show that the effects of persistent monetary shocks on output and inflation could depend on labor market conditions. We use the time-varying parameter VAR model with stochastic volatility (TVP-VAR-SV) that allows us to capture this variation over time.

In particular, we augment the standard three-variable VAR model in output growth, inflation, and nominal interest rate with a measure of long-run inflation that allows us to introduce a persistent monetary shock. We identify inflation target shock using a combination of sign and zero restrictions as the only shock that leads to a contemporaneous increase in the long-run inflation. We find that a positive inflation target shock leads to a contemporaneous increase in inflation, nominal interest rate, and output growth, which is consistent with the existing empirical literature (Lukmanova and Rabitsch, 2020; Mumtaz and Theodoridis, 2018; Uribe, 2020). Comparing magnitudes of impulse responses across different periods in time, we find that the VAR-based evidence is fairly consistent with the predictions of the NK model. First, we find that the on-impact responses of output and inflation to the inflation target shock appear to be negatively related over time. We further document some evidence that the magnitude of the output response to the inflation target shock relates positively to the unemployment rate suggesting that the expansionary effect of the shock is stronger when unemployment is higher. Finally, we find mixed evidence on the negative relation between the response of inflation to the inflation target shock and unemployment rate.

This paper contributes to the literature studying the effect of persistent monetary shocks. Ireland (2007) estimates a New Keynesian model to examine the behavior of the Federal Reserve's unobserved inflation target. Cogley et al. (2010) estimate a VAR model with drifting coefficients and stochastic volatility to investigate the changes in the persistency of the US inflation. More recently, employing a SVAR analysis, Mumtaz and Theodoridis (2018) indemnify shocks to the FED's inflation target as VAR innovations that make the largest contribution to future movements in long-horizon inflation expectations. Uribe (2020) estimates an empirical and a New Keynesian model with transitory and permanent monetary shocks. His main finding is that permanent monetary shocks that increase both the nominal interest rate and inflation in the long run already in the short run cause increases in interest rates, inflation, and output and explain about 45% of inflation changes. Lukmanova and Rabitsch (2020) estimate a New Keynesian model with a standard nominal interest rate shock and a highly persistent inflation target. Assuming imperfect information about the nature of monetary shocks, they show that the Neo-Fisherian effects arise only with a lagged effect and not in the immediate short-run, because, in such a case, inflation expectations do not adjust immediately to the target shock. We contribute to this strand of the literature by examining how labor market conditions affect the transmission of persistent monetary shocks.

Our paper further contributes to the literature on the interactions between nominal rigidities and labor market frictions. Early work in this area includes Cheron and Langot (2000), Walsh (2005), and Trigari (2009), see further Galí (2010) for the survey. While unemployment plays a central role in the policy debate, it is typically absent in the formal analysis of monetary policy. One of the reasons behind this is the lack of quantitative importance of labor market frictions in the transmission of monetary policy shocks, which has been shown in the previous literature. For example, Galí (2010) studies the interaction between labor market frictions and nominal rigidities in a New Keynesian DSGE model with involuntary unemployment. One of his main findings is that, quantitatively, the presence of labor market frictions has little impact on the economy's response to standard short-term monetary policy shocks. Our paper contributes to this strand of the literature showing that realistic labor market fictions do play role in the transition of persistent monetary shocks such as inflation target shocks.

The results of our analysis are relevant to the current policy debate. For example, in a recent speech, the chairman of the Fed, J. Powell, announced a course to higher long-run inflation expectations aiming to stimulate employment and inflation in the U.S. (Powell, 2020). Our results indicate that such a policy may have only little effect on output due to labor market frictions. On the other hand, in the post-COVID 19 pandemic world, which is, at least temporarily, characterized by an enlarged pool of unemployed many advanced and developing countries could try to stimulate their economies by raising inflation expectations (for example, through increasing inflation target). However, again this policy could be less effective in those countries that have less efficient labor markets (i.e., countries with higher hiring costs).

The rest of the paper proceeds as follows: Section 2 introduces a basic New Keynesian model with involuntary unemployment and a persistent monetary policy; Section 3 summarizes the calibration exercise and offers the analysis of the model's equilibrium dynamics; Section 4 examines the predictions of the theoretical model on the U.S. data; finally, Section 5 concludes.

2. NEW KEYNESIAN MODEL WITH LABOR MARKET FRICTIONS

To study the transmission of the inflation target shock in a model with labor market frictions, we employ a New Keynesian model with labor market frictions developed in Galí (2010). In this model households consume final good, supply labour to intermediate good producers, and save. Final good producers are monopolistically competitive firms, which use intermediate good as the only factor of production and are subject to nominal rigidities. Intermediate producers are competitive firms, which use labour as the only impact of production. Every period a fraction of workers exogenously separates from the firm and to hire new workers the firm must pay the hiring cost proportional to the aggregate labor market tightness. The wages are determined through a Nash bargaining protocol.

To model inflation expectations, which are affected by persistent monetary shocks, we introduce a time-varying inflation target into an otherwise standard generalized Taylor rule. Therefore, rather than adjusting the nominal policy rate as a response to the change in inflation, the monetary authority makes adjustments to the change in the inflation gap, which is defined as the difference between current inflation and inflation target.

Formally, the monetary authority follows a generalized Taylor rule–that is, it adjusts the policy rate i_t to price inflation π_t^p and the output gap $y_t - y_t^*$, which is defined as the difference between actual and potential output, y_t^*. To model inflation expectations, we follow the previous literature and introduce a time-varying price inflation target $\tilde{\pi}_t^p$ (Ireland (2007); De Graeve et al. (2009); Cogley et al. (2010); Lukmanova and Rabitsch (2020)). Therefore, the monetary authority will adjust the nominal policy rate as a response to the change in the inflation gap $\pi_t^p - \tilde{\pi}_t^p$. The inflation target evolves as a highly persistent AR(1) process

$$\tilde{\pi}_t = \rho_{\tilde{\pi}} \tilde{\pi}_{t-1} + \varepsilon_{\tilde{\pi},t}, \tag{1}$$

where $\rho_{\tilde{\pi}} \in (0,1)$ and $\varepsilon_{\tilde{\pi},t} \sim \mathcal{N}(0, \sigma^2_{\varepsilon_{\tilde{\pi}}})$ denotes the inflation target shock.

The log-linearized Taylor rule is given by

$$i_t = \rho i_{t-1} + (1-\rho)\left[\kappa_\pi(\pi_t - \tilde{\pi}_t) + \kappa_y(y_t - y_t^*)\right] + \varepsilon_{r,t}, \tag{2}$$

where $\rho \in (0,1)$ is the nominal rate smoothing parameter and $\varepsilon_{r,t} = \rho_\nu \varepsilon_{r,t-1} + \nu_t$ is the nominal interest rate shock with $\nu_t \sim \mathcal{N}(0, \sigma_\nu^2)$.

Below, we provide a short summary of the Galí (2010) model.

2.1 Households

There is a large number of identical households comprising a continuum of members represented by the unit interval. As in Merz (1995), it is assumed that there is a full consumption risk sharing within each household. The households maximize the life-time expected utility defined over the sequence of the composite consumption good C_t and the index of labor effort L_t:

$$\max \ \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left[ln(C_t) - \frac{\chi}{1+\varphi} L_t^{1+\varphi} \right] \tag{3}$$

where $\beta \in (0,1)$ is the discount factor and the composite consumption good is defined as $C_t = \left[\int_0^1 C_t(i)^{1-\frac{1}{\epsilon}} \mathrm{d}i\right]^{\frac{\epsilon}{\epsilon-1}}$.[3]

The labour effort index, L_t, is defined as

$$L_t = N_t + \psi U_t \tag{4}$$

where N_t is the fraction of households that are employed in period t; U_t are unemployed households that are looking for a job; $\psi \in [0,1]$ is the marginal disutility of unemployed workers relative to the

[3]In the baseline model, we assume that household utility is separable in consumption and leisure. In section B.2, we extend our analysis and allow for non-separable utility function to implicitly account for different levels of utility across employed and unemployed (as in Bilbiie (2011); Guerron-Quintana (2008); Yedid-Levi (2016) or Chodorow-Reich and Karabarbounis (2016), among others). There is vast empirical evidence pointing to substantial disutility of being unemployed (e.g. Chetty and Looney (2007); Rätzel (2012)), while the current model specification only accounts for the disutility from labor for employed workers. Since there is no disutility from unemployment, the per period utility of unemployed is higher than utility derived in the same period by employed worker. Christiano et al. (2020) address these concerns by introducing search frictions on the side of households, making unemployment in their model indeed involuntary. Chodorow-Reich and Karabarbounis (2016) empirical estimates of cyclicality of opportunity costs of moving from unemployed to employed contradict the implied disutility from unemployed in macro models, therefore, we assume utility non-separable in consumption and leisure. The non-separability assumption implies higher utility of employed workers, they are compensated (rewarded) for labor, and unemployed want to become employed.

employed ones. The aggregate labor force F_t is defined as the sum of employed and unemployed workers–that is, $F_t = N_t + U_t$. Household members that are nether employed nor unemployed and not looking for a job–that is, the fraction $1 - F_t$ of households–derive no disutility from being unemployed.[4] From the definition of L_t it is clear that the household is maximizes the utility of the whole family that includes employed and unemployed workers, thus accounting for the disutility from foregone leisure and disutility from being unemployed.

At the aggregate level, the evolution of employment is determined by the separation of old and creation of new matches between the workers and the firms. Let $\delta \in (0, 1)$ be the constant exogenous separation rate between the workers and the firms. Further, let $x_t \in (0, 1)$ be the endogenous time-varying job finding rate. Then the employment evolves according to the following law of motion:

$$N_t = (1 - \delta)N_{t-1} + x_t U_t^0 \tag{5}$$

which stipulates that the fraction of employed members of the household at time t is given by the sum of the old non-separated matches $(1 - \delta)N_{t-1}$ and the newly created matches $x_t U_t^0$, where U_t^0 is the fraction of unemployed workers at the beginning of period t. The job finding rate x_t is defined as $x_t = \frac{H_t}{U_t^0}$, where H_t is new hires.

Note that the bargaining over wages takes place prior to production. Once wages are determined, the new workers become employed and participate in the production of the same period. Those that failed to find job at t, become unemployed–that is,

$$U_t = (1 - x_t)U_t^0. \tag{6}$$

The household is subject to the sequence of the budget constraints:

$$\int_0^1 P_t(i)C_t(i)di + Q_t B_t = \int_0^1 W_t(i)L_t(i)di + T_t + B_{t-1} + \Pi_t, \tag{7}$$

where B_t is one-period bond at purchased at a price Q_t, T_t are transfers from the government, and Π_t are proceeds from capital ownership.[5]

[4] The standard settings without labor market frictions is nested as a special case when $\psi = 0$.

[5] The optimal demand for consumption of the variety i is given by $C_t(i) = [P_t(i)/P_t]^{-\epsilon} C_t$, where $P_t = \left[\int_0^1 P_t(i)^{1-\epsilon}di\right]^{1/(1-\epsilon)}$ so that $\int_0^1 P_t(i)C_t(i) = P_t C_t$.

The solution for the household maximization problem yield the standard intertemporal optimality condition for consumption:

$$Q_t = \beta \mathbb{E}\left[\frac{C_t}{C_{t+1}}\frac{P_t}{P_{t+1}}\right], \tag{8}$$

and a the intertemporal optimality condition for labor effort:

$$\frac{W_t}{P_t} = \zeta C_t N_t^{\varphi}. \tag{9}$$

Unlike in a standard New Keynesian model, where wage adjusts to ensure full employment, in this current settings the wage is determined as a result of a bargaining process between firms and households. It does not adjust automatically to reflect the labor supply. In fact, the amount of employment each period is aggregated over the hiring decisions of firms. Households can affect hiring decisions based on the degree of their bargaining power when negotiating the wage, and through hiring costs. Therefore, employment in this model reflects the demand for labor, which will later bring important implications for the effects of long-term monetary policies.

2.2 Production Sectors

The model has two production sectors. The firms of the final (retail) good sector sell consumption goods to households, while the intermediate sector firms produce these goods.

Retail firms buy the intermediate goods, re-pack and sell them to households. While no other production inputs but intermediate goods are used, retail firms are able to differentiate final goods by attaching different labels or brand names which enables them to have some monopolistic power. They charge markups and are subject to price rigidities à la Calvo (1983).[6]

There is a continuum of monopolistically competitive retail firms indexed by $i \in [0,1]$. Each retail firm produces a differentiated final good $Y_t(i)$ using an identical technology

$$Y_t(i) = X_t(i), \tag{10}$$

[6] In a standard setting final good producers operate in a perfectly competitive market. They produce one unit of final good from one unit of intermediate input while price rigidities arise at the intermediate production level. Here, since intermediate good producers are involved in wage negotiations, they are assumed to be price takers instead.

where $X_t(i)$ is the intermediate good used by firm i as an input.

