Monetary Theory: The Basic New Keynesian Model

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1. The New Keynesian Phillips curve relating inflation to the output gap.
2. A “Dynamic IS Equation” linking the evolution of aggregate demand (and the output gap) to the nominal interest rate.
3. A monetary-policy rule for setting the nominal interest rate (or, a money-supply rule plus a money-demand specification).

These equations determine the real interest rate, inflation, and the output gap. We will derive the first two equations and put them together with a policy rule below.
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The Output Gap

- Define the natural level of output as the level in the flexible-price equilibrium, and let $y^n_t$ denote the logarithm of natural output.
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- Define the natural level of output as the level in the flexible-price equilibrium, and let $y^*_t$ denote the logarithm of natural output.

- For example, in our model with iso-elastic utility and the production function

$$y_t = a_t + (1 - \alpha)n_t,$$

(1)

$0 < \alpha < 1$, we got

$$y^*_t = \frac{(1 - \alpha)[\log(1 - \alpha) - \mu]}{\varphi + \alpha + \sigma - \alpha\sigma} + \left(\frac{\varphi + 1}{\varphi + \alpha + \sigma - \alpha\sigma}\right)a_t$$

(2)

relating $y^*_t$ to productivity shocks.
The Output Gap

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relating $y_t^n$ to productivity shocks.
- We define the output gap as

$$\tilde{y}_t = y_t - y_t^n,$$

and define recessions as periods with a negative output gap.
The Output Gap

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- For example, in our model with iso-elastic utility and the production function

$$y_t = a_t + (1 - \alpha)n_t$$  \hspace{1cm} (1)

For $0 < \alpha < 1$, we got

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relating $y^n_t$ to productivity shocks.

- We define the output gap as

$$\tilde{y}_t = y_t - y^n_t$$

and define recessions as periods with a negative output gap.

- Comparison to real-world measures, and the role of productivity shocks.
Real Marginal Cost

- Recall that with flexible prices real marginal cost is constant at the steady-state value

\[ mc = \log \left( \frac{\epsilon - 1}{\epsilon} \right) , \]

which is the inverse of the monopoly markup
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- Recall also that, with sticky prices, real marginal cost is positively related to output because an increase in output increases the real wage, and may also lead to diminishing marginal product of labor (\( mpn \) in the textbook) if we have a fixed factor in the production function
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- For example, with our iso-elastic specification, with (1), we get:

\[ \hat{mc}_t = \left( \sigma + \frac{\alpha + \varphi}{1 - \alpha} \right) \tilde{y}_t \]
Marginal Cost and Output

\[ mc_t = (w_t - p_t) - mpn_t \]
\[ = (\sigma y_t + \varphi n_t) - (y_t - n_t) - \log(1 - \alpha) \]
\[ = \left( \sigma + \frac{\varphi + \alpha}{1 - \alpha} \right) y_t - \frac{1 + \varphi}{1 - \alpha} a_t - \log(1 - \alpha) \quad (6) \]

Under flexible prices

\[ mc = \left( \sigma + \frac{\varphi + \alpha}{1 - \alpha} \right) y_t^n - \frac{1 + \varphi}{1 - \alpha} a_t - \log(1 - \alpha) \quad (7) \]

\[ \implies y_t^n = -\delta_y + \psi_{ya} a_t \]

where \( \delta_y \equiv \frac{(\mu - \log(1 - \alpha))(1 - \alpha)}{\sigma + \varphi + \alpha(1 - \sigma)} > 0 \) and \( \psi_{ya} \equiv \frac{1 + \varphi}{\sigma + \varphi + \alpha(1 - \sigma)}. \)

\[ \implies \widehat{mc_t} = \left( \sigma + \frac{\varphi + \alpha}{1 - \alpha} \right) (y_t - y_t^n) \quad (8) \]

where \( y_t - y_t^n \equiv \tilde{y}_t \) is the output gap.
Note that this equation,

$$\hat{m}c_t = \left( \sigma + \frac{\alpha + \varphi}{1 - \alpha} \right) \hat{y}_t,$$

relates the proportional deviation of real marginal cost from its steady-state value to the output gap.
Real Marginal Cost and the Output Gap

