# Topic 2

# The Baseline New Keynesian Model,

# Monetary Policy, and the Liquidity Trap: Part 2

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# Outline

*Part 1*

Household consumption, labor supply, saving decisions, and money demand

Firm labor, capital and price setting decisions

Monetary policy: Taylor rules

Decentralized equilibrium: monetary non-neutrality and inefficient output fluctuations

*Part 2*

Loglinear model

Aggregate demand and the natural rate of interest

The New Keynesian Phillips curve

Monetary policy design in the basic NK model

The liquidity trap

# Loglinearization: Aggregate Demand

Let $x_t = \log X_t - \log X$, except for $r_t^n$, $\pi_t, p_t$ and $m_t$ which are in levels

Let $\rho \equiv$ steady state net real interest rate $\beta^{-1} - 1$

Log-linearize around the steady state $(A_t = A)$ with zero inflation ($\frac{P_t}{P_{t-1}} = 1$).

$$y_t = c_t \tag{1}$$

$$c_t = -\sigma \left[ r_t^n - E_t \pi_{t+1} - \rho \right] + E_t \{ c_{t+1} \} \tag{2}$$

$$r_t^n - E_t \pi_{t+1} - \rho = E_t \left\{ (1 - \nu)(mc_{t+1} + y_{t+1}) + \nu q_{t+1} - q_t \right\} \tag{3}$$

where $\pi_t = p_t - p_{t-1}$, $\nu = 1/[\alpha MC \frac{Y}{K} + 1]$, and $\sigma = \frac{1}{\gamma}$.

# Log-linearization: Aggregate Demand (con't)

Equation (3) can be rewritten as:

$$q_t = E_t \left[(1-\nu)(mc_{t+1} + y_{t+1}) + \nu q_{t+1} - (r_t^n - E_t \pi_{t+1} - \rho)\right] \tag{4}$$

$$\tag{5}$$

$$= E_t \sum_{i=0}^{\infty} \nu^i \left[(1-\nu)(mc_{t+1+i} + y_{t+1+i}) - (r_{t+i}^n - \pi_{t+1+i} - \rho)\right] \tag{6}$$

$\longrightarrow$ The log price of capital equals the loglinearized expected discounted value of earnings.

- Note that in a model with variable capital, investment will depend positively on $q_t$.

# Log-linearization: Aggregate Supply

$$y_t = a_t + (1-\alpha)l_t \tag{7}$$

$$y_t - l_t = -mc_t + \gamma_n l_t + \gamma c_t \text{ (note: } -mc_t = \mu_t) \tag{8}$$

$$p_t = \theta p_{t-1} + (1-\theta)p_t^o \tag{9}$$

$$\begin{aligned} p_t^o &= (1-\theta\beta)E_t \sum_{i=0}^{\infty} (\theta\beta)^i (mc_{t+i} + p_{t+i}) && (10) \\ &= (1-\theta\beta)E_t \sum_{i=0}^{\infty} (\theta\beta)^i (mc_{t+i} + p_{t+i}) && (11) \end{aligned}$$

Given $mc_t = \log MC_t - \log MC \rightarrow$

$$mc_t + p_t = \text{log nominal marginal cost} - \log MC$$

# Log-linearization: Monetary Policy

In the zero inflation steady state $r^n = r = \rho$. (from the consumption euler equation).

Monetary Policy Rule

$$r_t^n = \rho + \phi_\pi \pi_t + \phi_y (y_t - y_t^*) + \upsilon_t \tag{12}$$

Money demand

$$m_t - p_t = k + \frac{\gamma}{\gamma_m} y_t - \eta r_t^n$$

with $k = \frac{1}{\gamma_m} \log a_m + \frac{\gamma}{\gamma_m} y, \eta = \frac{1}{\gamma_m (R^n - 1)}$

Note again: we can ignore money demand since the central bank just adjusts $m_t$ to support its objective for $r_t^n$.