Under Calvo (1983) staggered price settings, each firm i adjust its price each period only with a constant probability $1-\theta_p \in [0,1]$. Since firms have identical production technology and identical probability of resetting price all firms that can adjust their prices at time t will select price P_t^*. Thus, the (log) aggregate price, p_t, will evolve according to the following law of motion:

$$p_t = \theta_p p_{t-1} + (1-\theta_p)p_t^*. \tag{11}$$

The standard (log-linearized) Phillips curve can then be obtained by combining the above equation with the optimal price setting condition, which we state in the Appendix A, and is given by

$$\pi_t^p = \beta \mathbb{E}_t[\pi_{t+1}^p] - \lambda_p \hat{\mu}_t^p, \tag{12}$$

where $\pi_t^p = p_t - p_{t-1}$, $\hat{\mu}_t^p$ is the deviation of the price markup from its steady state value, and $\lambda_p = (1-\theta_p)(1-\beta\theta_p)/\theta_p$.

Next, there is a continuum of identical, perfectly competitive intermediate good producing firms indexed by $j \in [0,1]$. These firms have access to a production function

$$Y^I(j) = A_t N_t(j)^{1-\alpha}, \tag{13}$$

where A_t represents the state of technology.

Let $H_t(j)$ denote the new hires by firm j at time t, then employment at firm j evolves according to

$$N_t(j) = (1-\delta)N_{t-1}(j) + H_t(j). \tag{14}$$

As in Blanchard and Galí (2010) and Galí (2010), it is assumed that new hires start working in the period they are hired, thus, employment is not a predetermined variable.

The labor market friction takes the form of a cost per hire, which is denoted by G_t and defined in terms of the bundle of final goods. Each firm j takes G_t as given. However, G_t depends on the aggregate state of the economy. In particular, this cost is increasing in the labor market tightness, which is captured by the job finding rate $x_t = H_t/U_t^0$, where $H_t = \int_{j=0}^1 H_t(j)\mathrm{d}i$ is the aggregate level of new hires.[7] Specifically, we assume that

$$G_t := G(x_t) = \Gamma x_t^{\gamma}, \tag{15}$$

where $\Gamma > 0$.

Each period firm j hires workers so that the marginal product of labor equals the cost of a marginal worker–that is,

$$\frac{P_t^I}{P_t}(1-\alpha)A_t N_t(j)^{-\alpha} = \frac{W_t(j)}{P_t} + G_t - (1-\delta)\mathbb{E}_t[\Lambda_{t,t+1}G_{t+1}]. \tag{16}$$

2.3 Wage Determination

As in Galí (2010), the wages are assumed to be sticky: only a constant fraction $(1-\theta_w) \in [0,1]$ of firms can adjust their nominal wages in any given period. The wage is determined via a Nash bargaining protocol with constant shares of the total surplus, which is due to the existing employment. Since the probability of resetting wage in a given period is identical for all firms, in equilibrium all firms that readjust the wage will chose the same wage W_t^*. Thus, the law of motion for the log aggregates wage $w_t = \int_0^1 w_t(j)\mathrm{d}j$ is given by

$$w_t = \theta_w w_{t-1} + (1-\theta_w)w_t^*. \tag{17}$$

Galí (2010) derives the optimal wage setting equation in log-linearized form, which is given by

$$w_t^* = (1-\beta(1-\delta)\theta_w)\mathbb{E}_t \sum_{k=0}^{\infty} (\beta(1-\delta)\theta_w)^k \, \mathbb{E}_t[\omega_{t+k|t}^{tar} + p_{t+k}] \tag{18}$$

where $\omega_{t+k|t}^{tar}$ is the log of the k-period ahead target *real* wage under flexible wages (i.e., when $\theta_w = 0$). Thus, the nominal wage set through Nash bargaining is a weighted average of the current and expected future target nominal wages, $\omega_{t+k|t}^{tar} + p_{t+k}$, of the firm that is resetting wages. The weights decline geometrically with the horizon at a rate $\beta(1-\delta)\theta_w$, which is is a function of the wage stickiness degree θ_w and the separation rate δ, as both of these determine the expected duration of

[7] As explained in Galí (2010), this modeling approach is equivalent to the matching function approach adopted in the macro labor literature.

the newly set wage.

Galí (2010) further shows that combining equations (17) and (18) gives rise to the wage inflation equation:

$$\pi_t^w = \beta(1-\delta)\mathbb{E}_t[\pi_{t+1}^w]\lambda_w\left(\hat{\omega}_t - \hat{\omega}_t^{tar}\right), \tag{19}$$

where $\lambda_w = \frac{(1-\beta(1-\delta)\theta_w)(1-\theta_w)}{\theta_w(1-(1-\Upsilon)(1-\Phi))}$, and $\hat{\omega}_t - \hat{\omega}_t^{tar}$ is the wage gap defined as the deviation between the average real wage and the average real target wage. Finally, Υ and Φ are constants with their values determined by the model's parameters and are defined in Appendix A.

Finally, as shown in Galí (2010), the household's optimal labor market participation constraint can be written in the log-linearized form as

$$\hat{c}_t + \phi\hat{l}_t = \frac{1}{1-x}\hat{x}_t + \hat{g}_t - \Theta\pi_t^{\omega}, \tag{20}$$

where $\Theta = \frac{\xi(W/P)}{(1-\xi)G}\frac{\theta_w}{(1-\theta_w)(1-\beta(1-\delta)\theta_w)} > 0$ when wages are sticky and zero otherwise. The left-hand side is the marginal rate of substitution between consumption and labor effort index, which is the marginal cost of labor market participation, expressed in terms of log-deviation from its steady state value. The right-hand side is the marginal expected benefit from participation in the labor market. This expected marginal benefit is increasing in the probability of finding job x_t, the cost of hiring G_t (since newly hired workers obtain surplus proportional to this cost), and decreasing in the wage inflation π_t^{ω} (since it captures the discrepancy between the newly reset wage and the average prevailing wage–the wage that is relevant to job market participation decision).

2.4 Aggregate Demand and Output

Note that under assumption that hiring costs take the form of a bundle of final goods, the demand for final good i is given by $Y_t(i) = [P_t(i)/P_t]^{-\epsilon}(C_t + G_tH_t)$. Then under the CES aggregator for the final good production—that is, $Y_t = \left[\int_0^1 Y_t(i)^{\frac{\epsilon-1}{\epsilon}}di\right]^{\frac{\epsilon}{\epsilon-1}}$—one can write the aggregate demand for the final good as

$$Y_t = C_t + G_tH_t. \tag{21}$$

Thus, the aggregate demand consists of consumption, which is determined by the Euler equation (8), and the demand for the final good to cover the hiring costs.

To derive the aggregate supply, first, we relate the aggregate intermediate input, X_t, to the aggregate output of final goods, Y_t, which is

$$X_t := \int_0^1 X_t(i)\mathrm{d}i = \int_0^1 Y_t(i)\mathrm{d}i = Y_t D_t^p, \tag{22}$$

where $D_t^p = \int_0^1 [P_t(i)/P_t]^{-\epsilon}\mathrm{d}i \geq 1$ is therm that captures inefficiencies due to price dispersion of staggered prices. Next, we aggregate the total supply of intermediate goods and obtain

$$X_t = \int_0^1 Y_t^I(j)\mathrm{d}j = A_t \int_0^1 N_t(j)^{1-\alpha}\mathrm{d}i = A_t N_t^{1-\alpha} D_t^w, \tag{23}$$

where $D_t^w = \int_0^1 [N_t(j)/N_t]^{1-\alpha}\mathrm{d}i \geq 1$ is therm that captures inefficiencies due to wage dispersion.

Galí (2010) shows that in the neighborhood of steady state $D_t^p \approx D_t^w \approx 1$. Therefore, combining equations (22) and (23) one can write the aggregate supply of the final good as

$$Y_t = A_t N_t^{1-\alpha}. \tag{24}$$

3. EQUILIBRIUM DYNAMICS: THE EFFECTS OF MONETARY POLICY SHOCKS

3.1 Calibration

To calibrate the model, we follow closely Galí (2010) and Lukmanova and Rabitsch (2020). The values of the model parameters and their source of calibration are summarized in Table 1. See Galí (2010) for the detailed description of the calibration exercise.

The Taylor rule parameters κ_π and κ_y are set to 1.5 and 0.125, respectively. Consistent with the previous literature, we set the autoregressive coefficient of the inflation target process, $\rho_{\bar{\pi}}$, to 0.997 and its standard deviation parameter, $\sigma_{\varepsilon_{\bar{\pi}}}$, to 0.1, which reflects the high persistence and low volatility of this process.[8] The standard deviation of the nominal interest rate shock, σ_ε, is set to 0.25, implying roughly one percentage point deviation per year. Finally, while Galí (2010) has no interest rate smoothing in his model—that is, the coefficient ρ is set to zero—it sets the persistency of the nominal interest rate shock to 0.5. In our baseline calibration, we set the persistence of the nominal interest rate shock to zero highlighting the temporary nature of the interest rate shock and

[8] The values for these parameters are consistent with posterior mean estimates from Lukmanova and Rabitsch (2020) and Cogley et al. (2010).

contrasting it with the persistent inflation target shock. Nevertheless, in the sensitivity section, we further provide results under interest-rate smoothing by setting ρ to 0.8. The rest of the parameters are set to conventional values.

In the following subsections, we examine the impulse responses of the various endogenous variables of the model to a positive inflation target shock of one standard deviation and explore how these responses vary with labor market frictions. We further contrast these results with the impulse responses to a (positive) nominal rate shock.

3.2 Inflation Target Shock and Labour Market Frictions

We begin our analysis by examining the transmission of the inflation target shock in the model when wages are flexible–that is, when $\theta_w = 0$. Figure 1 presents the impulse responses of the various endogenous variables of the model to a positive inflation target shock of one standard deviation in the model with flexible wages. The impulse responses generated by the model with the labor market frictions are depicted by the blue dotted line, while the responses from the model without the labor market frictions are depicted by the black solid line.[9]

Figure 1 shows that under flexible wages the labor market frictions in the model generate qualitatively similar results with the exception of the response of the unemployment rate. Quantitatively, however, the presence of the labor market frictions in the model results in substantially larger magnitudes of the responses of the variables to the shock. Upon a persistent increase in the inflation target $\tilde{\pi}$, households anticipate that the monetary authority will aim at stabilizing the economy around the new inflation target (via the Taylor rule in equation (2)). Thus, expecting a persistent price growth in the future, households increase their consumption relative to savings resulting in a persistent growth in the aggregate demand. To accommodate the increased aggregate demand the production sector responds by increasing output leading to the expansionary effect on the aggregate output. The firms' capacity to increase production, however, depends on their ability to raise the production input, i.e. labor. Intuitively, it is easier for firms to hire when there is a pool of unemployed looking for a job–which is the case in the model with labor market frictions. It is easy to see that even if the labor market participation were kept at a fixed level, the model with labor market friction would still produce an expansionary effect on output following the shock:

[9] The model without labor market frictions has perfectly competitive labor market so that $W_t/P_t = MRS_t$.

with a surge in the number of new vacancies, the market tightness would decline, leading to a higher probability of finding a job and, consequently, to lower unemployment and higher aggregate output.

While our analysis suggests that the labor market frictions significantly magnifies the effect of output to the inflation target shock, this is not the case for a standard nominal interest rate shock. Figure 2 depicts the impulse responses of the various endogenous variables of the model to a *negative* nominal interest rate shock of one standard deviation in the model with flexible wages. Figure 2 replicates the result from Galí (2010) showing that under quantitatively realistic labor market frictions the responses of the real variables to the nominal shock are not significantly altered by the presence of the frictions. Because of the short-term nature of a standard monetary shock, quantitatively realistic labor market frictions are not sufficiently large enough to affect the dynamics in the model. Intuitively, following a negative standard monetary shock firms increase their production only on impact without the need to sustain it for multiple periods–this appears to be not long enough for the labor market frictions to have a meaningful effect. In contrast, due to the persistency of the inflation target shock firms need to increase their production for a long period to accommodate the increased demand.

We note that the effect of the inflation target shock on the real variables in the model with flexible wages is rather quantitatively small. The reason is that most of the shock is completely absorbed by inflation. Therefore, next, we assume sticky wages and examine the effect of this assumption on the transmission of the inflation target shock in the model with the labor market frictions. Figure 3 depicts the impulse responses of the various endogenous variables of the model with labor market frictions to a positive inflation target shock of one standard deviation under sticky wages by setting $\theta_w = 0.75$. We contrast these results to the case with flexible wages–that is, when $\theta_w = 0$. As seen from the figure, assuming sticky wages substantially magnifies the effect of the shock on real variables. Intuitively, since wages cannot quickly adjust upward under the increased aggregate demand, the firms are able to hire more workers, which results in a stronger increase in the output. Interestingly, the model predicts a simultaneous decline in real wage and unemployment following the shock to the inflation target shock. The reason is that under persistently high inflation and sticky wages the real wages are deflating making reducing the marginal cost and allowing for more hiring.

