Economics 704a Lecture 7: New Keynesian Model Intuitions and Critiques

Adam M. Guren

Boston University

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New Keynesian Model: Outline

1. The Baseline New Keynesian Model
   1.1 Setup
   1.2 Nonlinear Equations: Intuition
   1.3 Log-Linearized Version
   1.4 The Three Equation Model
   1.5 Calibrated Model: Impulse Responses and Intuition
2. Early Critiques of the New Keynesian Model
   2.1 Credible Disinflation
   2.2 Sticky Inflation and Responses
3. Medium-Scale NK Models
4. Recent Critiques and Tests of the New Keynesian Model
   4.1 The Minnesota Critique
   4.2 The Cochrane Critique: Taylor Rule and Indeterminacy
   4.3 The New Keynesian Phillips Curve in the Data

Review of Last Class: Calvo Assumption

- New Keynesian model mostly differs on supply side.
- Calvo: Random fraction $1-\theta$ of intermediate producers resets:

$$P_t = \left[\theta P_{t-1}^{1-\varepsilon} + (1-\theta)\, P_t^{*1-\varepsilon}\right]^{\frac{1}{1-\varepsilon}}$$

  - Price index is *recursive*.
  - Reduces dimensionality: To solve equilibrium only need P_{t-1} and P_t^*, not infinite dimensional distribution of prices.
- Means NK model has one additional state variable and one additional equation relative to money model.
  - Instead of markup formula (from profit max), updating rule for Calvo Price Index and optimal reset pricing (profit max).

Review of Last Class: Optimal Reset Pricing

$$\max_{\left\{Y_{t+s|t}\right\}_{s=0}^{\infty}, P_t^*} E_t \left\{ \sum_{s=0}^{\infty} \theta^s \Lambda_{t,t+s}^n \left(P_t^* Y_{t+s|t} - MC_{t+s}^n Y_{t+s|t} \right) \right\} \text{ s.t}$$

$$Y_{t+s|t} = \left(\frac{P_t^*}{P_{t+s}} \right)^{-\varepsilon} Y_{t+s}$$

- If $\theta = 0$, no stickiness and this collapses to flex price model:

$$P_t^* = (1+\mu) \, MC_t^n$$

- If $\theta > 0$, then the optimal reset price is a markup over a weighted average of expected future nominal marginal costs:

$$P_t^* = (1+\mu) \, E_t \left\{ \sum_{s=0}^{\infty} \omega_{t,t+s} MC_{t+s}^n \right\}$$

$$\text{where } \omega_{t,t+s} = \frac{\theta^s \Lambda_{t,t+s}^n Y_{t+s} P_{t+s}^{\varepsilon}}{E_t \left\{ \sum_{k=0}^{\infty} \theta^k \Lambda_{t,t+k}^n Y_{t+k} P_{t+k}^{\varepsilon} \right\}}$$

Review of Last Class: Nonlinear Equations

$$\begin{aligned}
\frac{W_t}{P_t} &= \frac{\chi N_t^{\varphi}}{C_t^{-\gamma}} \\
1 &= \beta E_t \left\{ Q_t \frac{P_t}{P_{t+1}} \frac{C_{t+1}^{-\gamma}}{C_t^{-\gamma}} \right\} \\
P_t &= \left[\theta P_{t-1}^{1-\varepsilon} + (1-\theta) P_t^{*1-\varepsilon} \right]^{\frac{1}{1-\varepsilon}} \\
P_t^* &= (1+\mu) E_t \left\{ \sum_{s=0}^{\infty} \frac{\theta^s \Lambda_{t,t+s}^n P_{t+s}^{\varepsilon} Y_{t+s}}{E_t \left\{ \sum_{k=0}^{\infty} \theta^k \Lambda_{t,t+k}^n P_{t+k}^{\varepsilon} Y_{t+k} \right\}} \frac{W_{t+s}}{A_{t+s}} \right\} \\
Y_t &= C_t \\
Y_t &= A_t N_t \left[\int_0^1 \left(\frac{N_t(i)}{N_t} \right)^{\frac{\varepsilon-1}{\varepsilon}} \right]^{\frac{\varepsilon}{\varepsilon-1}}
\end{aligned}$$