# Log-linearization: Flexible Price Equilibrium

$(y_t^*, c_t^*, l_t^*, r_{t+1}^*)$ determined by

$$y_t^* = c_t^*$$

$$c_t^* = -\sigma \left[ r_{t+1}^* - \rho \right] + E_t\{c_{t+1}^*\}$$

$$y_t^* = a_t + (1-\alpha) l_t^*$$

$$y_t^* - l_t^* = \gamma_n l_t^* + \gamma c_t^*$$

given $y_t^* = c_t^* \rightarrow y_t^*, l_t^*$ jointly determined by

$$y_t^* = a_t + (1-\alpha) l_t^*$$

$$y_t^* - l_t^* = \gamma_n l_t^* + \gamma y_t^*$$

with $r_{t+1}^*$ given by

$$y_t^* = -\sigma \left[ r_{t+1}^* - \rho \right] + E_t\{y_{t+1}^*\}$$

# "IS/AS" Formulation

The above system can be collapsed into two equations: an IS curve that relates output demand inversely to the real interest rate and an aggregate supply curve that relates inflation to excess demand:

$$IS \quad : \quad y_t = -\sigma(r_t^n - E_t\pi_{t+1} - \rho) + E_t y_{t+1} \tag{13}$$

$$AS \quad : \quad \pi_t = \lambda(y_t - y_t^*) + \beta E_t \pi_{t+1} \tag{14}$$

with $\lambda = \frac{(1-\theta)(1-\beta\theta)}{\theta}\kappa$, and where $\kappa \equiv$ elasticity of $mc_t$ w.r.t. $y_t$

$$y_t^* = \frac{1+\varphi}{1+\varphi+(\gamma-1)(1-\alpha)} a_t$$

and where the markup (and hence the labor wedge) is countercyclical

$$mc_t = \kappa(y_t - y_t^*) \rightarrow \mu_t = -\kappa(y_t - y_t^*)$$

$r_t^n$ is given by the Taylor rule 12

# AS Curve

The Phillips curve (14) is derived from the recursive formulation of equation (10):

$$p_t^o = (1 - \beta\theta)(mc_t + p_t) + \beta\theta E_t p_{t+1}^o \tag{15}$$

From the price index equation (9), we get:

$$p_t - p_{t-1} = \pi_t = \frac{1-\theta}{\theta}(p_t^o - p_t) \tag{16}$$

Combining (15) and (16) yields:

$$\begin{aligned} p_t^o - p_t &= (1 - \beta\theta) mc_t + \beta\theta E_t \left[p_{t+1}^o - p_{t+1} + p_{t+1} - p_t\right] & (17) \\ \frac{\theta}{1-\theta}\pi_t &= (1 - \beta\theta) mc_t + \beta\theta E_t \left[\frac{\theta}{1-\theta}\pi_{t+1} + \pi_{t+1}\right] & (18) \\ \pi_t &= \frac{(1-\theta)(1-\beta\theta)}{\theta} mc_t + \beta E_t \pi_{t+1} & (19) \end{aligned}$$

# Loglinearization: Connecting $mc_t$ to $y_t - y_t^*$

Log-linearizing equations describing the flexible price equilibrium, we get:

$$\begin{aligned} y_t^* &= a_t + (1-\alpha) l_t^* \\ y_t^* - l_t^* &= \varphi l_t^* + \gamma y_t^* \end{aligned}$$

which (given $mc = -\mu$) can be combined into

$$y_t^* = \frac{1+\varphi}{1+\varphi+(\gamma-1)(1-\alpha)} a_t \tag{20}$$

Similarly, combine (1), (7) and (8) for the sticky price eq.:

$$y_t = \frac{1+\varphi}{1+\varphi+(\gamma-1)(1-\alpha)} a_t + \frac{mc_t}{(\gamma-1)+\frac{\varphi+1}{1-\alpha}} \tag{21}$$

Then

$$y_t = y_t^* + \frac{mc_t}{(\gamma-1)+\frac{\varphi+1}{1-\alpha}} \tag{22}$$

# Connecting $mc_t$ to $y_t - y_t^*$ (con't)

- marginal cost and the output gap.

$$mc_t = \kappa(y_t - y_t^*) \tag{23}$$

with $\kappa = (\gamma - 1) + \frac{\varphi+1}{1-\alpha}$.

- – note: $mc_t = -\mu_t \rightarrow$ countercyclical markup $\rightarrow$ countercyclical labor wedge

- Combining (19) and (23) yields the New Keynesian Phillips curve (14):

$$\pi_t = \lambda(y_t - y_t^*) + \beta E_t \pi_{t+1} \tag{24}$$

with $\lambda = \frac{(1-\theta)(1-\beta\theta)}{\theta}\kappa$.

Captures short run positive relation between $y_t - y_t^*$ and $\pi_t$.

Forward looking in contrast to traditional PC: $E_t\pi_{t+1}$ enters, not $\pi_{t-1}$.