Note that the labor force increases relatively less than does employment under sticky wages than under flexible ones, which can be seen by comparing Figures 1 and 3. This is because, from the participation constraint in equation (20), the marginal expected benefit of job market participation is decreasing in wage inflation. Intuitively, when wages cannot readily re-adjust, the benefit of participation declines due to wage inflation since once in the market and employed a worker gets caught up with a deflating away real wage without a possibility to promptly reset it. As a result, when wages are sticky employment grows relatively more from the pool of unemployed than from the pool of those who do not participate in the labor market.

Interestingly, imposing the assumption of sticky wages produces more amplification in the response of the real variables to the inflation target shock than in the response to the nominal interest shock. This can be seen by comparing Figure 3 and 4, where the latter figure depicts the impulse responses of the various endogenous variables of the model to a *negative* nominal interest rate shock of one standard deviation in the model with flexible and sticky wages. The reason is that under the inflation target shock real wages decline more and for longer leading to a similar decline in the marginal cost that allows for a substantial increase in the output.

3.3 Sensitivity Analysis

3.3.1 Sensitivity with respect to the calibration of the model

Figure 5 offers some sensitivity analysis by plotting the impulse responses of the various endogenous variables of the model with the labor market frictions and sticky wages under different values for (steady-state value of) unemployment and the cost of hiring. These results are in general in line with our intuition. For example, by re-calibrating the model so that it has larger steady-state unemployment (which is equivalent to assuming either a larger separation rate δ or a lower rate of filling a vacancy x), we find that the real effect of the inflation target shock increase. On the other hand, by increasing the cost of hiring, we find that the real effects of the shock decline and the shock itself is more absorbed by inflation.

3.3.2 Sensitivity with respect to structure of the model

To show the robustness of our results, we also provide extensions of the baseline model that reflect potentially important mechanisms of the model to react to persistent monetary shocks (appendix B). We first introduce a zero lower bound (ZLB) constraint on the nominal interest rate to reflect the current situation of persistently low/zero nominal rates. We find that the environment of persistently low interest rates reinforces the demand channel of the persistent long-term monetary shock – at the ZLB a positive inflation target shock has a higher impact on inflation expectations, and the shock transmits more through an increase in demand and less through an increase in the labor force and production (figures B.1 and B.2, appendix B). We then introduce a utility function non-separable in consumption and leisure to reflect possible concerns about the design of unemployed in the model – the non-separability in the utility function implies that unemployment is undesirable.[10] We find that when households are confronted with the continuous choice between consumption and leisure, the supply channel of the inflation target shock is in the spotlight – unemployment drops on impact of the shock, however, labor force and employment are lower than in the baseline model. Additionally, the real rate goes up and households are less willing to spend on impact. These changes lead to a slightly dampened effect on economic growth, but the difference compared to the baseline model is small (figure B.3, appendix B). The last extension of the model concerns households' consumption – we introduce consumption habits to reflect empirical evidence of households' preference towards consumption smoothing (Krueger and Perri, 2005; Chetty and Szeidl, 2016) which might be important in defining the reaction to a highly persistent shock. Consumption habits reinforce spending and highlight the demand channel (the real rate is negative after the shock), yet it delays the contribution of the supply channel – with a similar change in the unemployment rate, real wages, labor force, employment are lower – all delaying the effect on output and we observe output growth almost three times lower compared to the baseline model (figure B.4, appendix B).

[10]Empirical evidence suggests that unemployment indeed reduces the utility of households (Chetty and Looney, 2007; Rätzel, 2012).

4. EMPIRICAL EVIDENCE ON THE EFFECTS OF PERSISTENT MONETARY POLICY SHOCKS

4.1 Empirical model and identification strategy

Equipped with the evidence from the New Keynesian model on the role of labor markets in the transmission of persistent monetary policy shocks, we confront these predictions empirically using U.S. data. We employ a parsimonious setup extending the traditional three-variable vector autoregression (VAR) model to account for two types of monetary policy shocks: short-term shocks like a shock to the nominal interest rate and persistent long-term shocks that drive long-term inflation.[11] To do this, we augment the three-variable VAR with time series for the long-run inflation. We identify monetary policy shocks using a combination of sign and zero restrictions where efforts of the Fed to increase long-run inflation are summarized by a positive inflation target shock.

To examine the predictions of our theoretical model from the previous section, in particular, that the effects of persistent monetary shocks depend on labor market conditions, we allow for time variation in parameters and stochastic volatility, i.e. we employ a time-varying parameters VAR model with stochastic volatility (TVP-VAR-SV). This way we are able to access the effects of inflation target shocks across different moments in history with arguably different labor market conditions. Our model nests the standard VAR with stable parameters, and, in case no variation is detected and the results of the theoretical NK model are rejected by the data, the TVP-VAR-SV model will naturally collapse to the standard VAR model. Formally, the model can be written as:

$$\boldsymbol{Y}_t = \boldsymbol{B}_t \boldsymbol{X}_t + \boldsymbol{e}_t, \boldsymbol{e}_t \sim \mathbb{N}(0, \boldsymbol{\Omega}_t) \tag{25}$$

where $\boldsymbol{Y}_t = [\pi_t^*, \Delta y_t, \pi_t, i_t]$ is a vector of N (four) macroeconomic time series: long-term inflation, π_t^*, a measure of aggregate activity (real output growth rate, Δy_t), inflation, π_t, and the nominal interest rate, i_t, $\boldsymbol{X}_t$ is the vector of lagged endogenous variables and an intercept, $\boldsymbol{B}_t$ is a $N(Np+1)$ matrix of time-varying autoregressive coefficients, where p is the number of lags and $\boldsymbol{e}_t$ are unobservable shocks with the time-varying covariance matrix $\boldsymbol{\Omega}_t$. Following Primiceri (2005), we

[11] A traditional approach in the literature to study the effects of monetary policy is to run a three-variable VAR model looking at a shock to the nominal rate. A typical system contains output growth, inflation and nominal interest rate. Persistent long-term monetary policy shocks are introduced either via a permanent shock to the nominal interest rate (Uribe, 2020) or through a highly persistent shock to the time-varying inflation target (Mumtaz and Theodoridis, 2018).

assume that

$$\boldsymbol{A}_t \boldsymbol{\Omega}_t \boldsymbol{A}_t' = \boldsymbol{\Sigma}_t \boldsymbol{\Sigma}_t'$$

where $\boldsymbol{A}_t$ is the lower triangular matrix with ones on the main diagonal and $\alpha_{i,t}$ as non-zero off-diagonal elements, and $\boldsymbol{\Sigma}_t$ is the diagonal matrix, $\boldsymbol{\Sigma}_t = diag(\sigma_{t,1}, ..., \sigma_{t,N})$. Thus, we can define $\boldsymbol{e}_t = \boldsymbol{A}_t^{-1} \boldsymbol{\Sigma}_t \boldsymbol{\epsilon}_t$, where $\boldsymbol{\epsilon}_t \sim \mathbb{N}(0, \boldsymbol{I}_N)$. As is common in the literature, we assume that the evolution of parameters in our model follows random walk, i.e.:

$$\boldsymbol{B}_t = \boldsymbol{B}_{t-1} + \boldsymbol{\nu}_t, \boldsymbol{\nu}_t \sim \mathbb{N}(0, \boldsymbol{V})$$

$$\alpha_t = \alpha_{t-1} + \xi_t, \xi_t \sim \mathbb{N}(0, X)$$

$$log(\sigma_t) = log(\sigma_{t-1}) + \eta_t, \eta_t \sim \mathbb{N}(0, S)$$

To identify two monetary policy shocks, we employ a combination of sign and zero restrictions summarized in table 2. As we are interested in the reaction of macroeconomic variables to the inflation target shock, we only restrict long-run inflation to be positive after a positive inflation target shock. Empirical evidence from related literature suggests that a positive inflation target shock leads to an increase in output growth, inflation and the nominal interest rate (Lukmanova and Rabitsch, 2020; Mumtaz and Theodoridis, 2018; Uribe, 2020). The rest of restrictions are standard. A demand shock is restricted to lead to an increase in inflation, nominal interest rate, and economic activity with no contemporaneous reaction of long-run inflation. Restrictions to identify the supply shock include an increase in inflation but a decrease in aggregate activity, with no contemporaneous reaction of long-run inflation. Finally, a positive nominal interest rate shock leads to an increase in the nominal rate, decreasing inflation and economic activity(Uhlig, 2005), again with no contemporaneous reaction of long-run inflation. We use Bayesian methods to estimate the model. Priors on the initial values of autoregressive parameters are assumed to be Normally distributed, and we use the independent inverse-Wishart prior on the covariance matrix coefficients. To estimate posterior densities, we employ Gibbs sampler.

4.2 Data

We use U.S. data from 1979Q4 to 2019Q1 from the Federal Reserve Bank of St.Louis. All data is on quarterly basis, and we use 2 lags of endogenous variables for the estimation. Inflation is measured as a change in the CPI index, The Consumer Price Index for All Urban Consumers All Items, CPIAUCSL. The nominal interest rate is represented by the treasury bill rate, the 3-Month Treasury Bill Secondary Market Rate, TB3MS, an average of monthly time series over each quarter. As a measure of aggregate activity we use the growth rate of the real gross domestic product: output growth is the nominal GDP (GDPC1) deflated with GDP deflator (GDPDEF). We check all time series for stationarity using the augmented Dickey-Fuller test.

Long-run inflation is unobserved and we experiment with various measures (observed, survey-based, or structural, model-based) that we believe largely co-move with the long-run inflation in the US. In particular, we use the inflation forecast from the Survey of Professional Forecasters (Livingstone survey), denoted as SPF which is the 10-year ahead inflation forecast available from 1991Q4.[12] There are other alternative measures of long-run inflation (figure 6): (i) households' 5-year ahead inflation forecast from the Survey of Consumers conducted by the University of Michigan (short: *Michigan*), which is available from 1990Q1, (ii) 10-year inflation expectations estimated by the federal Reserve Cleveland, using a structural model with treasury yields, inflation, inflation swaps, and survey-based measures of inflation expectations, available from 1982Q1, and, finally, (iii) trend inflation as in Stock and Watson (2007) augmented with a measure of long-run inflation expectations (Chan et al., 2018), available from 1960Q2 until 2016Q1. All these measures display similar dynamics, we use the SPF measure in the baseline model specification.[13]

4.3 Effects of monetary policy shocks: evidence from the TVP-VAR-SV model

Figure 8 displays estimation results of the baseline TVP-VAR-SV model (with SPF as a measure of long-run inflation) along three dimensions: time, impulse response horizon, and the amplitude of the response. We focus on the effects of a positive inflation target shock.[14] By construction, a

[12] To extend the number of observations we augment this forecast with observations from the Blue Chip Economic Indicators, a survey of top business economists, available from 1979 Q4. The Blue Chip Economic Indicators are available on a biannual basis, missing observations are interpolated.

[13] Robustness checks with alternative measures of long-run inflation confirm our results.

[14] The nominal interest rate shock leads to standard results: due to the presence of nominal rigidities in the data, an increase in the nominal rate leads to an increase in the real rate, economic agents postpone consumption which

positive inflation target shock increases long-run inflation expectations.

As economic agents now expect prices to be higher, they increase consumption today, which results in elevated aggregate demand and an increase in aggregate production. To accommodate higher demand producers react by increasing prices leading to an increase in inflation. This evidence is consistent with the evidence from empirical literature using VAR models with stable parameters (Mumtaz and Theodoridis, 2018; Uribe, 2020). Finally, in response to the economic expansion, Fed reacts to movements in output and inflation increasing the policy rate to prevent overheating.

Examining figure 8, it is clear that there is responses of macroeconomic variables to the inflation target shock vary over time. We plot the responses of output growth and inflation over time along with the unemployment rate in the US over the same time period (figures 9 and 10, respectively). We cut impulse response along the impulse horizon dimension and plot responses at horizons 0, 1 and 2. We observe a positive co-movement in output growth response to the inflation target shock and the level of unemployment rate in the US economy supporting, while inflation and unemployment rate are negatively related on impact of the shock. We additionally plot the impulse response of inflation and the output growth on impact of the inflation target shock over the same period of time, from 1990Q2 to 2019Q1, and observe a negative co-movement (figure 11).

We read this empirical evidence as being overall consistent with the predictions of our theoretical model: in periods when US had large unemployment, target shocks led to larger increases in output and the other way around. With respect to inflation we can support the evidence from our theoretical model only on impact of the shock, later we observe a co-movement in inflation and the observed unemployment rate. Even in the theoretical model marginal differences in inflation response due to varying labor market conditions are small, our TVP-VAR-SV model might not pick up on this. Secondly, Fed was committed to keep inflation stable over the period from 1900 to 2019, therefore, any movements in inflation were immediately counteracted by adjustments in the nominal rate. We do observe criticality in response of the nominal rate to the inflation shock (figure 8), therefore, inflation response might be muted.

diminishes aggregate demand and the production falls. In response to lower demand, producers decrease prices, and inflation falls.