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with $\alpha = 0$, the connection involves the preference parameters $\sigma$ and $\varphi$, reflecting the effect of output on real wages.
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Either way, an expansion of output raises real marginal cost, and this erodes the monopoly markup
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New prices, in Calvo’s model, rise with real marginal cost (in response to the erosion of the markup), and this leads to inflation
The New Keynesian Phillips Curve (NKPC)

- More precisely, we saw that (with Calvo price setting) inflation dynamics are governed by

\[ \pi_t = \beta E_t \pi_{t+1} + \lambda \hat{m}c_t \]

with a coefficient \( \lambda > 0 \) that is inversely related to the degree of price rigidity \( \theta \)
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\[ \pi_t = \beta E_t \pi_{t+1} + \lambda \widehat{mc}_t \]

with a coefficient \( \lambda > 0 \) that is inversely related to the degree of price rigidity \( \theta \)

- Combining this with

\[ \widehat{mc}_t = \left( \sigma + \frac{\alpha + \varphi}{1 - \alpha} \right) \tilde{y}_t \]

we get the New Keynesian Phillips Curve

\[ \pi_t = \beta E_t \pi_{t+1} + \kappa \tilde{y}_t \]

with

\[ \kappa = \lambda \left( \sigma + \frac{\alpha + \varphi}{1 - \alpha} \right) > 0 \]
Digression: Phillips Curves, Old and New

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- The original Phillips Curve
  1. inverse relation, in the data, between inflation and unemployment
  2. the traditional Keynesian interpretation

\[ \pi_t = E_t \pi_{t+1} + \kappa (y_t - y_n) \]
\[ \kappa > 0 \]

Contrast with the forward-looking NKPC

\[ \pi_t = \beta E_t \pi_t + 1 + \kappa (y_t - y_n) \]
\[ \kappa > 0 \]

(setting \( \kappa = 1/\phi \))
The original Phillips Curve

1. inverse relation, in the data, between inflation and unemployment
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3. an inflation-unemployment (inflation-output) trade-off for policymakers?
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- The Phelps-Friedman "Expectations-augmented" Phillips Curve
  - the New Classical rendition (with Rational Expectations)

\[
\pi_t = E_{t-1} \pi_t + \kappa^* (y_t - y_t^n), \quad \kappa^* > 0
\]
The original Phillips Curve

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\[ \pi_t = E_{t-1} \pi_t + \kappa^* (y_t - y^n_t), \ \kappa^* > 0 \]

- may arise from the Lucas aggregate-supply curve

\[ y_t = y^n_t + \phi (p_t - E_{t-1} p_t), \ \phi > 0 \]

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  - Contrast with the forward-looking NKPC
    \[ \pi_t = \beta E_t \pi_{t+1} + \kappa (y_t - y^n_t) \quad , \quad \kappa > 0 \]
The consumers’ Euler equation governs the evolution of aggregate demand, given our market-clearing condition $C_t = Y_t$.
Equilibrium

*Goods markets clearing*

\[ Y_t(i) = C_t(i) \]

for all \( i \in [0, 1] \) and all \( t \).

Letting \( Y_t \equiv \left( \int_0^1 Y_t(i)^{1-\epsilon} \, di \right)^{\frac{\epsilon}{\epsilon-1}} \),

\[ Y_t = C_t \]

for all \( t \). Combined with the consumer’s Euler equation:

\[ y_t = E_t\{y_{t+1}\} - \frac{1}{\sigma} \left( i_t - E_t\{\pi_{t+1}\} - \rho \right) \] (5)
The consumers’ Euler equation governs the evolution of aggregate demand, given our market-clearing condition $C_t = Y_t$.