# Baseline New Keynesian Model

Standard representation

$$
\begin{aligned}
IS &: \ y_t = -\sigma(r_t^n - E_t\pi_{t+1} - \rho) + E_t y_{t+1} \\
AS &: \ \pi_t = \lambda(y_t - y_t^*) + \beta E_t \pi_{t+1} \\
MP &: \ r_t^n = \rho + \phi_\pi \pi_t + \phi_\pi (y_t - y_t^*) + \upsilon_t
\end{aligned}
$$

with

$$y_t^* = \frac{1+\varphi}{1+\varphi+(\gamma-1)(1-\alpha)} a_t$$

$$a_t = \rho_a a_{t-1} + \varepsilon_{at}$$

$$\upsilon_t = \rho_m \upsilon_{t-1} + \varepsilon_{mt}$$

Monetary policy non-neutral. $\upsilon_t \uparrow \rightarrow r_t^n \uparrow \rightarrow y_t \downarrow \rightarrow \pi_t \downarrow$ .

Nominal price stickiness key.

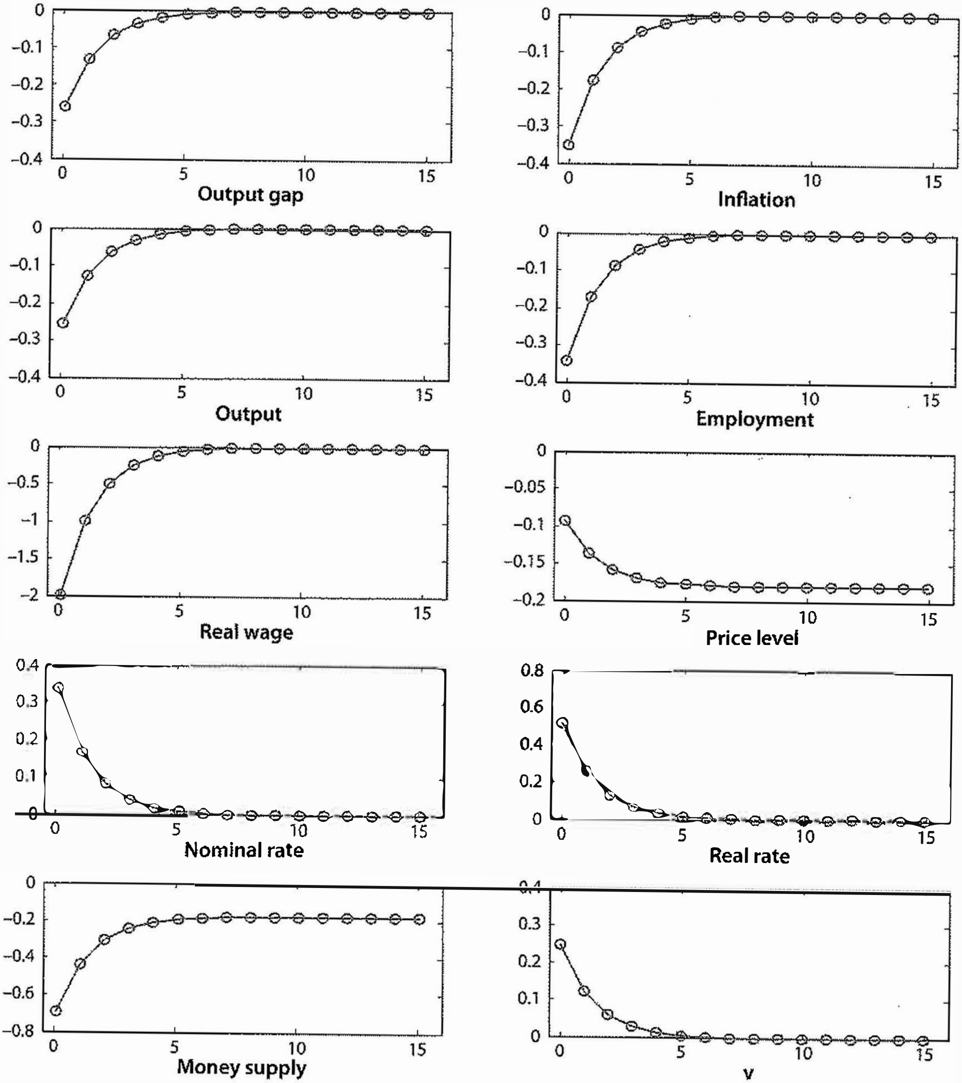


Figure 3.1. Dynamic Responses to a Monetary Policy Shock: Interest Rate Rule.