5. CONCLUSIONS

In this paper, we study the transmission of persistent monetary policy shocks, which target long-term inflation expectations, using a New Keynesian (NK) model with labor market frictions. Our analysis predicts that labor market conditions, which are shaped by labor market frictions, play important role in the transmission channel of the persistent inflation target shock. Results from the NK model indicate that: (i) quantitatively reasonable labor market frictions amplify the real effect of the inflation target shock, (ii) increasing the pool of unemployed further increases the real effect of the inflation target shock, while (iii) more restricted access to the labor (e.g., higher hiring costs) leads to a smaller reaction of real output but a higher reaction of inflation.

Our VAR-based evidence is fairly consistent with the predictions of the NK model. First, we find that the on-impact responses of output and inflation to the inflation target shock appear to be negatively related over time. We further document some evidence that the magnitude of the output response to the inflation target shock relates positively to the unemployment rate suggesting that the expansionary effect of the shock is stronger when unemployment is higher. Finally, we find mixed evidence on the negative relation between the response of inflation to the inflation target shock and unemployment rate.

The results of our analysis are relevant to the current policy debate. For example, in a recent speech, the chairman of the Fed, J. Powell, announced a course to higher long-run inflation expectations aiming to stimulate employment and inflation in the U.S. ((Powell, 2020)). Our results indicate that such a policy may have only little effect on output due to labor market frictions. On the other hand, in the post-COVID 19 pandemic world, which is, at least temporarily, characterized by an enlarged pool of unemployed many advanced and developing countries could try to stimulate their economies by raising inflation expectations (for example, through increasing inflation target). However, again this policy could be less effective in those countries that have less efficient labor markets (i.e., countries with higher hiring costs).

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TABLES

Table 1

Model parameters. This table presents the values of the model parameters and their description. The parameter values are borrowed from Galí (2010).

Parameter	Description	Value
$1-\alpha$	Labour share	0.3
β	Quarterly discount factor	0.99
γ	Exponential term from the cost of hiring function	1
Γ	The cost of hiring parameter	0.02
δ	Separation rate	0.12
θ_p	Price stickiness parameter	0.75
θ_w	Wage stickiness parameter	0.75
κ_π	The Taylor rule parameter: inflation gap	1.5
κ_y	The Taylor rule parameter: output gap	0.125
$\mathcal{M}^p(1-\tau)$	Effective mark-up	1
ξ	Firm's Nash bargaining share	0.05
ρ	Interest rate smoothing	$\{0, 0.8\}$
$\rho_{\tilde{\pi}}$	Inflation target AR(1) coefficient	0.997
ρ_ν	Nominal rate shock AR(1) coefficient	0.6
σ_ε	Inflation target shock volatility	0.1
σ_ν	Nominal rate shock volatility	0.25
ϕ	The inverse of Frisch elasticity	5
χ	Utility labor effort scaling parameter	12.3
ψ	Marginal unemployment disutility parameter	0.82

Table 2

Identification strategy. IT shock - inflation target shock, AD shock - aggregate demand shock, AS shock - aggregate supply shock, NIR shock - nominal interest rate shock. Empty cells - no restriction imposed. All restrictions are imposed for one period.

	IT shock	AD shock	AS shock	NIR shock
π^*	+	0	0	0
Δy		+	+	-
π		+	-	-
i		+		+

Figure 1: **Inflation target shock: Effect of labour market Frictions under flexible wages.** This figure presents the impulse responses of various endogenous variables of the model to a positive inflation target shock of one standard deviation in the model with flexible wages ($\theta_w = 0$). The blue dotted line corresponds to the case with the labour market frictions, while the black solid line depicts the results from the model without the labour market frictions (perfectly competitive labor market).

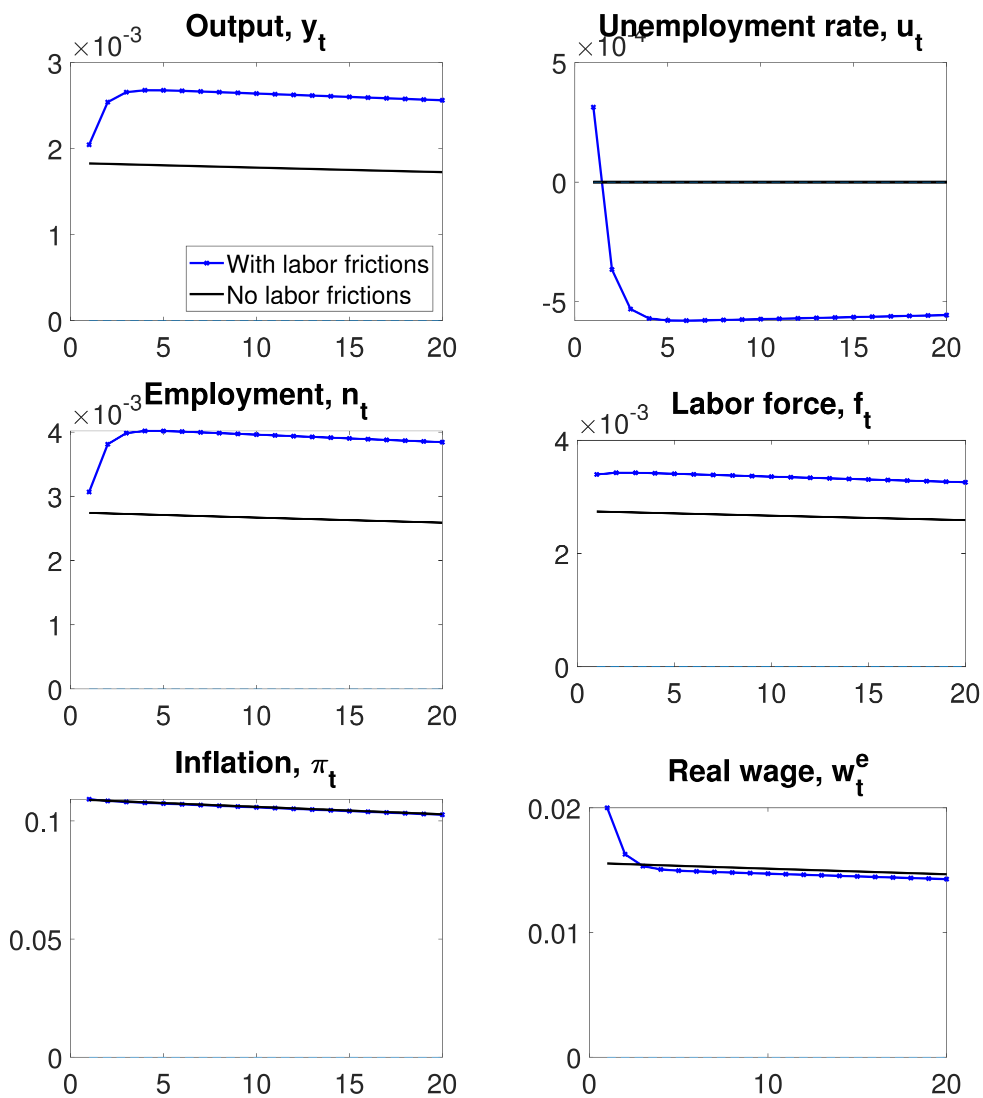


Figure 2: **Nominal interest rate shock: Effect of labour market Frictions under flexible wages.**
This figure presents the impulse responses of various endogenous variables of the model to a positive nominal interest rate shock of one standard deviation in the model with flexible wages ($\theta_w = 0$). The blue dotted line corresponds to the case with the labour market frictions, while the black solid line depicts the results from the model without the labour market frictions (perfectly competitive labor market).

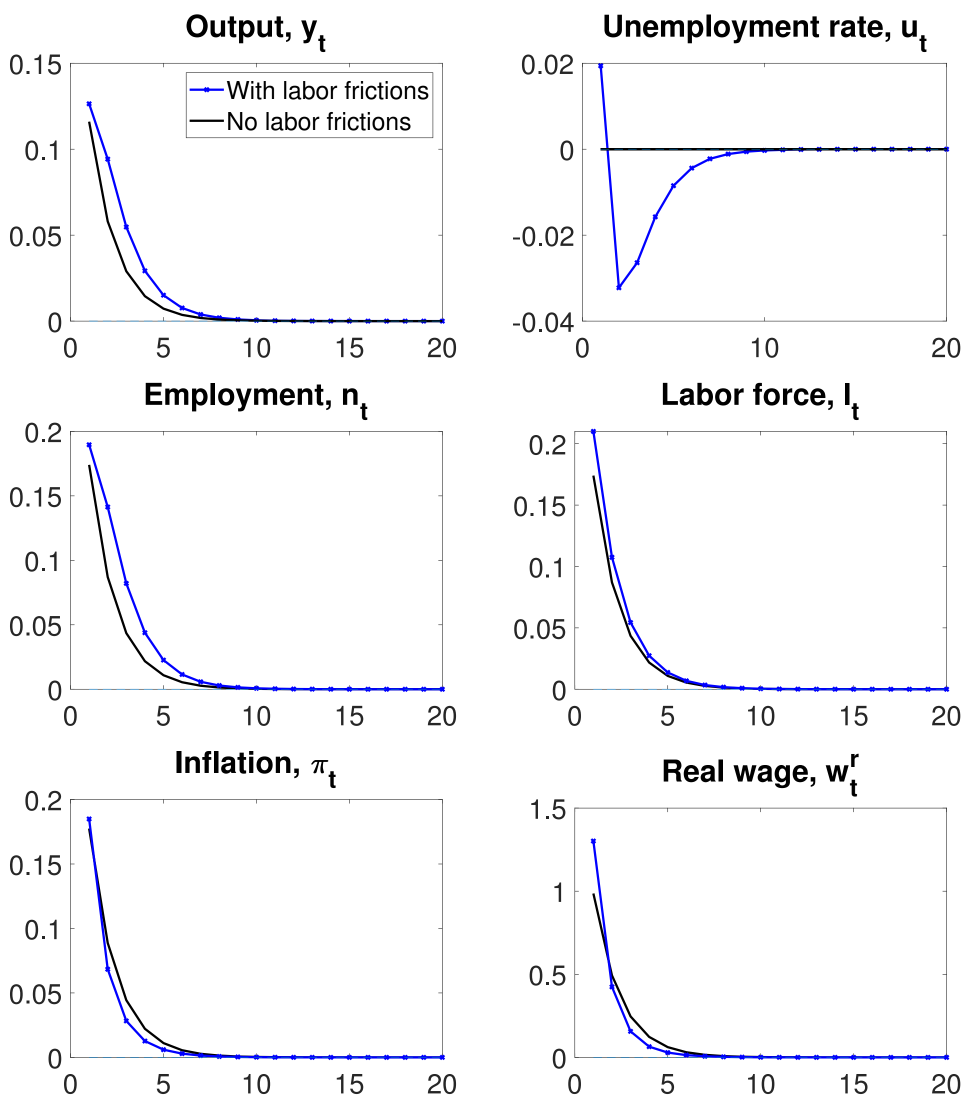


Figure 3: **Inflation target shock and labour market Frictions: Effect of sticky wages.** This figure presents the impulse responses of various endogenous variables of the model with labour market frictions to a positive inflation target shock of one standard deviation. The red-dashed line depicts the results from the model with sticky wages ($\theta_w = 0.75$), while the blue dotted line corresponds to the model with flexible wages ($\theta_w = 0$).

