The exam consists of three parts: A, B, and C. In the grading, part A is given 10 % weight, part B is given 30 % weight, and part C is given 60 % weight.

## Part A (10 %)

The first-order conditions of the firm problem with sticky prices can be combined to

$$\sum_{k=0}^{\infty} \theta^k E_t \left\{ \Delta_{t,t+k} Y_{t+k|t} \left[ P_t^* - \mathcal{M} \Psi_{t+k|t} \right] \right\} = 0 \tag{1}$$

where $\Delta_{t,t+k} = \beta^k \frac{U_{c,t+k}}{U_{c,t}} \frac{P_t}{P_{t+k}}$, $\theta$ is the Calvo probability (not change prices), $Y_{t+k|t}$ is the production of a firm in period $t+k$ that last reset its price in period $t$, $P_t^*$ is the optimal price in period $t$, $\mathcal{M}$ is the desired mark-up, and $\Psi_{t+k|t}$ is nominal marginal cost in period $t+k$ for a firm that last reset its price in period $t$. Interpret equation (1). What does the firms take into considerations when setting prices?

## Part B (30 %)

A large, negative shock to the natural rate of interest has brought the policy rate to 0, while inflation and output remains below target.

**a)** Outline and *briefly* discuss what types of measures the central bank can implement to provide further stimulus.

**b)** Suppose the central bank contemplates using its balance sheet as a tool for further stimulus. Discuss the main types of balance sheet operations and under which economic conditions they are suitable.

**c)** Suppose the central bank contemplates setting the policy rate to a negative number. Sketch a model of the bank lending channel of negative monetary policy rates when banks fund themselves with deposits and an alternative funding source, and there is a zero lower bound on deposit rates. Discuss the conditions which determine the strength of the bank lending channel of negative policy rates.

## Part C (60 %)

We are going to use the New Keynesian model to see how the economy responds to a cost-push shock under an interest rate rule. We assume that the model is

$$\pi_t = \beta E_t\{\pi_{t+1}\} + \kappa \tilde{y}_t + u_t \tag{2}$$

$$\tilde{y}_t = E_t\{\tilde{y}_{t+1}\} - \frac{1}{\sigma}\left(i_t - E_t\{\pi_{t+1}\} - \rho\right) \tag{3}$$

$$i_t = \phi_\pi \pi_t + \phi_y \tilde{y}_t + \rho \tag{4}$$

$$u_t = \rho_u u_{t-1} + \epsilon_t^u \tag{5}$$

$$\epsilon_t^u \sim N(0, \sigma_u) \tag{6}$$

$$\kappa = \left(\sigma + \frac{\phi + \alpha}{1-\alpha}\right)\left(\frac{1-\theta}{\theta}\right)(1-\beta\theta)\left(\frac{1-\alpha}{1-\alpha+\alpha\epsilon}\right) \tag{7}$$

**a)** Insert (4) into (3) and guess that

$$\begin{aligned}
\tilde{y}_t &= \psi_{yu} u_t \\
\pi_t &= \psi_{\pi u} u_t \\
E_t\{\tilde{y}_{t+1}\} &= \rho_u \psi_{yu} u_t \\
E_t\{\pi_{t+1}\} &= \rho_u \psi_{\pi u} u_t.
\end{aligned}$$

Solve the equation system and show that

$$\psi_{yu} = -(\phi_\pi - \rho_u)\Lambda_u \tag{8}$$

$$\psi_{\pi u} = (\sigma(1-\rho_u) + \phi_y)\Lambda_u \tag{9}$$

$$\Lambda_u = \frac{1}{(1-\beta\rho_u)(\sigma(1-\rho_u)+\phi_y) + \kappa(\phi_\pi - \rho_u)}. \tag{10}$$

**b)** Figure 1 shows the impulse responses of the output gap, inflation, the nominal interest rate, and the cost push shock to an initial shock to $\epsilon_0^u$ of 0.25. We have used the following calibration: $\beta = 0.99$, $\sigma = 1$, $\phi = 5$, $\alpha = 0.25$, $\epsilon = 9$, $\theta = 0.75$, $\phi_\pi = 1.5$, $\phi_y = 0$, and $\rho_u = 0$. Explain why the cost push shock affects the economy the way it does in Figure 1.