# Output Gap and the Natural Rate of Interest

Output gap: $\widetilde{y}_t = y_t - y_t^*$; Natural rate of interest $\equiv r_{t+1}^*$

$y_t^*$ and $r_{t+1}^*$ determined in flexible price equilibrium:

$$y_t^* = -\sigma(r_{t+1}^* - \rho) + E_t y_{t+1}^*$$
$$y_t^* = \frac{1+\varphi}{1+\varphi+(\gamma-1)(1-\alpha)} a_t$$

$\longrightarrow$

$$r_{t+1}^* = \rho + \frac{1}{\sigma}\frac{1+\varphi}{1+\varphi-(1-\gamma)(1-\alpha)}(E_t a_{t+1} - a_t))$$
$$= \rho + \frac{1}{\sigma}\frac{1+\varphi}{1+\varphi-(1-\gamma)(1-\alpha)}(\rho_a - 1)a_t$$

$r_{t+1}^*$ depends on expected productivity growth

# The NK Model in Terms of $\widetilde{y}_t$ and $\pi_t$

Combining sticky and flex price equilibria $\rightarrow$

$$\widetilde{y}_t = -\sigma[(r_t^n - E_t\pi_{t+1}) - r^*_{t+1}] + E_t\widetilde{y}_{t+1}$$

$$\pi_t = \lambda(\widetilde{y}_t) + \beta E_t\pi_{t+1}$$

$$r_t^n = \rho + \phi_\pi \pi_t + \phi_\pi \widetilde{y}_t + \upsilon_t$$

with

$$r^*_{t+1} = \rho + \frac{1}{\sigma}\frac{1+\gamma_n}{1+\gamma_n-(1-\gamma)(1-\alpha)}(\rho_a - 1)a_t$$

$\rightarrow$ $\widetilde{y}_t$ depends inversely on "interest rate" gap $(r_t^n - E_t\pi_{t+1}) - r^*_{t+1}$

# The Role of Expectations

We can represent the IS and AS curves as a system of simultaneous first order difference equations in $\widetilde{y}_t$ and $\pi_t$ conditional on the path of the policy instrument $r_t^n$.

$$\widetilde{y}_t = -\sigma[(r_t^n - E_t\pi_{t+1}) - r_{t+1}^*] + E_t\widetilde{y}_{t+1}$$
$$\pi_t = \lambda(\widetilde{y}_t) + \beta E_t\pi_{t+1}$$

There are no endogenous predetermined states. Both $\widetilde{y}_t$ and $\pi_t$ are endogenous at $t$ and depend on beliefs about the future. $\longrightarrow$ To solve iterate forward

$$\widetilde{y}_t = E_t \sum_i -\sigma[(r_{t+i}^n - E_t\pi_{t+1+i}) - r_{t+1+i}^*]$$
$$\pi_t = E_t \left\{ \sum_{i=0}^{\infty} \beta^i \lambda(\widetilde{y}_{t+i}) \right\}$$

$\widetilde{y}_t$ depends inversely on expected path of interest rate gap. (forward guidance matters!)

$\pi_t$ depends positively on expected path of $\widetilde{y}_t$ (forward looking price setting).

# Monetary Policy Design: The "Taylor" Principle

$$\widetilde{y}_t = \sum_i -\sigma[(r^n_{t+i} - E_t\pi_{t+1+i}) - r^*_{t+1+i}]$$

$$\pi_t = E_t\left\{\sum_{i=0}^{\infty} \beta^i \lambda(\widetilde{y}_{t+i})\right\}$$

$$r^n_t = \rho + \phi_\pi \pi_t + \phi_y \widetilde{y}_t + \upsilon_t$$

Suppose the objective of policy is $\widetilde{y}_t, \pi_t = 0$.

For a unique solution for $(y_t, \pi_t)$ to exist with $\lim_{i\to\infty} E_t\{\widetilde{y}_{t+i}\} = 0$ and $\lim_{i\to\infty} E_t\{\pi_{t+i}\} =$ 0, it must be the case that

$$\lim_{i\to\infty} E_t\{(r^n_{t+i} - E_t\pi_{t+1+i}) - r^*_{t+1+i}\} = 0.$$

A sufficient condition to ensure convergence is that $\phi_\pi > 1$.("Taylor" principle": see Gali).

# The Taylor Principle and Macroeconomic Stability: Intuition

$$\widetilde{y}_t = \sum_i -\sigma[(r^n_{t+i} - E_t\pi_{t+1+i}) - r^*_{t+1+i}]$$

$$\pi_t = E_t\left\{\sum_{i=0}^{\infty} \beta^i \lambda(\widetilde{y}_{t+i})\right\}; \qquad r^n_t = \rho + \phi_\pi \pi_t + \phi_y \widetilde{y}_t + \upsilon_t$$

Intuitively, suppose $r^*_{t+1+i} \uparrow$ (due e.g. to a drop in $a_t$) $\rightarrow \widetilde{y}_t \uparrow$ (given $r^n_t$) $\rightarrow \pi_t \uparrow$ .