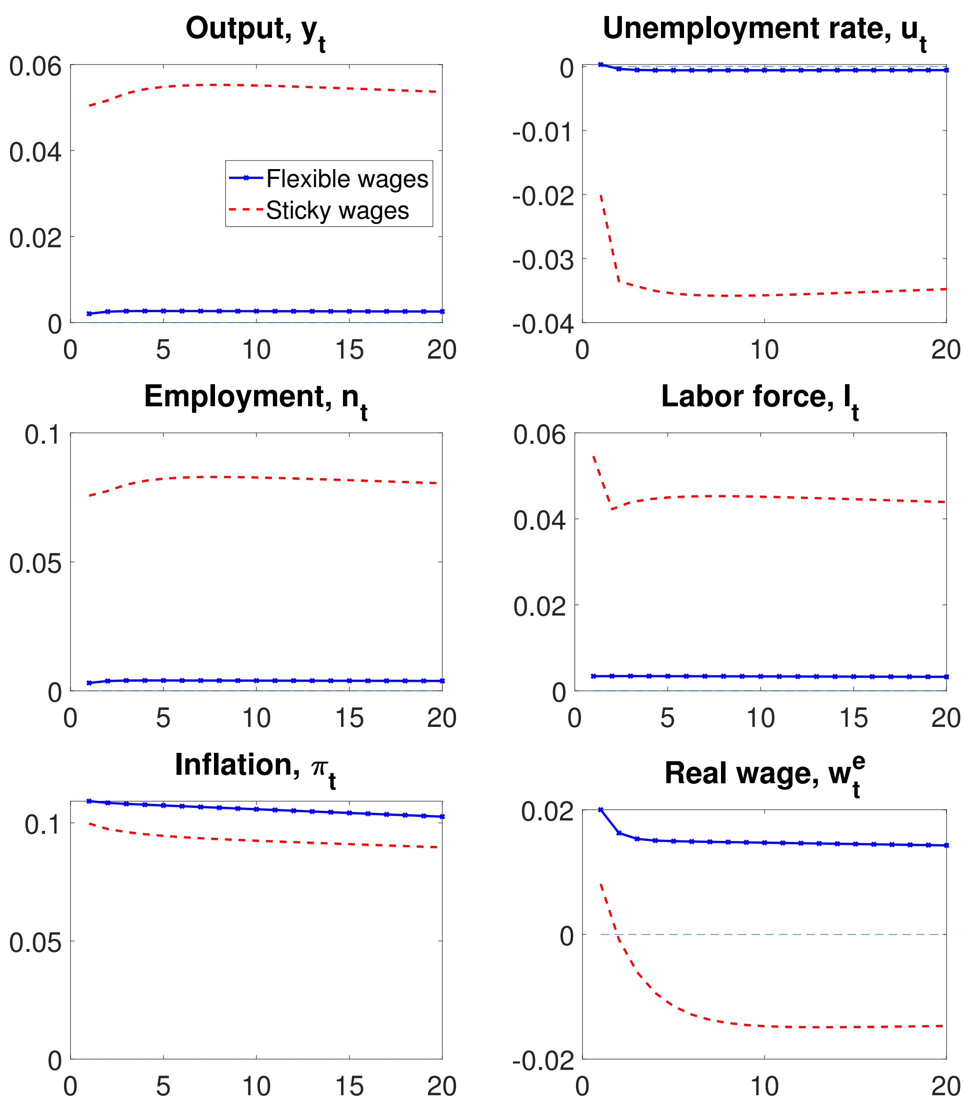


Figure 4: **Nominal interest rate shock and labour market Frictions: Effect of sticky wages.**

This figure presents the impulse responses of various endogenous variables of the model with labour market frictions to a positive nominal interest rate shock of one standard deviation. The red-dashed line depicts the results from the model with sticky wages ($\theta_w = 0.75$), while the blue dotted line corresponds to the model with flexible wages ($\theta_w = 0$).

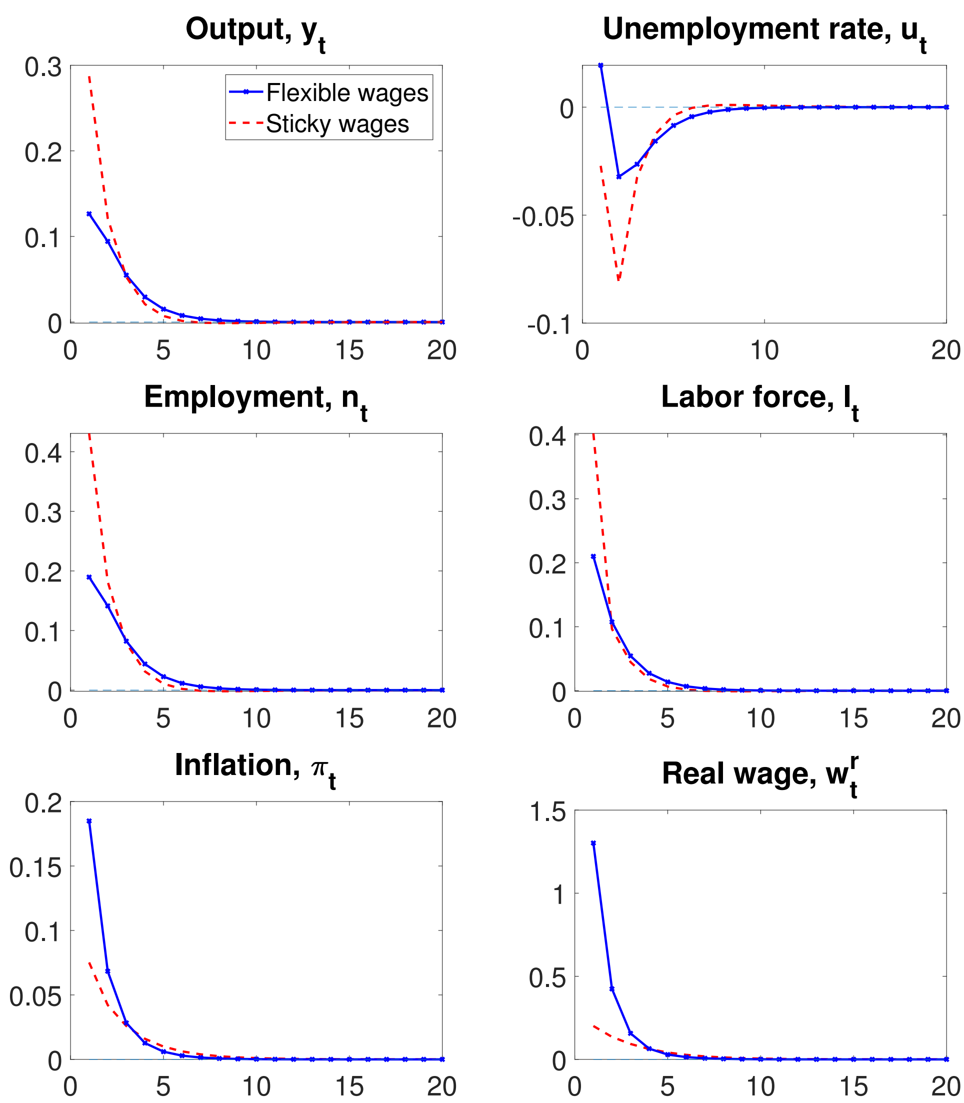


Figure 5: **Impulse responses to an inflation target shock: Varying labour market conditions.**
This figure presents the impulse responses of various endogenous variables of the model to an inflation target shock of one standard deviation under different labour market conditions. The blue dashed line with dots corresponds to the model with higher unemployment, the red dotted line is the baseline model, the black line with dots is the model with lower job finding rate.

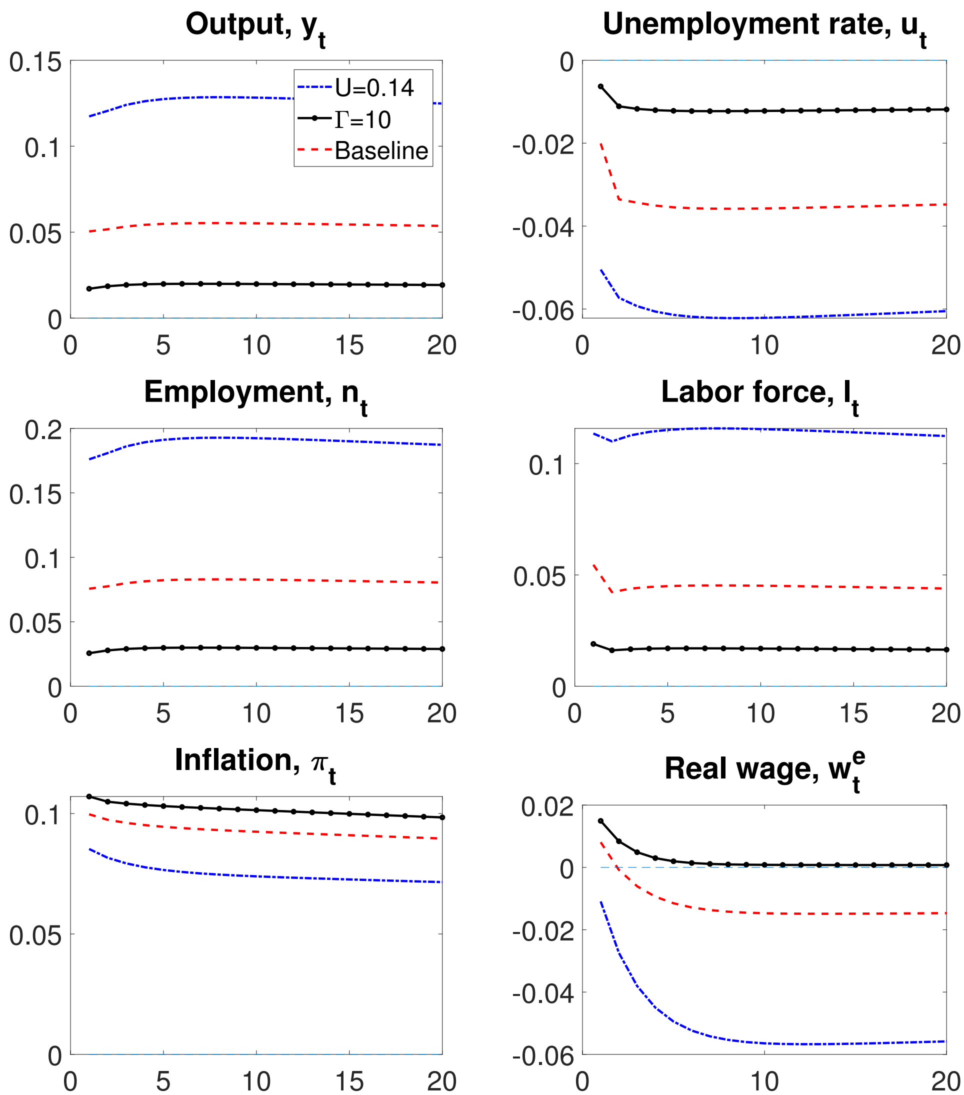


Figure 6: **Measures of long run inflation expectations.**
This figure presents various measures of inflation expectations for US during 1979Q4 to 2019Q1.

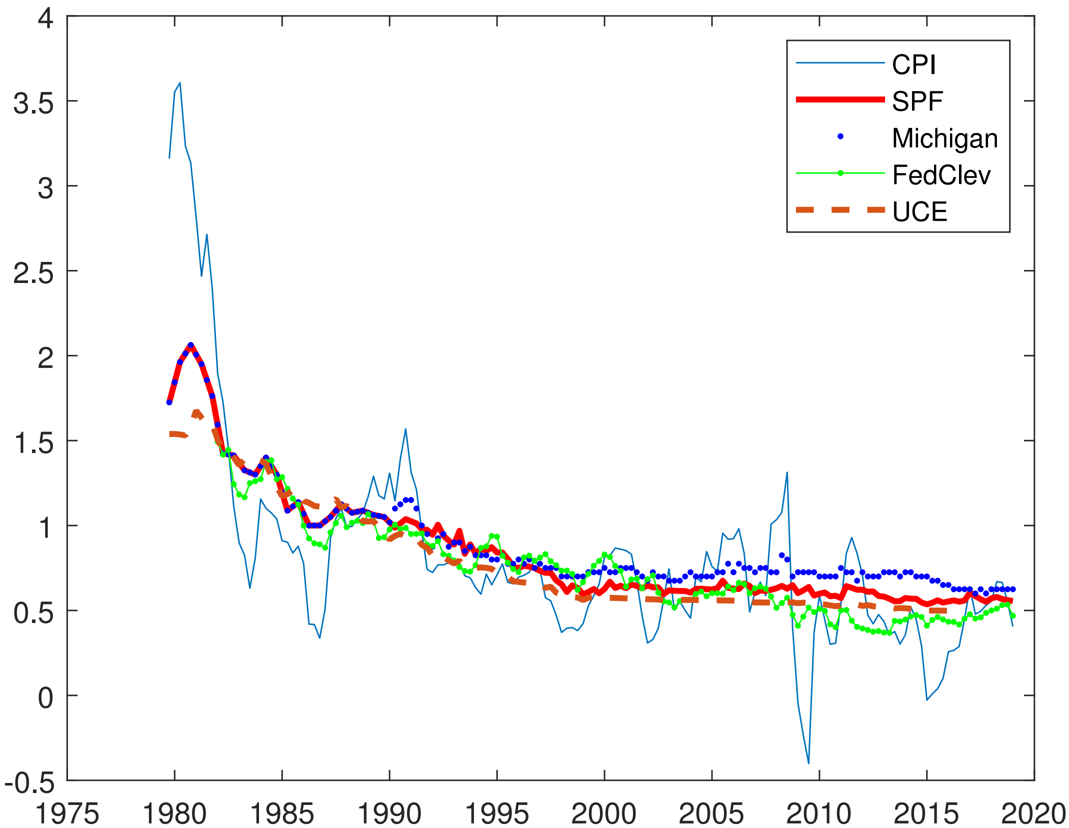


Figure 7: **Impulse responses to an inflation target shock.**
This figure presents the impulse response of output growth to an inflation target shock of one standard deviation over three dimensions: x-asis - time, from 1990Q2 to 2019Q1, y-axis - magnitude of the response, z-axis - impulse response horizon.