Define the natural real interest rate $r^n_t$ as the real rate in the flexible-price equilibrium.
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Define the natural real interest rate $r^n_t$ as the real rate in the flexible-price equilibrium

Recall that $r^n_t$ depends on productivity, but not on the prevailing nominal interest rate (nor anything else that monetary policy can affect)
The consumers’ Euler equation governs the evolution of aggregate demand, given our market-clearing condition $C_t = Y_t$.

Define the natural real interest rate $r^n_t$ as the real rate in the flexible-price equilibrium.

Recall that $r^n_t$ depends on productivity, but not on the prevailing nominal interest rate (nor anything else that monetary policy can affect).

For example, in our iso-elastic specification leading to (2), we have

$$y^n_t = -\frac{1}{\sigma}(r^n_t - \rho) + E_t y^n_{t+1}$$

and

$$r^n_t = \rho + \sigma \left( \frac{\varphi + 1}{\varphi + \alpha + \sigma - \alpha \sigma} \right) E_t(\Delta a_{t+1})$$
Combining the Euler equations in the two equilibria (with flexible and sticky prices), we can relate the evolution of the output gap to the interest-rate gap $r_t - r^n_t$.
New Keynesian Phillips Curve

\[ \pi_t = \beta \ E_t\{\pi_{t+1}\} + \kappa \ \tilde{y}_t \]  \hspace{1cm} (9)

where \( \kappa \equiv \lambda \left( \sigma + \frac{\varphi + \alpha}{1 - \alpha} \right) \).

Dynamic IS equation

\[ \tilde{y}_t = E_t\{\tilde{y}_{t+1}\} - \frac{1}{\sigma} \left( i_t - E_t\{\pi_{t+1}\} - r^n_t \right) \]  \hspace{1cm} (10)

where \( r^n_t \) is the natural rate of interest, given by

\[ r^n_t \equiv \rho + \sigma \ E_t\{\Delta y^n_{t+1}\} \]
\[ = \rho + \sigma \psi_y \ E_t\{\Delta a_{t+1}\} \]

Missing block: description of monetary policy (determination of \( i_t \)).
Combining the Euler equations in the two equilibria (with flexible and sticky prices), we can relate the evolution of the output gap to the interest-rate gap $r_t - r^n_t$.

Monetary policy affects the output gap through its effect on the interest-rate gap:

$$y_t - y^n_t = E_t(y_{t+1} - y^n_{t+1}) - \frac{1}{\sigma} [i_t - E_t(\pi_{t+1}) - r^n_t]$$

i.e.

$$\bar{y}_t = E_t(\bar{y}_{t+1}) - \frac{1}{\sigma} [r_t - r^n_t]$$
We can close the model by specifying an interest-rate rule for monetary policy.
New Keynesian Phillips Curve

\[ \pi_t = \beta \ E_t\{\pi_{t+1}\} + \kappa \tilde{y}_t \]  \hspace{1cm} (9)

where \( \kappa \equiv \lambda \left( \sigma + \frac{\varphi + \alpha}{1 - \alpha} \right) \).

Dynamic IS equation

\[ \tilde{y}_t = E_t\{\tilde{y}_{t+1}\} - \frac{1}{\sigma} \left( i_t - E_t\{\pi_{t+1}\} - r^n_t \right) \]  \hspace{1cm} (10)

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Missing block: description of monetary policy (determination of \( i_t \)).
We can close the model by specifying an interest-rate rule for monetary policy.

For example, near the steady state with zero inflation, a Taylor Rule

\[ i_t = \rho + \phi_\pi \pi_t + \phi_y \hat{y}_t + v_t \]

delivers determinacy if it satisfies the Taylor Principle, \( \phi_\pi > 1 \), and \( \phi_y \geq 0 \) (the necessary condition for determinacy, presented in the textbook, is a bit weaker).
Equilibrium under a Simple Interest Rate Rule

\[ i_t = \rho + \phi \pi_t + \phi_y \tilde{y}_t + v_t \quad (11) \]

where \( v_t \) is exogenous (possibly stochastic) with zero mean.