Then $\phi_\pi > 1 \rightarrow r^n_{t+i} \uparrow$ enough to raise real rates $r^n_{t+i} - E_t\pi_{t+1+i} \rightarrow$ $r^n_{t+i} - E_t\pi_{t+1+i}$ converge to $r^*_{t+1+i} \rightarrow \widetilde{y}_{t+i}$ and $\pi_{t+i} \rightarrow 0$

$\phi_\pi > 1$ also eliminates self-fulfilling movements in inflation.

Suppose $E_t\pi_{t+1} \uparrow \rightarrow (r^n_t - E_t\pi_{t+1}) \downarrow$ (given $r^n_t$)$\rightarrow \widetilde{y}_t \uparrow \rightarrow \pi_t \uparrow$

With $\phi_\pi > 1 \rightarrow r^n_t \uparrow$ enough to raise real rates, choking off self-fulfilling inflation

Evidence: $\phi_\pi < 1$ from mid 60s to late 70s, a period of volatile inflation and output

Conversely, $\phi_\pi > 1$ from early 1980s to 2007, the Great Moderation.

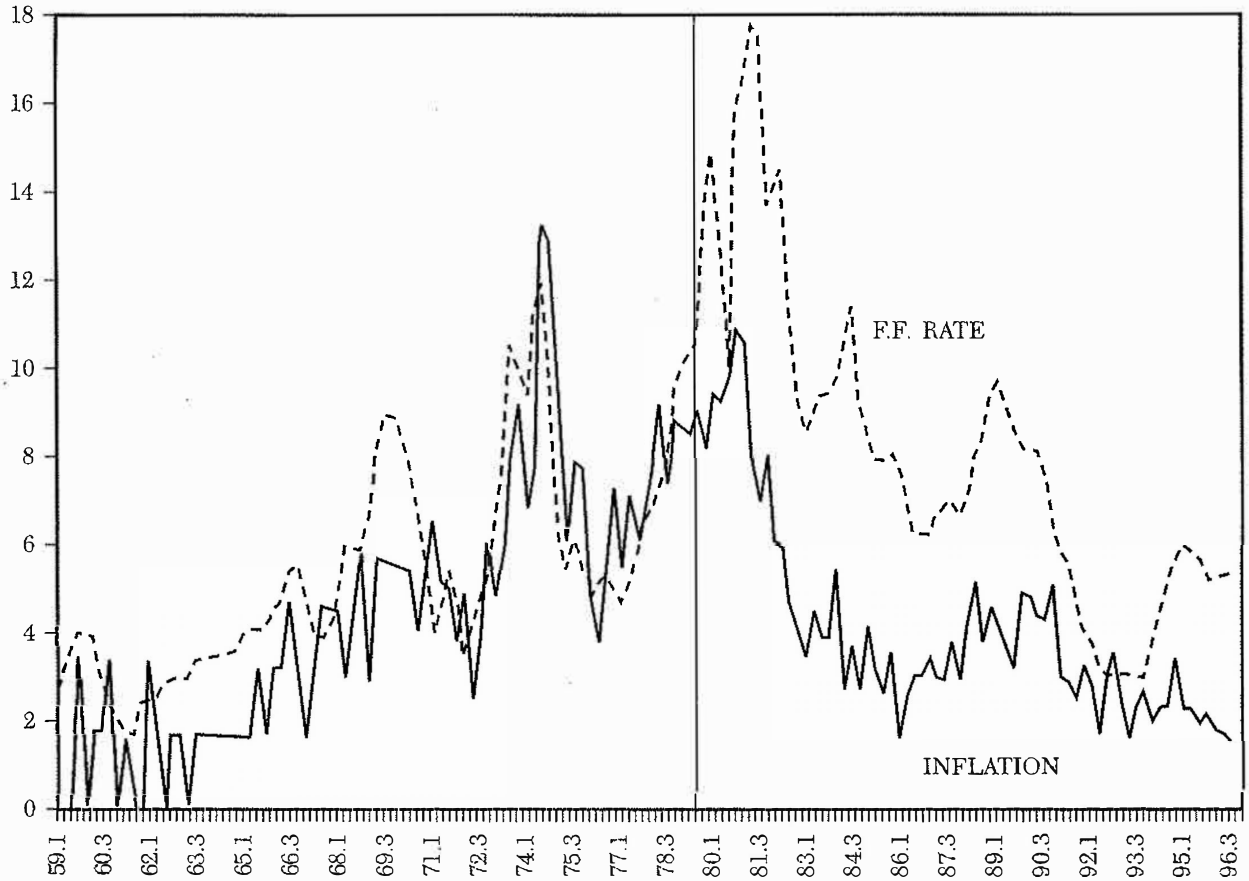


*Figure* 4. The Federal Funds Rate and the Inflation Rate

TABLE 1
ESTIMATES OF POLICY REACTION FUNCTION

| | $\gamma_\pi$ | $\gamma_x$ | $\rho$ |
|---|---|---|---|
| Pre-Volcker | 0.83 | 0.27 | 0.68 |
| | (0.07) | (0.08) | (0.05) |
| Volcker–Greenspan | 2.15 | 0.93 | 0.79 |
| | (0.40) | (0.42) | (0.04) |

## The Taylor Principle and Macroeconomic Stability: Formalities

$$\widetilde{y}_t = -\sigma[(r_t^n - E_t\pi_{t+1}) - r_{t+1}^*] + E_t\widetilde{y}_{t+1}$$

$$\pi_t = \lambda(\widetilde{y}_t) + \beta E_t\pi_{t+1}$$

$$r_t^n = \rho + \phi_\pi\pi_t + \phi_y\widetilde{y}_t + \upsilon_t$$

Use the policy rule to eliminate $r_t^n$ in the IS equation$\longrightarrow$

$$\begin{bmatrix} y_t \\ \pi_t \end{bmatrix} = A \begin{bmatrix} E_t y_{t+1} \\ E_t\pi_{t+1} \end{bmatrix} + B \cdot u_t$$