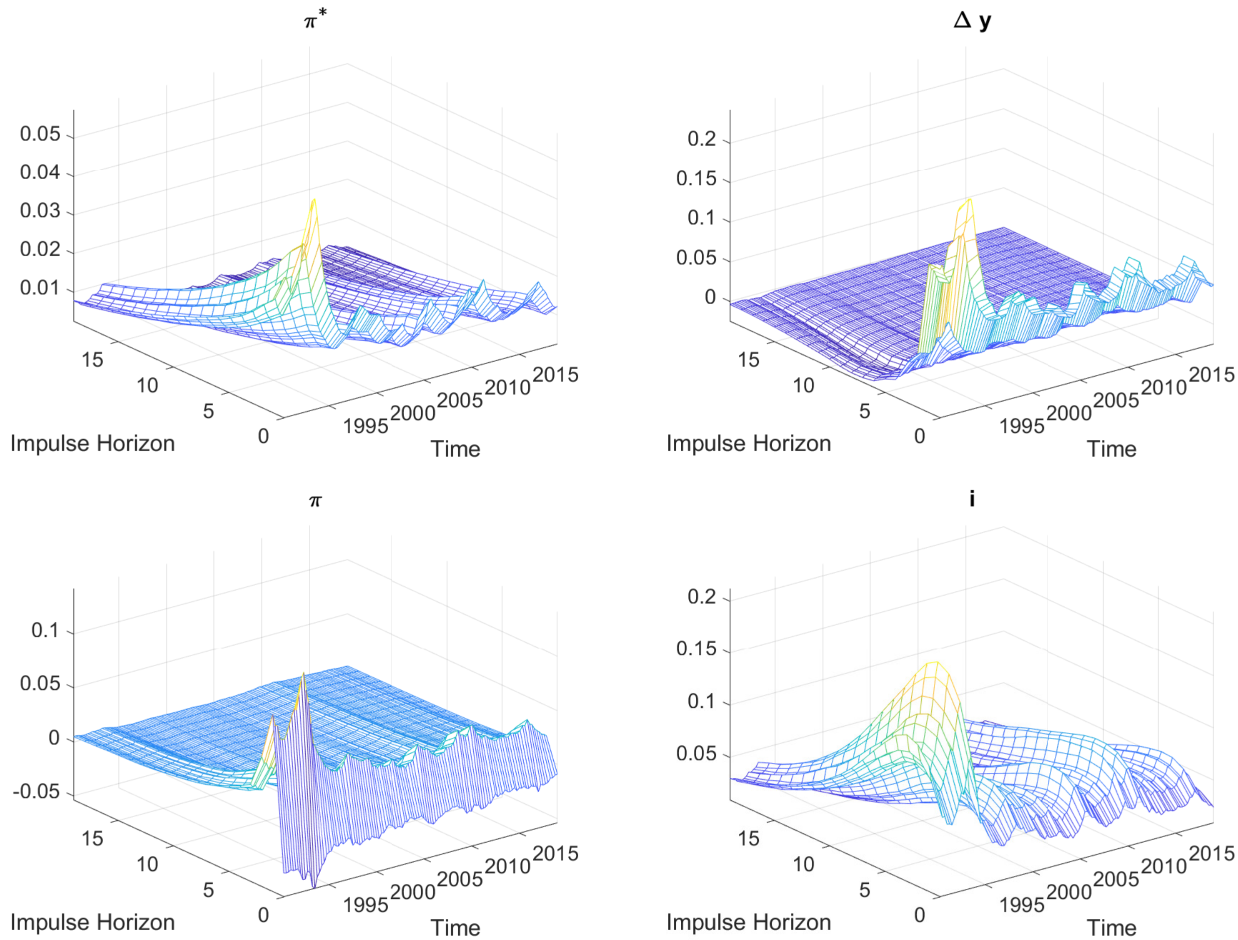


Figure 8: The figure plots impulse responses to the persistent inflation target shock across time, 1990Q2 to 2019Q1, and impulse response horizons.

Figure 9: **Impulse responses to an inflation target shock and unemployment rate.** This figure presents the impulse response of output growth to an inflation target shock of one standard deviation at different horizons over the period from 1990Q2 to 2019Q1. The red dashed line displays time series for the unemployment rate in the US over the same period. Blue, green and faded blue lines are impulse responses of output growth to an inflation target shock at horizons 0, 1 and 2. Left vertical axis - magnitude of the impulse response, right vertical axis - magnitude of the unemployment rate.

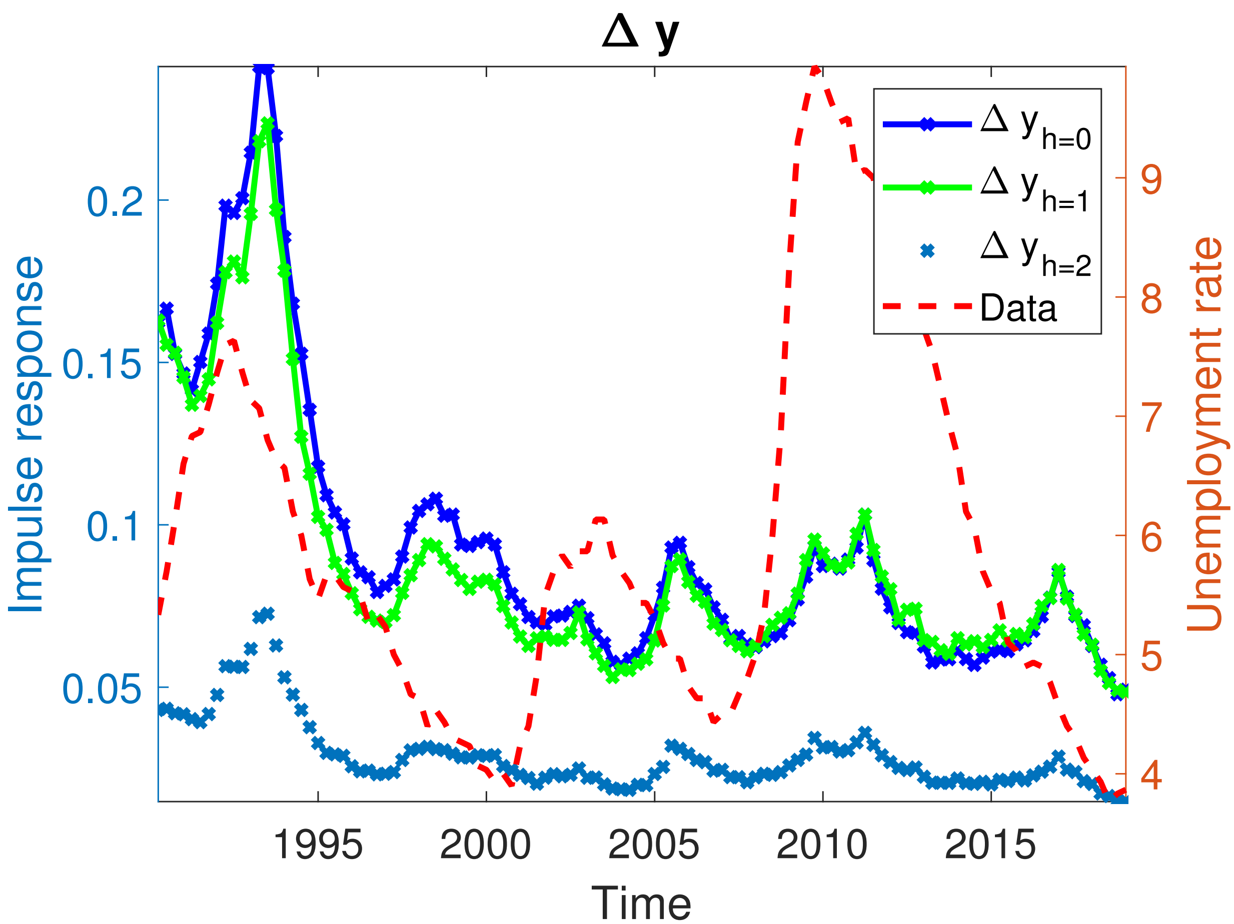


Figure 10: **Impulse responses to an inflation target shock and unemployment rate.** This figure presents the impulse response of inflation to an inflation target shock of one standard deviation at different horizons over the period from 1990Q2 to 2019Q1. The red dashed line displays time series for the unemployment rate in the US over the same period. Blue, green and faded blue lines are impulse responses of inflation to an inflation target shock at horizons 0, 1 and 2. Left vertical axis - magnitude of the impulse response, right vertical axis - magnitude of the unemployment rate.

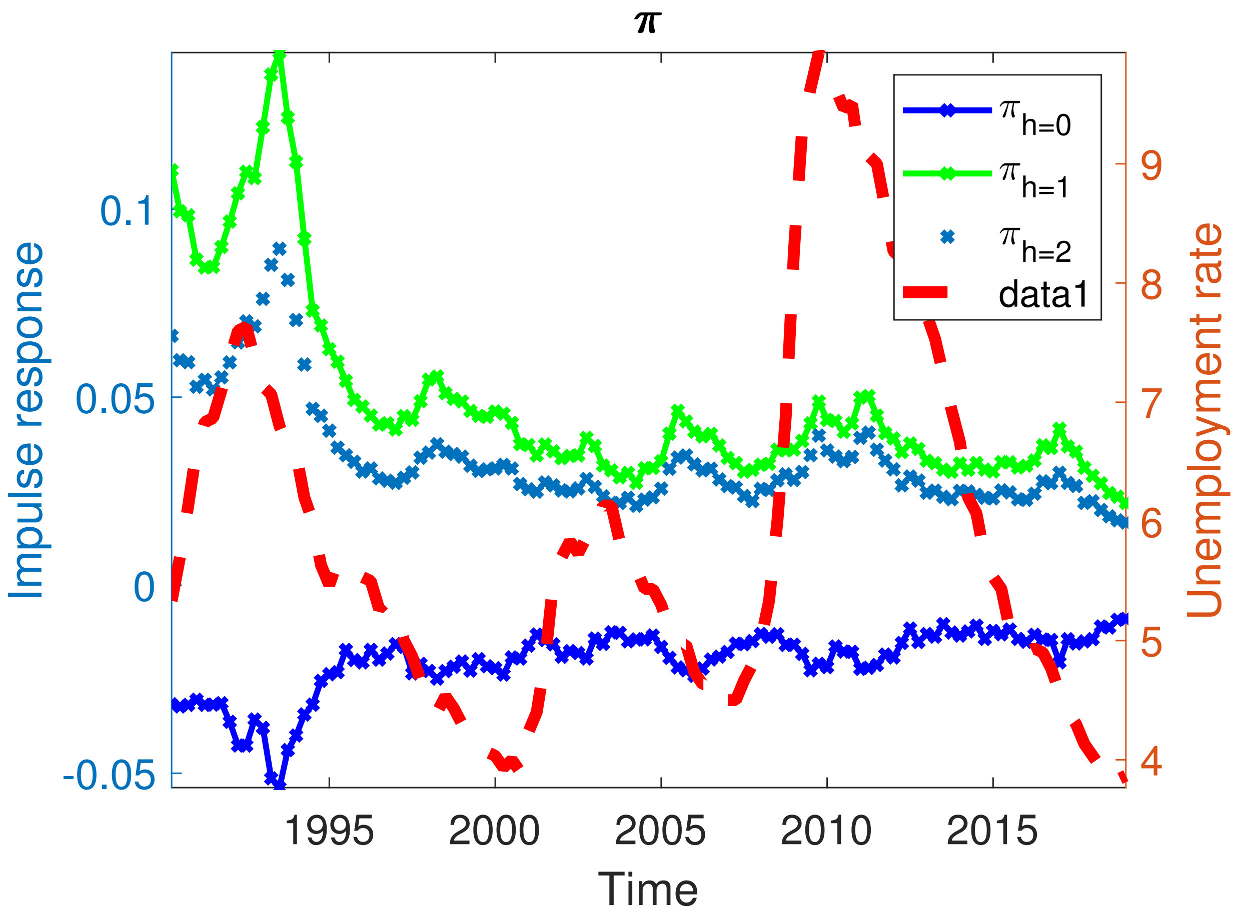
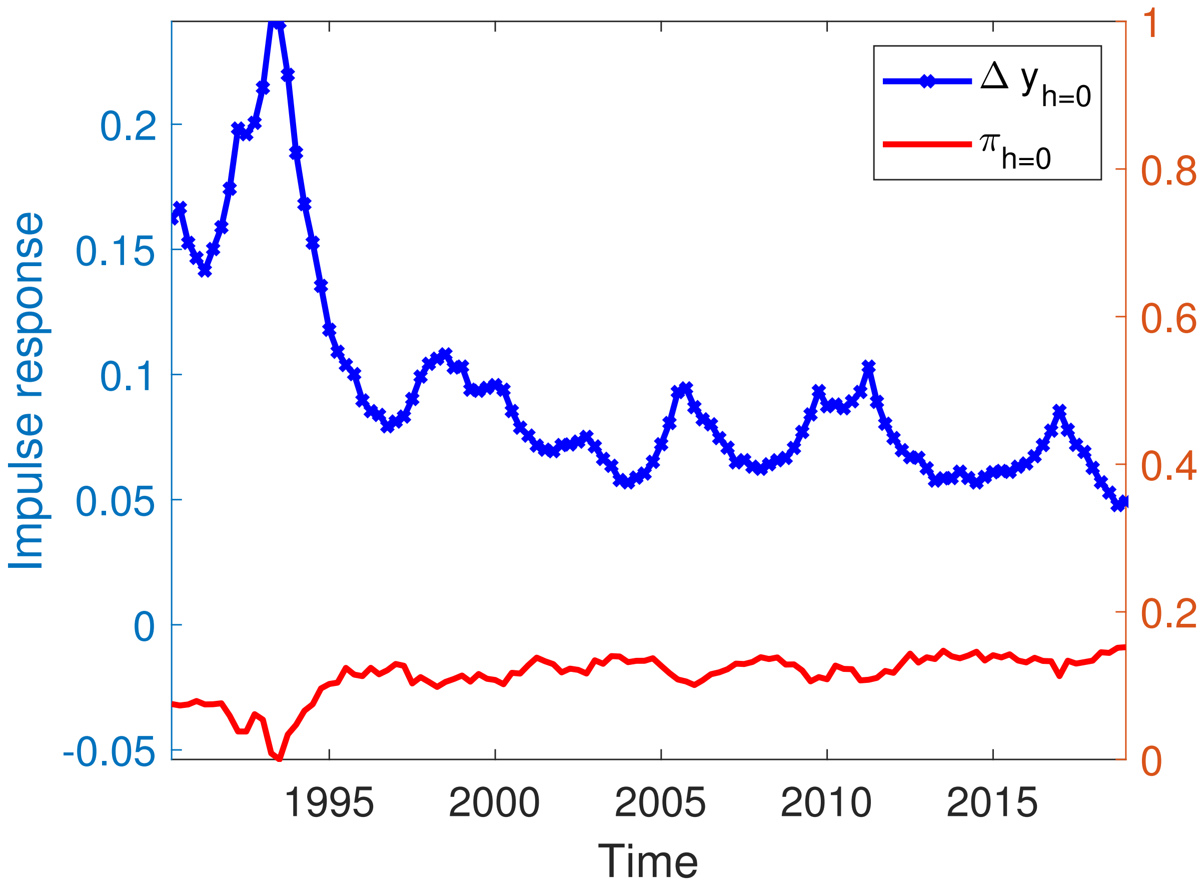