Review of Last Class: Nonlinear Equations Implications

- Examining the non-linear equations we found:

1. **Expectations Augmented**: With forward-looking price setters, expected future inflation affects expected future nominal marginal costs and causes inflation today.
2. Useful to compare to **ficticious flexible price equilibrium**:
   - If $E_t[\pi_{t+1}] = 0$ and at $y_t = y_t^{flex}$, $\pi_t = 0$.
   - If $E_t[\pi_{t+1}] = 0$ and $y_t > y_t^{flex}$, $\pi_t > 0$ because raise reset prices to cover rising nominal wage bill from two sources in CRS model with only labor:
     - Moving up labor supply curve (controlled by φ)
     - Shift in labor supply due to wealth effect (controlled by γ)
   - Implication: Phillips curve with intercept at flex price output.

- Consequently, strategy is to log-linearize model, log linearize flex price model, and difference to **write log-linear model in terms of output gap $\tilde{y}_t = \hat{y}_t - \hat{y}_t^{flex}$**.

Review of Last Class: Log-Linear NKPC

- Combine reset pricing and Calvo updating to get NKPC:

$$\hat{\pi}_t = \lambda \hat{mc}_t + \beta E_t \left\{ \hat{\pi}_{t+1} \right\} \text{ where } \lambda = \frac{(1-\theta)(1-\beta\theta)}{\theta}$$

- Log-linearize marginal costs and flex price equilibrium:

$$\hat{mc}_t = (\gamma + \varphi) \hat{y}_t - (1+\varphi) \hat{a}_t$$
$$(\gamma + \varphi) \hat{y}_t^{flex} = (1+\varphi) \hat{a}_t$$

- Subtract to get NKPC in terms of *output gap* $\tilde{y}_t = \hat{y}_t - \hat{y}_t^{flex}$:

$$\hat{\pi}_t = \kappa \tilde{y}_t + \beta E_t \left\{ \hat{\pi}_{t+1} \right\} \text{ where } \kappa = \lambda (\gamma + \varphi)$$

- Slope determined by:
  - θ: More resetters, more inflation immediately.
  - φ: More inelastic labor supply, more π for given $\tilde{y}_t$.
  - γ: Lower IES, stronger wealth effect, more π for given $\tilde{y}_t$.

Log Linearization: The Aggregate Demand Block

$$
\begin{aligned}
1 &= \beta E_t \left\{ Q_t \frac{P_t}{P_{t+1}} \frac{C_{t+1}^{-\gamma}}{C_t^{-\gamma}} \right\} \\
Y_t &= C_t
\end{aligned}
$$

- Log-linearize Euler around zero-inflation:

$$\hat{c}_t = -\frac{1}{\gamma}\left(\hat{i}_t - E_t\{\hat{\pi}_{t+1}\}\right) + E_t\{\hat{c}_{t+1}\}$$

  - Steady state nominal interest rate is $i_t = \rho$.

- Combine with market clearing and use $\sigma = 1/\gamma$:

$$\hat{y}_t = -\sigma\left(\hat{i}_t - E_t\{\hat{\pi}_{t+1}\}\right) + E_t\{\hat{y}_{t+1}\}$$

- This is the *dynamic IS curve*. It relates output to future expectations of output and the real interest rate.