where $A$ is 2$x$2 and $B$ is 2x1.

Unique solution exists if the two roots of $A$ lie within the unit circle.

$\longrightarrow$ unique solution can be obtained through forward iteration.

Sufficient condition for the roots of $A$ in the unit circle: $\phi_\pi > 1$. (Gali p.65)

## Optimal Policy Rule: Given objective $\widetilde{y}_t, \pi_t = 0$

$$\widetilde{y}_t = \sum_i -\sigma[(r^n_{t+i} - E_t\pi_{t+1+i}) - r^*_{t+1+i}]$$

$$\pi_t = E_t \left\{ \sum_{i=0}^{\infty} \beta^i \lambda(\widetilde{y}_{t+i}) \right\}$$

Preferable policy rule (ignoring issues of commitment for now):

$$r^n_{t+i} = r^*_{t+1+i} \forall i \geq 0 \rightarrow \widetilde{y}_t, \pi_t = 0$$

To ensure $\pi_t \rightarrow 0$, need to specify that policy will adjust if $\pi_t$ deviates from 0 :

A rule that accomplishes this is

$$r^n_t = r^*_{t+1} + \phi_\pi \pi_t \text{ with } \phi_\pi > 1$$

As in the previous case, $\phi_\pi > 1$ ensures a determinate solution for $\widetilde{y}_t$ and $\pi_t$ (thus ruling out self-fulfilling solutions).

The difference in this case is that $\widetilde{y}_t$ and $\pi_t$ go right to 0

# Demand Shocks

Standard approach: preference shifter to induce fluctuations in consumption demand:

Modify utility function as follows:

$$E_t\{\sum_{i=0}^{\infty}\beta^i e^{b_{t+i}}[\frac{1}{1-\gamma}C_{t+i}^{1-\gamma} - \frac{1}{1+\varphi}L_{t+i}^{1+\varphi}]\}$$

where the preference shock $b_t$ obeys

$$b_t = \rho_b b_{t-1} + \varepsilon_{bt}$$

$\rightarrow$ Consumption euler equation:

$$e^{b_t}C_t^{-\gamma} = E_t\{\beta e^{b_{t+1}}C_{t+1}^{-\gamma}R_t^n\frac{P_t}{P_{t+1}}\}$$