Equilibrium Dynamics: combining (9), (10), and (11)

\[
\begin{bmatrix}
\tilde{y}_t \\
\pi_t
\end{bmatrix} = A_T \begin{bmatrix}
E_t\{\tilde{y}_{t+1}\} \\
E_t\{\pi_{t+1}\}
\end{bmatrix} + B_T (\tilde{r}_t^n - v_t) \quad (12)
\]

where

\[
A_T \equiv \Omega \begin{bmatrix}
\sigma & 1 - \beta \phi \\
\sigma \kappa & \kappa + \beta (\sigma + \phi_y)
\end{bmatrix} ; \quad B_T \equiv \Omega \begin{bmatrix}
1 \\
\kappa
\end{bmatrix}
\]

and \( \Omega \equiv \frac{1}{\sigma + \phi_y + \kappa \phi} \)
Uniqueness $\iff \mathbf{A}_T$ has both eigenvalues within the unit circle

Given $\phi_\pi \geq 0$ and $\phi_y \geq 0$, (Bullard and Mitra (2002)):

$$\kappa \left( \phi_\pi - 1 \right) + (1 - \beta) \phi_y > 0$$

is necessary and sufficient.
We can close the model by specifying an interest-rate rule for monetary policy.

For example, near the steady state with zero inflation, a Taylor Rule

\[ i_t = \rho + \phi_{\pi} \pi_t + \phi_y \tilde{y}_t + \nu_t \]

delivers determinacy if it satisfies the Taylor Principle, \( \phi_{\pi} > 1 \), and \( \phi_y \geq 0 \) (the necessary condition for determinacy, presented in the textbook, is a bit weaker).

Here, \( \nu_t \) represents a "monetary-policy shock" and may, for example, follow an exogenous AR(1) process.
We can close the model by specifying an interest-rate rule for monetary policy.

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Here, \( \nu_t \) represents a "monetary-policy shock" and may, for example, follow an exogenous AR(1) process.

Although we can solve this simple model analytically, we usually rely on a calibration and stochastic simulations to assess the quantitative implications of our models.
Effects of a Monetary Policy Shock

Set $\hat{r}_t^n = 0$ (no real shocks).

Let $v_t$ follow an AR(1) process

$$v_t = \rho_v v_{t-1} + \varepsilon_t^v$$

Calibration:

$$\rho_v = 0.5, \phi_\pi = 1.5, \phi_y = 0.5/4, \beta = 0.99, \sigma = \varphi = 1, \theta = 2/3, \eta = 4.$$  

Dynamic effects of an exogenous increase in the nominal rate (Figure 1).  
Exercise: analytical solution
Figure 3.1: Effects of a Monetary Policy Shock (Interest Rate Rule)
Effects of a Technology Shock

Set $\nu_t = 0$ (no monetary shocks).

Technology process:

$$a_t = \rho_a a_{t-1} + \varepsilon_t^a.$$ 

Implied natural rate:

$$\tilde{r}_t^n = -\sigma \psi_y (1 - \rho_a) a_t$$

Dynamic effects of a technology shock ($\rho_a = 0.9$) (Figure 2)

Exercise: AR(1) process for $\Delta a_t$
Figure 3.2: Effects of a Technology Shock (Interest Rate Rule)
Alternatively, we may specify a policy rule that sets the money supply—e.g., an AR(1) process for money growth—and solve the (simple) model or simulate (richer) models.
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The practical motivation for this specification is weaker because major central banks use the nominal interest rate as their policy instrument.
Equilibrium under an Exogenous Money Growth Process

\[ \Delta m_t = \rho_m \Delta m_{t-1} + \varepsilon_t^m \]  

(13)

Money market clearing

\[ \hat{l}_t = \hat{y}_t - \eta \hat{i}_t \]  

(14)

\[ = \tilde{y}_t + \hat{y}_t^n - \eta \hat{i}_t \]  

(15)

where \( l_t \equiv m_t - p_t \) denotes (log) real money balances.