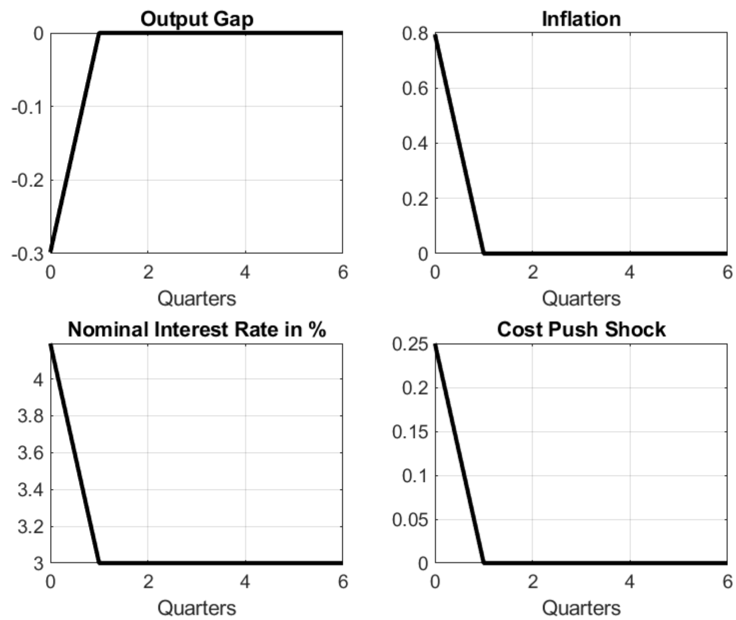


**Figure 1:** Impulse responses to a cost push shock

**c)** We now change the calibration by increasing $\phi$ from 5 to 30. All other parameters are the same as in problem b. Figure 2 presents the impulse responses in the benchmark scenario and in the new calibration. Explain what $\phi$ is, how it changes the economic environment, and explain how agents alter their behavior. Next, explain why the aggregate responses of the economy change in the way presented in Figure 2.

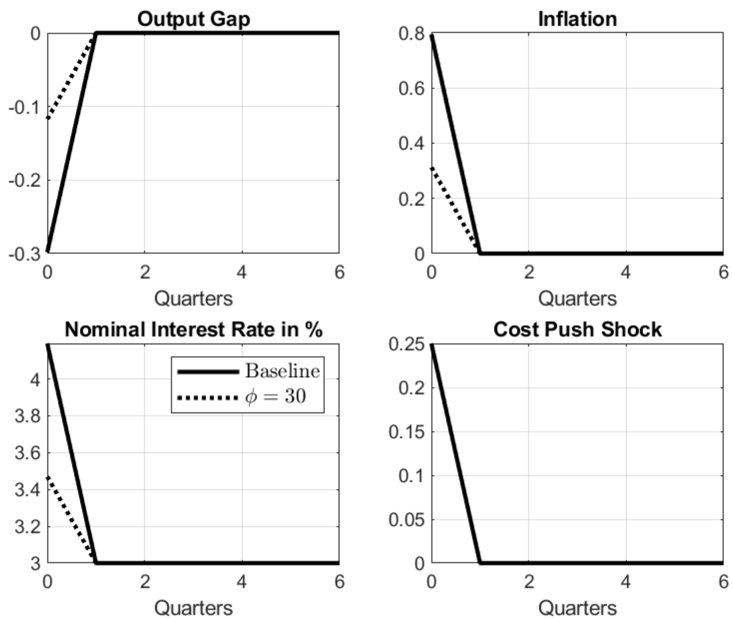


**Figure 2:** Impulse responses to a cost push shock: variation in $\epsilon$

**d)** Assume now that the central bank follows optimal monetary policy instead of a Taylor rule (4). The loss function is

$$L_t = \frac{1}{2}\sum_{k=0}^{\infty}\beta^k\left(\lambda\tilde{y}_{t+k}^2 + \pi_{t+k}^2\right)$$

Show that the solution for optimal monetary policy under discretion is

$$\pi_t = \frac{\lambda}{\lambda+\kappa^2}u_t \tag{11}$$

$$\tilde{y}_t = -\frac{\kappa}{\lambda+\kappa^2}u_t \tag{12}$$

$$\lambda\tilde{y}_t = -\kappa\pi_t \tag{13}$$

**e)** Interpret equation (13). What trade-off does the central bank face?

**f)** Figure 3 presents the impulse responses from b) (Taylor Rule) and the responses under optimal monetary policy. Should we put more or less (relative) weight on output in the Taylor rule to get closer to the optimal monetary policy?