Figure 11: **Impulse responses on impact of an inflation target shock of output growth and inflation.**
This figure presents the impulse response of output growth and inflation on impact of an inflation target shock of one standard deviation (horizon 0) over the period from 1990Q2 to 2019Q1. The red solid line presents impulse response of inflation, the blue with with dots presents impulse response of the output growth. Left vertical axis - magnitude of the impulse response of output growth, right vertical axis - magnitude of the impulse response of inflation.



APPENDIX

A. DSGE MODEL

A.1 Optimal Price Setting by Final Good Producers

Without price rigidities, each firm i would set the price of its good optimally to its marginal cost—that is,

$$P_t(i) = P_t = \mathcal{M}^p(1-\tau)P_t^I, \tag{A.1}$$

where $\mathcal{M} = \epsilon/(\epsilon-1)$ is the steady state mark-up, τ a subsidy on the purchases of intermediate goods, and P_t^I is the price of the intermediate good.

Under Calvo (1983) price setting, each firm will adjust its price each period only with a constant probability $1-\theta_p \in [0,1]$. The firm adjusting its price at time t will select price P_t^*. That is, each price resetting firm i solves

$$\begin{aligned} &\max_{P_t^*} \ \mathbb{E}_t \sum_{k=0}^{\infty} \theta_p^k \beta^k \frac{\Lambda_{t,t+k}}{P_{t+k}} \left[P_t^* - \mathcal{M}^p(1-\tau)P_{t+k}^I\right] Y_{t+k}(i) \\ &\text{s.t. } Y_{t+k}(i) = \left[\frac{P_t^*}{P_{t+k}}\right]^{-\epsilon} Y_{t+k}, \end{aligned} \tag{A.2}$$

where $Y_{t+k} = \left[\int_0^1 Y_{t+k}(i)^{\frac{\epsilon-1}{\epsilon}} di\right]^{\frac{\epsilon}{\epsilon-1}}$.

Galí (2010) shows that the optimal price setting condition from the above optimization problem in the log-linearized form is given by

$$p_t^* = \mu_p + (1-\beta\theta_p)\sum_{k=0}^{\infty}(\beta\theta_p)^k(\mathbb{E}_t[p_{t+k}^I] - \tau), \tag{A.3}$$

where $\mu_p = log(\mathcal{M})$ is the log steady state mark-up and p_{t+k}^I is the log price of the intermediate good at time $t+k$.

By combining equation (A.3) with the law of motion of the aggregate price

$$p_t = \theta_p p_{t-1} + (1-\theta_p)p_t^*, \tag{A.4}$$

one obtains the standard (log-linearized) Phillips curve

$$\pi_t^p = \beta \mathbb{E}_t[\pi_{t+1}^p] - \lambda_p \hat{\mu}_t^p, \tag{A.5}$$

where $\pi_t^p = p_t - p_{t-1}$, $\hat{\mu}_t^p = p_t - (p_t^I - \tau) - \mu^p$ is the deviation of the price markup from its steady state value, and $\lambda_p = (1-\theta_p)(1-\beta\theta_p)/\theta_p$.

A.2 Definitions of Υ and Φ

Galí (2010), derives that $\Upsilon = \frac{\xi MRS}{W/P}$, where MRS is the steady state value of the household's marginal rate of substitution between consumption and labor market effort and $\Phi = \frac{B}{W/P+B}$, where B is the steady state value of net hiring cost.

B. DSGE MODEL EXTENSIONS: ZLB, NON-SEPARABLE UTILITY, AND HABITS

B.1 Model with the ZLB Constraint

First, we impose a zero lower bound (ZLB) constraint on the nominal interest rate, i.e. the nominal interest rate is bounded to be nonnegative. Post 2007/08 crisis economic environment can be described by persistently low or zero policy rates which restricted the ability of central banks to provide economic stimulus by lowering policy rates. In such an environment, persistent monetary policy shocks can still be used to stimulate the economy. We study if the effects of persistent monetary policy shocks are different, quantitatively or qualitatively, when the ZLB is binding. We are also interested in the role of deteriorating labor market conditions (as typically observed during crises) in the effects of persistent monetary policy shocks under the ZLB.

The extension of the baseline model concerns the monetary policy rule. In particular, an updated policy rule i_t^{ext} takes the following form (in log-linearized terms):

$$i_t^{ext} = max\left[i_t, 0\right] \tag{A.6}$$

where i_t is the nominal interest rate from the baseline model (in log-linearized terms):

$$i_t = \rho i_{t-1} + (1-\rho)\hat{\bar{\pi}}_t + \rho(\hat{\bar{\pi}}_t - \hat{\bar{\pi}}_{t-1}) + (1-\rho)\kappa^{\pi}(\bar{\pi}_t - \hat{\bar{\pi}}_t) + \kappa^y(y_t - y_t^*) + \varepsilon_{I,t}$$

Following Aruoba et al. (2017), we introduce the economy to the binding zero lower bound constraint using a discount factor shock. Once the economy is in a downfall with declining demand for consumption, production, and prices, the central bank cuts the policy rate to stimulate the economy. When the policy rate hits the ZLB, the standard expansionary monetary policy provided via a decrease in the policy rate is unavailable, and we introduce a positive inflation target shock. This exercise is designed as an approximation to the current environment when interest rates are low and the Fed is reserving to alternative monetary policies to stimulate long-run inflation expectations. There is significant evidence on different dynamics of economic variables once the economy hits(or close to) the zero lower bound (Guerrieri and Iacoviello (2015)), we focus on the effects of inflation target shocks.[15]

[15]We solve the model with ZLB using piece-wise linear approximation as in Guerrieri and Iacoviello (2015) using

To introduce the discount factor shock, we modify the utility function of households. In particular, the lifetime utility of households is:

$$U^H(\beta_t, C_t, L_t) = \overset{\infty}{\underset{t=0}{\mathbb{E}}} \beta^t exp(\beta_t) \left[ln(C_t) - \frac{\zeta}{1+\varphi} L_t^{1+\varphi} \right]$$

where β_t is an exogenous process for the discount factor shock, it follows an AR(1) process, i.e. $\beta_t = \rho^\beta \beta_{t-1} + \varepsilon_{\beta,t}$. The shock is intended to capture frictions that affect the intertemporal preferences of a household. Fluctuations in β_t affect households patience and their desire to postpone consumption. Eventually, a sufficiently large shock to β_t makes the central bank cut interest rates all the way to the ZLB.

We implement the discount factor shock that, in the absence of monetary stimulus, leads to the binding constraint on the policy rate for 12 quarters after the shock (figure **??**). Then, in the 4th quarter after such shock, we supply a positive inflation target shock (figureB.1). We find that an expansionary persistent monetary policy shock leads to even higher positive spillovers on output when implemented at the ZLB with smaller effects on the labor markets. In fact, at the ZLB a positive inflation target shock leads to higher inflation expectations enough for the real rate to turn negative right after the shock. A negative real rate stimulates consumption and increases aggregate demand, which increases output. Note that the shock allows to increase the policy rate and exit the binding ZLB episode. In an economy with a high level of unemployment and binding ZLB constraint, the positive inflation target shock leads to higher output increase and higher inflation (figure B.2). The real rate increases muting demand effects, to increase production firms have to offer higher wages, and wages increase (in contrast to the model with ZLB but baseline level of unemployment), and spillovers on labor markers are amplified compared to the baseline model with ZLB. The model with high unemployment but no ZLB constraint leads to higher output and lower inflation.

Overall, our results suggest that an inflation target shock implemented during binding ZLB leads to an increase in output, inflation, and the nominal interest rate. Depending on labor market conditions, these effects can be amplified. If the shock provides enough economic stimulus to increase inflation expectations and decrease the real rate, it stimulates aggregate demand which

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the OccBin package.

explains higher output effects compared to the model without ZLB constraint.

B.2 Model with Non-Separable Utility

In this section, we address the concerns discussed in the beginning of section 2 on the design of the unemployed. Deriving the optimal conditions in the baseline model, employed workers suffer from the disutility of working while unemployed workers, by definition, do not. There are no extra costs of being unemployed and workers, employed and unemployed, live in the same household which allows spreading consumption. Christiano et al. (2020) argues that this is inconsistent with the evidence of discomfort and disutility from being unemployed. Christiano et al. (2020) address these concerns by introducing search frictions on the side of households, making unemployment in their model indeed involuntary. Chodorow-Reich and Karabarbounis (2016) empirical estimates of the cyclicality of opportunity costs of moving from unemployed to employed contradict the implied disutility from unemployed in macro models, therefore, we assume utility non-separable in consumption and leisure. The non-separability assumption implies higher utility of employed workers, they are compensated (rewarded) for labor, and the unemployed want to become employed.

Following Shimer (2005), we assume that the households' utility function takes the following form:

$$\max \mathop{\mathbb{E}}_{t=0}^{\infty} \beta^t \left[\frac{(C_t^{1-\gamma^C}(1+(\gamma^C-1)\frac{\zeta\varphi}{1+\varphi}L_t^{1+\frac{1}{\varphi}})^{\gamma^C}-1}{1-\gamma^C} \right]$$

where $\gamma^C > 0$ the coefficient of (constant) relative risk aversion, and $\zeta > 0$ is the disutility of labor supply, thus utility is increasing and concave in consumption and decreasing and concave in labor. As $\gamma^C \to 1$ we approaches a separable case comparable to the baseline model. Following Yedid-Levi (2016), we set $\gamma^C = 1.497$, this implies the marginal utility of consumption is higher when households work more.

The effects of a positive inflation target shock in a model with non-separable utility function are presented on figure B.3 (for consistency we present the effects of the nominal interest rate shock in appendix on figure **??**). We find that the effects of introducing the non-separable utility function are not big compared to the baseline scenario: the response of output is somewhat smaller, inflation reaction is the same. Indeed, with non-separable utility function the unemployment rate drops more on impact of the shock, this still leaves the economy with less employment. The real rate is positive and higher on impact, yet real wages are higher as well. Overall, this creates positive demand effects through positive expectations of future consumption: wages are rising and unemployment falls. Consumption might be smaller on impact, dampening output growth, yet overall the shock brings clear positive dynamics both for the production sector and for households.