# Demand Shocks (con')

In loglinear form (given $\sigma = 1/\gamma$)

$$c_t = -\sigma[(r_t^n - E_t\pi_{t+1}) - \rho] + E_t\{c_{t+1}\} + \sigma(b_t - E_t\{b_{t+1}\})$$
$$= -\sigma[(r_t^n - E_t\pi_{t+1}) - \rho] + E_t\{c_{t+1}\} + \sigma(1 - \rho_b)b_t$$

since $y_t = c_t$ :

$$y_t = -\sigma[(r_t^n - E_t\pi_{t+1}) - \rho] + E_t\{y_{t+1}\} + \sigma(1 - \rho_b)b_t$$

natural rate of output:

$$y_t^* = -\sigma[r_{t+1}^* - \rho] + E_t\{y_{t+1}^*\} + \sigma(1 - \rho_b)b_t$$

$\longrightarrow r_{t+1}^*$ depends on $b_t$

# IS/AS Model with Demand Shocks

Given $\widetilde{y}_t = y_t - y_t^*$

$$\widetilde{y}_t = -\sigma[(r_t^n - E_t\pi_{t+1}) - r_{t+1}^*] + E_t\widetilde{y}_{t+1}$$

$$\pi_t = \lambda(\widetilde{y}_t) + \beta E_t\pi_{t+1}$$

with

$$y_t^* = \frac{1+\varphi}{1+\varphi+(\gamma-1)(1-\alpha)}a_t$$

$$r_{t+1}^* = \rho + \frac{1}{\sigma}\frac{1+\gamma_n}{1+\gamma_n-(1-\gamma)(1-\alpha)}(\rho_a - 1)a_t + (1-\rho_b)b_t$$

$r_{t+1}^*$ summarizes the effect of $b_t$ and $a_t$ relevant to monetary policy

Optimal to continue to set $r_t^n = r_{t+1}^*$.

Complication: $r_{t+1}^*$ not directly observable (though $\pi_t$ provides information).

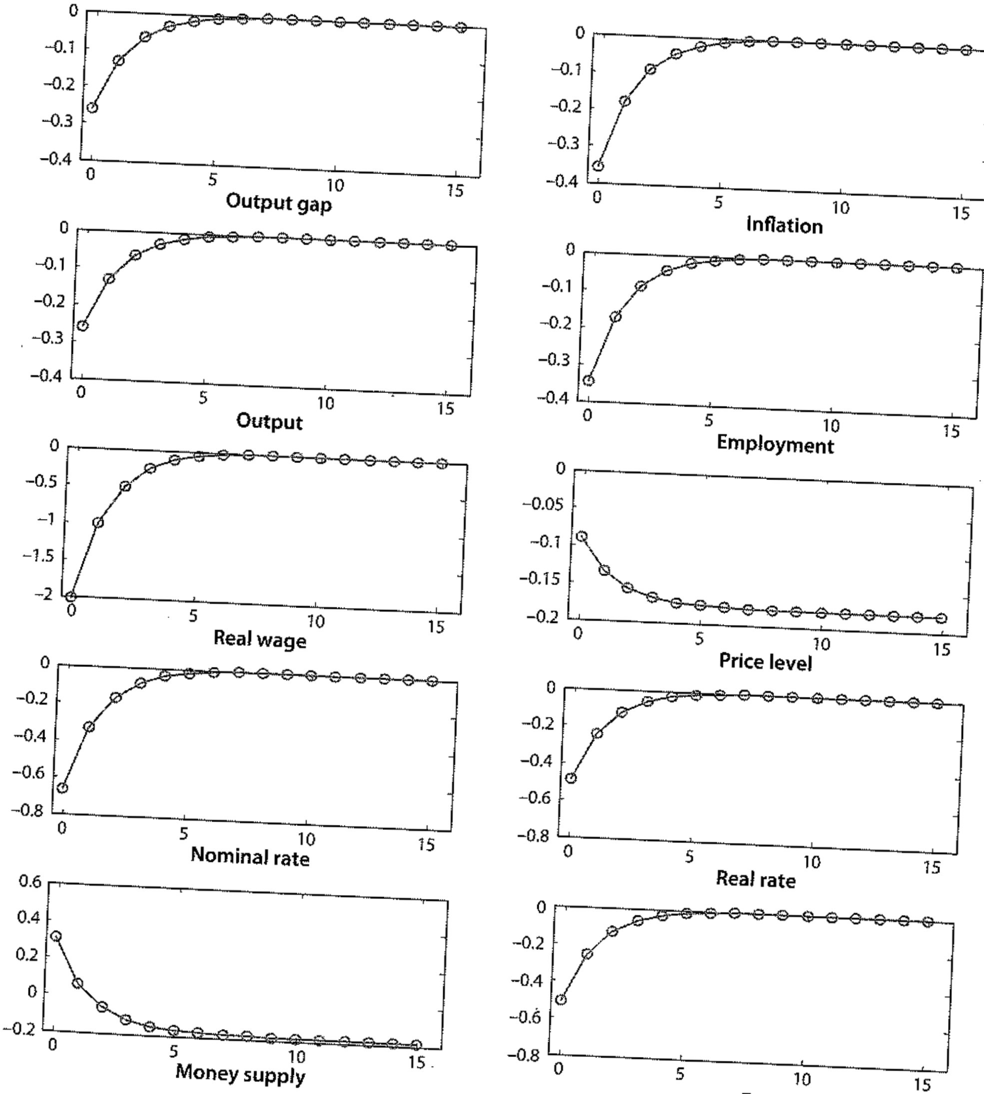


Figure 3.2. Dynamic Responses to a Discount Rate Shock: Interest Rate Rule.