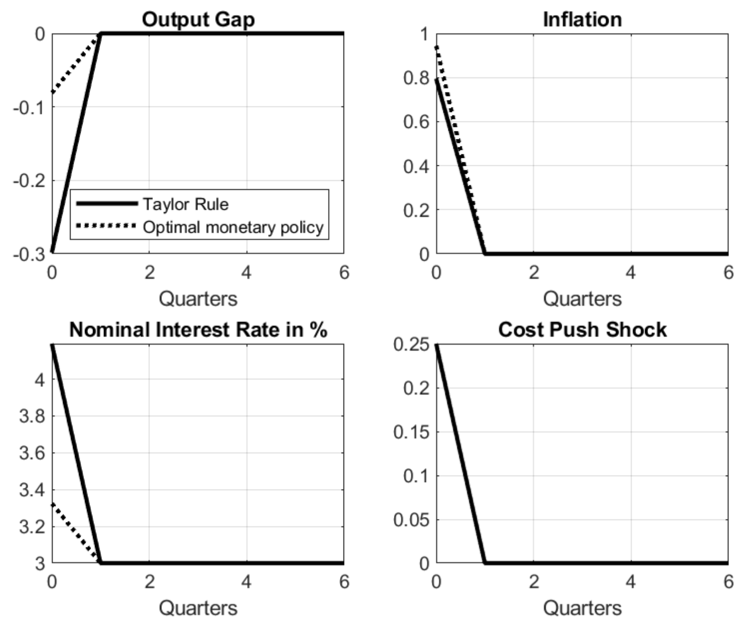


**Figure 3:** Impulse responses to a cost push shock: including first-order condition from optimal monetary policy

**g)** Optimal monetary policy can in this model be implemented as a Taylor rule with an updated coefficient $\hat{\phi}_y$. Use the solutions you found in problem a) and d) to show that one way to implement optimal monetary policy is to adopt a Taylor rule with

$$\hat{\phi}_y = \frac{\lambda\phi_\pi - \kappa\sigma}{\kappa}$$

for any $\phi_\pi$.

# Solution proposal

## PART A

The firms want to set prices as a constant mark-up over nominal marginal costs. With flexible prices, the price would be $P^*_{t+k} = \mathcal{M}\Psi_{t+k} \forall k$. With sticky prices, the firms also risk to be stuck with the price they set in period $t$ in the future. Hence, they set the price as a constant mark-up over a weighted average of current and future nominal marginal costs. The weight on period $t+k$ depends on (i) the probability of still being stuck with the price ($\theta^k$) and (ii) the marginal rate of substitution between period $t$ and $t+k$, i.e. how much you value consumption in period $t+k$ relative to period $t$ (also taking into account price movements). Hence, if you are more likely to be stuck with a price and/or consumption is expected to be low (high marginal utility), then the firm cares more about setting the price close to the mark-up over nominal marginal costs in that period relative to other periods.

## PART B

**a)** A good answer to this exercise is a list of the five different areas of unconventional monetary policy that we have focused on, plus 1-2 sentences on (1) what the measures are and (2) what we know about their effectiveness. For instance;

1. Forward guidance
   - Forward guidance entails changing expectations about future interest rates.
   - Important issues are time-inconsistency and the FG puzzle.
   - Empirical evidence suggests some impact on interest rates in the short-run, but long-run impact is unclear.

2. Liquidity support to the banking sector
   - Liquidity support to the banking sector typically entails providing additional funds to banks.
   - Additional funds reduces liquidity risk premia and can thereby be expansionary.
   - Empirical evidence (Jasova et.al 2019) suggest they can be effective.