B.3 Model with Consumption Habits

We introduce external consumption habits as in, for example, Smets and Wouters (2003). Specifically, we use the constant relative risk-aversion utility function with the coefficient of relative risk-aversion γ^C taking the value of 1 (log utility) with external habits.[16] The utility function takes the following form:

$$\max \mathop{\mathbb{E}}_{t=0}^{\infty} \beta^t \left[\frac{(C_t - H_t)^{1-\gamma^C} - 1}{1-\gamma^C} - \frac{\zeta}{1+\varphi} L_t^{1+\varphi} \right]$$

where H_t is the external habit, it is assumed to be proportionate to the past level of consumption, i.e. $H_t = bC_{t-1}$. We follow Christiano et al. (2020) and set the habit parameter b to 0.75, i.e. households' utility of consumption can become negative if the current consumption is three quarters below yesterday's consumption.

Results from the model with external habit formation are presented on figure B.4, the nominal interest rate shock results are in appendix, figure ??. Once confronted with consumption habits, households prefer consumption smoothing. This desire to keep consumption stable drives their consumption and labor decisions. In response to a positive inflation target shock, we observe an active demand channel: the shock increases expectations enough to lower the real rate stimulating consumption and demand on impact of the shock. The unemployment rate reacts almost in the same way as in the baseline model, yet real wages go down (real wages are negative on impact and below the baseline model's reaction for the first 10 quarters), labor force and employment are lower on impact – firms are more reluctant to increase the quantity of production, they increase prices instead. As a result, there is no loop for an additional increase in spending generated from higher

[16] The CRRA log utility function is consistent with balanced growth.

wages or employment. The output increases three times less than it does in the baseline model.

Figure B.1: **Impulse responses to an inflation target shock: Utility function non-separable in leisure and consumption.**
This figure presents the impulse responses of various endogenous variables of the model to an inflation target shock of one standard deviation under different labour market conditions. The red dotted line is the baseline model, the black line with dots is the model with ZLB constraint.

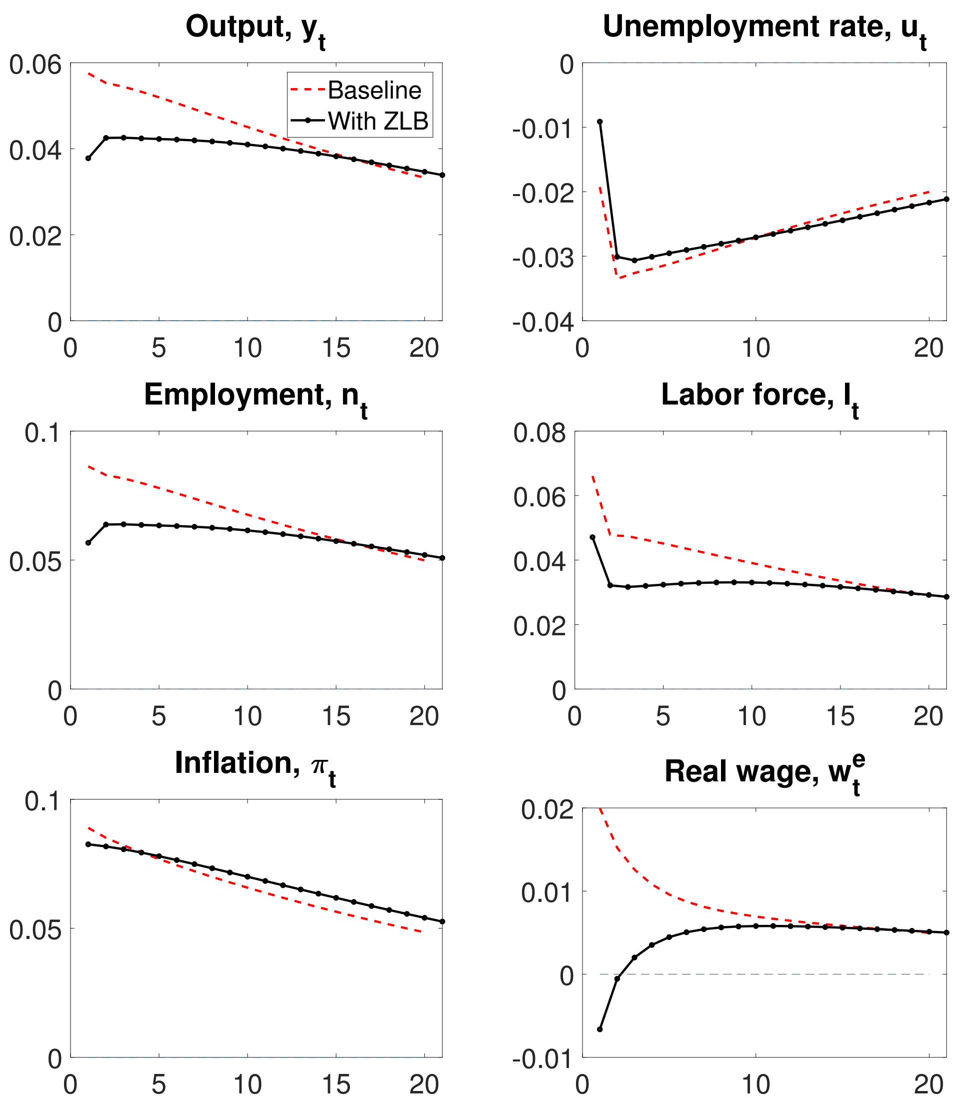

Figure B.2: **Impulse responses to an inflation target shock: ZLB and high unemployment.**

This figure presents the impulse responses of various endogenous variables of the model to an inflation target shock of one standard deviation under different labour market conditions. The blue dashed line with dots corresponds to the model with ZLB constraint and high level of unemployment, the red dotted line is baseline model with high unemployment, the black line with dots is the model with ZLB constraint and baseline level of unemployment.

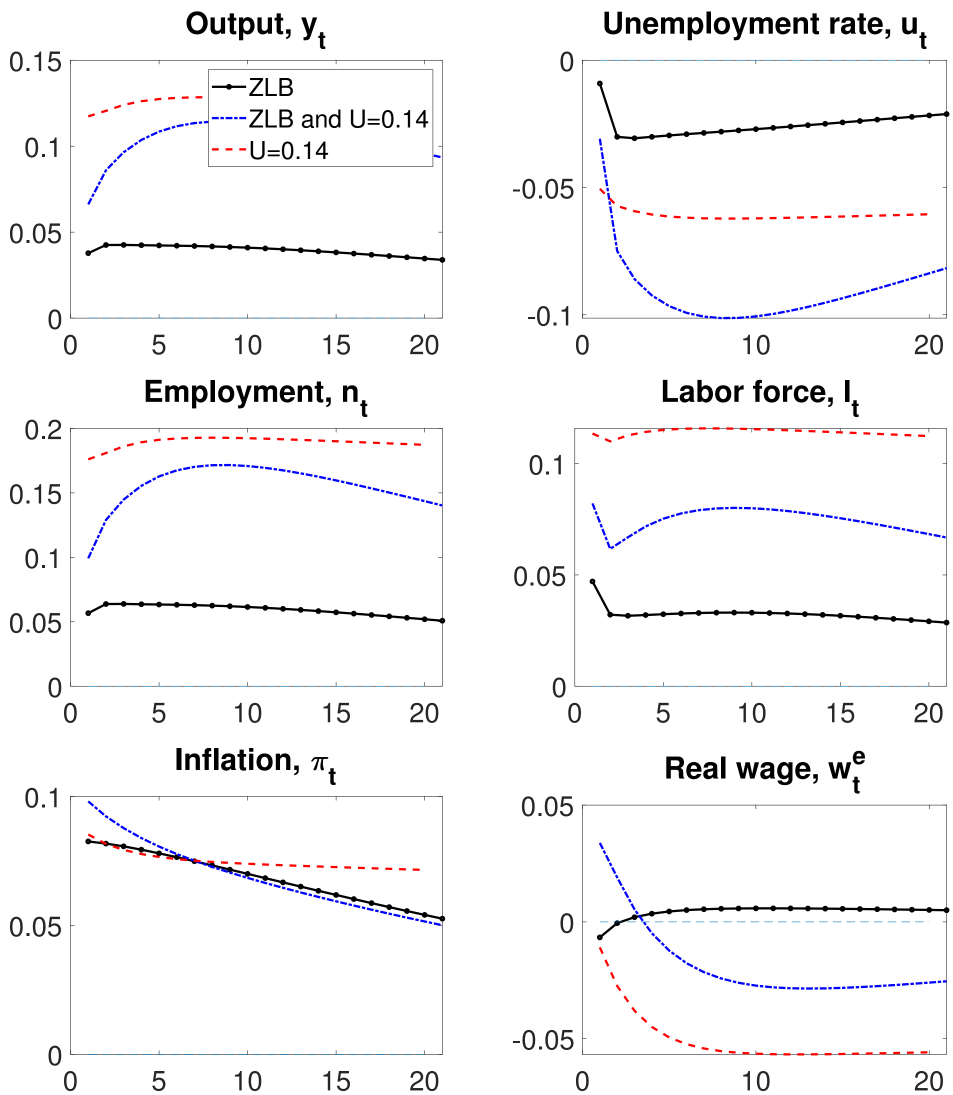

Figure B.3: **Impulse responses to an inflation target shock: Utility function non-separable in leisure and consumption.**
This figure presents the impulse responses of various endogenous variables of the model to an inflation target shock of one standard deviation under different labour market conditions. The red dotted line is the baseline model, the black line with dots is the model with utility function non-separable in leisure and consumption.

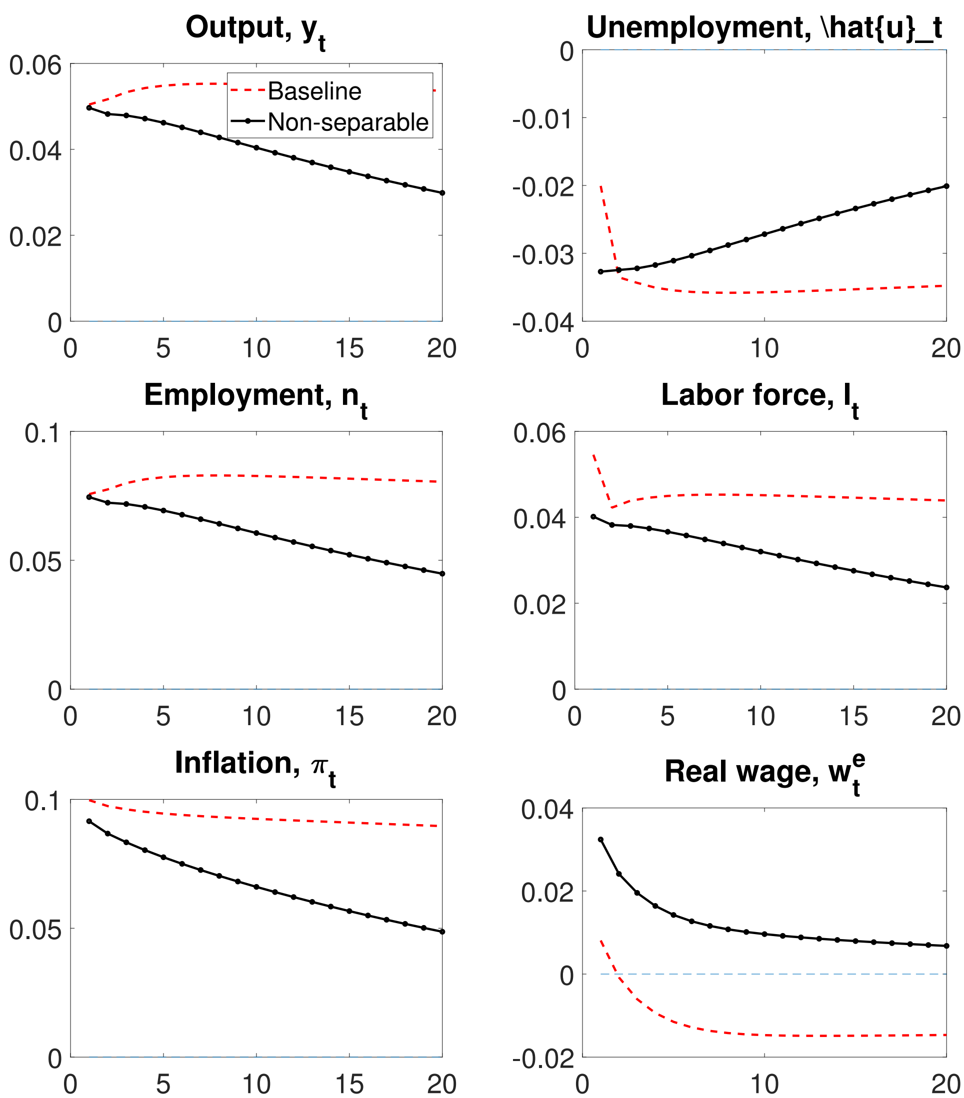

Figure B.4: **Impulse responses to an inflation target shock: Consumption habits.**
This figure presents the impulse responses of various endogenous variables of the model to an inflation target shock of one standard deviation under different labour market conditions. The red dotted line is the baseline model, the black line with dots is the model with consumption habits.