# Baseline New Keynesian Model: Properties

- $\widetilde{y}_t$ depends inversely on current and expected future movements of $(r^n_{t+i} - E_t\pi_{t+1+i})$ relative to $r^*_{t+1+i}$.
- $\pi_t$ depends positively on current and expected future movements of $\widetilde{y}_t$.
- No short run trade-off between $\pi_t$ and $\widetilde{y}_t$ for a **credible** central bank (i.e. a central bank that can commit to keeping $\widetilde{y}_{t+i} = 0 \ \forall i > 0$.
  - Requires committing to adjust path of $r^n_{t+i}$ so $(r^n_{t+i} - E_t\pi_{t+1+i}) - r^*_{t+1+i} = 0 \ \forall i$.
  - Result depends on absence of labor market frictions (otherwise $mc_t$ not simply proportionate to $\widetilde{y}_t$).
  - If steady state output is inefficiently low, the central might be tempted to inflate.
  - If zero lower bound on the nominal rate binds, the economy is susceptible to deflation and output losses.

# Liquidity Trap and the Zero Lower Bound (ZLB)

- Liquidity trap: a situation where the central bank cannot stimulate the economy by reducing the short term interest rate.

- Emerges when ZLB constraint on net nominal interest rate binds
  - ZLB: $R_t^n - 1 \geq 0 \Leftrightarrow R_t^n \geq 1 \Leftrightarrow \log R_t^n = r_t^n \geq 0$
  - From earlier: desirable to set $r_t^n = r_{t+1}^*$ (natural interest rate)$\rightarrow$

- ZLB binds if natural real rate $R_{t+1}^* < 1 \Leftrightarrow r_{t+1}^* < 0$ where $r_{t+1}^* = \log R_{t+1}^*$

- Deflationary spiral can emerge, with $\widetilde{y}_t < 0$ and $\pi_t < 0$.

# Liquidity Trap and the Zero Lower Bound (con't)

- Suppose:
  - for $k$ periods $r^*_{t+1+i} < 0$
  - central bank pushes $r^n_{t+i}$ to ZLB over this period $\rightarrow r^n_{t+i} = 0$

$$\tilde{y}_t = E_t\{\sum_{i=0}^{k-1} -\sigma[(-E_t\pi_{t+1+i}) - r^*_{t+1+i}] + \sum_{i=k}^{\infty} -\sigma[(r^n_{t+i} - E_t\pi_{t+1+i}) - r^*_{t+1+i}]\}$$

- If for $i \geq k+1$, $(r^n_{t+i} - E_t\pi_{t+1+i}) = r^*_{t+1+i}$ :

$$\tilde{y}_t = E_t\{\sum_{i=0}^{k-1} -\sigma[(-E_t\pi_{t+1+i}) - r^*_{t+1+i}]\}$$

- $r^*_{t+1+i} < 0 \rightarrow$ a liquidity trap emerges with $\tilde{y}_{t+i}, \pi_{t+i} < 0$ until $i \geq k+1$.

# Escaping A Liquidity Trap

- Way out - commit to inflation after $r^*_{t+1+i}$ becomes positive.

$$\widetilde{y}_t = \sum_{i=0}^{k-1} -\sigma[(-E_t\pi_{t+1+i}) - r^*_{t+1+i}] + \sum_{i=k}^{\infty} -\sigma[(r^n_{t+i} - E_t\pi_{t+1+i}) - r^*_{t+1+i}]$$

- That is commit to $[(r^n_{t+1+i} - E_t\pi_{t+1+i}) - r^*_{t+1+i}] < 0$ for $i \geq k+1$.
- Note that this implies $\pi_{t+i} > 0$ if this commitment is kept $\Rightarrow$ credibility problem: Incentive to renege when out of liquidity trap.
- Fiscal policy may be an alternative (to raise $r^*_{t+1+i}$)
- In an economy with financial market frictions, credit policy may also be an alternative.