3. Balance sheet operations

- Quantitative and credit easing
- Helicopter money
- Empirical literature suggests that quantitative easing has been somewhat of a failure due to collapse of the money multiplier. Credit easing have some short-run impact on long-term interest rates (Gagnon), and appears to expand bank lending (Darmouni and Rodnyanskiy). Expansions in bank credit leads to more favorable macroeconomic outcomes (Luck and Zimmermann).

4. Negative policy rates

    - Introducing negative policy rates.
    - Empirical evidence suggests that the impact varies with the extent of a ZLB on deposit rates (Eggertsson et al, Altavilla et al) and whether it reduces or increases bank profitability.

5. Macroprudential policies

    - Lower capital requirements for banks.
    - Empirical evidence suggests that it can expand credit supply (Arbatli and Juelsrud)

**b)** A good answer to this problem entails (1) discussing what pure quantitative easing and credit easing are (expanding reserves vs. targeted asset purchases) and how they differ and (2) discuss when each of the two measures are efficient. When discussing the effectiveness of pure quantitative easing, a good answer should touch upon

- The extent to which more reserves lead to more broad money. (Are banks reserve-constrained? How close substitutes are bonds and reserves?)
- The quantity theory of money and the extent through the velocity of money is constant.

When discussing the effectiveness of credit easing, a good answer should touch upon

- The importance of "portfolio rebalancing" by private investors in order to bring down long-term rates

- The strength of the bank capital channel (Are banks likely to be capital constrained and therefore respond to a net worth increase by lending more?)

A good answer also ties the discussion to the empirical evidence covered in the lecture.

**c)** A good answer to this problem should touch upon

- Sketch banking model with a zero lower bound on the deposit rate and an alternative funding source as in lecture 12.
- Discussion should be centered around: Is the deposit rate at the ZLB? If so, what is the impact on bank capital?

## PART C

**a)** Solve by the method of undetermined coefficients.

**b)** A cost-push shock is an increase in inflation that is initially not due to a change in output. The central bank responds to this increase in inflation by increasing the interest rate (by more than the initial change in inflation). Hence, the real interest rate also increases and households cut back on consumption, resulting in a reduction in output. This reduction in aggregate demand next results in lower prices, dampening the initial impact on prices, and so on. The total effect is therefore lower output, higher prices, and higher nominal and real interest rates.

**c)** $\phi$ is the parameter on the curvature of labor disutility. A higher $\phi$ implies that households dislike working one extra hour more. Hence, a higher $\phi$ implies that households need more compensation to increase their labor supply. A given movements in output is therefore accompanied by a greater reduction in wages (wages have to move more to move output), and therefore also marginal costs and prices. The total effect of a higher $\phi$ is therefore that inflation is more sensitive to changes in output ($\kappa \uparrow$). Initially, the central bank responds to the cost-push shock by increasing the interest rate, which subsequently reduces output. This reduction in output has a greater impact on inflation through the higher $\kappa$. Since interest rate changes have more impact on inflation, the interest rate moves less, output moves less, and inflation moves less (less deviation from steady state).

**d)** Solve by any method you want.

**e)** The trade-off when the central bank faces a positive cost-push shock is that the central bank has to reduce output in order to get inflation down. Equation (13) is the combination of first order conditions illustrating this trade-off. At the optimum, the marginal loss from lower output ($\gamma \tilde{y}_t$) is equal to the marginal gain from lower inflation ($-\kappa \pi_t$).

**f)** The student should note that the output gap response is too strong while the inflation response is too weak compared with optimal monetary policy. Hence, the central bank should put relatively more weight on output in the Taylor rule to obtain the optimal solution.

**g)** You have to compare the solutions in a) and d) and solve the equation system for the $\phi_y$. The two equations are:

$$-\frac{\phi_\pi}{\sigma + \phi_y + \kappa\phi_\pi} = -\frac{\kappa}{\lambda + \kappa^2}$$
$$\frac{\sigma + \phi_y}{\sigma + \phi_y + \kappa\phi_\pi} = \frac{\lambda}{\lambda + \kappa^2}$$

These equations have the same solution $\phi_y = \frac{\lambda\phi_\pi - \kappa\sigma}{\kappa}$.