Substituting (14) into (10):

\[ (1 + \sigma \eta) \tilde{y}_t = \sigma \eta E_t \{ \tilde{y}_{t+1} \} + \hat{l}_t + \eta E_t \{ \pi_{t+1} \} + \eta \hat{r}_t^n - \hat{y}_t^n \]  

(16)

Furthermore, we have

\[ \hat{l}_{t-1} = \hat{l}_t + \pi_t - \Delta m_t \]  

(17)
Equilibrium dynamics

\[
\begin{bmatrix}
\tilde{y}_t \\
\pi_t \\
\hat{l}_{t-1}
\end{bmatrix}
A_{M,0}
\begin{bmatrix}
E_t\{\tilde{y}_{t+1}\} \\
E_t\{\pi_{t+1}\} \\
\hat{l}_{t-1}
\end{bmatrix}
= A_{M,1}
\begin{bmatrix}
\tilde{r}_t^n \\
\hat{y}_t^n \\
\Delta m_t
\end{bmatrix}
+ B_M
\] (18)

where

\[
A_{M,0} \equiv \begin{bmatrix} 1 + \sigma \eta & 0 & 0 \\ -\kappa & 1 & 0 \\ 0 & -1 & 1 \end{bmatrix}; \quad A_{M,1} \equiv \begin{bmatrix} \sigma \eta & \eta & 1 \\ 0 & \beta & 0 \\ 0 & 0 & 1 \end{bmatrix}; \quad B_M \equiv \begin{bmatrix} \eta & -1 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & -1 \end{bmatrix}
\]

Uniqueness \(\iff\) \(A_M \equiv A_{M,0}^{-1}A_{M,1}\) has two eigenvalues inside and one outside the unit circle.
Effects of a Monetary Policy Shock
Set $r^n_t = y^n_t = 0$ (no real shocks).

Money growth process

$$\Delta m_t = \rho_m \Delta m_{t-1} + \varepsilon^m_t$$ \hspace{1cm} (19)

where $\rho_m \in [0, 1)$

Figure 3 (based on $\rho_m = 0.5$)

Effects of a Technology Shock
Set $\Delta m_t = 0$ (no monetary shocks).

Technology process:

$$a_t = \rho_a a_{t-1} + \varepsilon^a_t.$$

Figure 4 (based on $\rho_a = 0.9$).

Empirical Evidence
Figure 3.3: Effects of a Monetary Policy Shock (Money Growth Rule)
Figure 3.4: Effects of a Technology Shock (Money Growth Rule)
Alternatively, we may specify a policy rule that sets the money supply—e.g., an AR(1) process for money growth—and solve the (simple) model or simulate (richer) models.

The practical motivation for this specification is weaker because major central banks use the nominal interest rate as their policy instrument.

But the ability of various models to generate liquidity effects, under money-supply rules, has motivated some academic researchers.
New Keynesian (NK) Insights

- The core RBC framework plays an important role in the NK model, and in its implications for the effects of productivity (and fiscal) shocks.
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The NK concept of stabilization policy is fundamentally different from the traditional notion of stabilizing (de-trended) output.
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- The output target $y_t^n$ depends on productivity.
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- The NK model’s household block (maximizing utility over time) makes it very different from traditional Keynesian models.
- The NK concept of stabilization policy is fundamentally different from the traditional notion of stabilizing (de-trended) output:
  - the output target $y^*_t$ depends on productivity
  - as an illustration, consider the effects of a productivity shock in the simple model with one-period price rigidity.
New Keynesian (NK) Insights

- The core RBC framework plays an important role in the NK model, and in its implications for the effects of productivity (and fiscal) shocks.
- The NK model’s household block (maximizing utility over time) makes it very different from traditional Keynesian models.
- The NK concept of stabilization policy is fundamentally different from the traditional notion of stabilizing (de-trended) output.
  - the output target $y_t^n$ depends on productivity.
  - as an illustration, consider the effects of a productivity shock in the simple model with one-period price rigidity.
- The NK model offers fundamentally new insights about the output-inflation "trade-off" facing the central bank, as we will see in Chapter 4.