The Natural Rate of Interest

- Define the **natural rate of interest** $\hat{r}^n_{t+1}$ as the real interest rate that would prevail when output is equal to its flexible level:

$$\hat{y}^{flex}_t = -\sigma \hat{r}^n_{t+1} + E_t \left\{ \hat{y}^{flex}_{t+1} \right\}$$

- Recall $\hat{y}^{flex}_t = \left(\frac{1+\varphi}{\gamma+\varphi} \right) \hat{a}_t$ so:

$$\begin{aligned} \hat{r}^n_{t+1} &= \gamma \frac{1+\varphi}{\gamma+\varphi} E_t \left\{ \hat{a}_{t+1} - \hat{a}_t \right\} \\ &= \gamma \frac{1+\varphi}{\gamma+\varphi} E_t \left\{ \Delta \hat{a}_{t+1} \right\} \end{aligned}$$

  - If a_t follows an AR(1) and grows today, it will be expected to decline between today and tomorrow due to mean reversion.
  - So positive tech shock causes real interest rate to fall by standard RBC logic.

Dynamic IS In Terms of the Output Gap

$$\tilde{y}_t = -\sigma E_t \left\{ \hat{i}_t - \hat{\pi}_{t+1} - \hat{r}^n_{t+1} \right\} + E_t \left\{ \tilde{y}_{t+1} \right\}$$

- Iterating forward, the current output gap depends negatively on the gap between the real interest rate and the natural rate of interest:

$$\tilde{y}_t = -\sigma E_t \left\{ \sum_{s=0}^{\infty} \left(\hat{r}_{t+s+1} - \hat{r}^n_{t+s+1} \right) \right\}$$

The Three Equation NK Model

- The basic NK model boils down to three equations:

$$\begin{aligned}
\tilde{y}_t &= -\sigma E_t \left\{ \hat{i}_t - \hat{\pi}_{t+1} - \hat{r}^n_{t+1} \right\} + E_t \left\{ \tilde{y}_{t+1} \right\} \\
\hat{\pi}_t &= \kappa \tilde{y}_t + \beta E_t \left\{ \hat{\pi}_{t+1} \right\} \\
\hat{i}_t &= \phi_\pi \hat{\pi}_t + \phi_y \tilde{y}_t + v_t
\end{aligned}$$

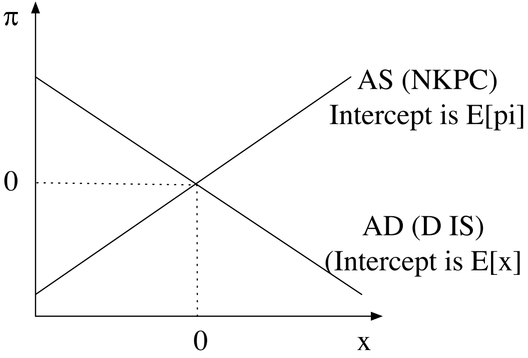
  with three unknowns: $\hat{i}_t$, $\tilde{y}_t$, and $\hat{\pi}_t$ and an exogenous driving process for the natural rate:

$$\hat{r}^n_t = \gamma \frac{1+\varphi}{\gamma+\varphi} E_t \left\{ \Delta \hat{a}_{t+1} \right\}.$$

- Key new ingredient is NK Phillips curve:
  - $\beta E_t \left\{ \pi_{t+1} \right\}$: Price setters forward looking.
  - $\kappa \tilde{y}_t$: Output gap $\uparrow \Rightarrow$ MC $\uparrow \Rightarrow$ markups $\downarrow \Rightarrow$ raise prices.

AD-AS Diagram

- Can draw diagram with $\beta E_t \{\hat{\pi}_{t+1}\}$ and $E_t \{\tilde{y}_{t+1}\}$ held fixed.
  - NKPC: Positive relationship between $\hat{\pi}_t$ and $\tilde{y}_t$.
  - DIS and Taylor: Negative relationship between $\hat{\pi}_t$ and $\tilde{y}_t$ as long as $\phi_\pi > 0$ (required for determinacy as we prove below).
  - Here $x = \tilde{y}_t$.



Solving the Model: Monetary Policy Shocks

- Plug in interest rate rule and rewrite as a difference equation:

$$\begin{bmatrix} \tilde{y}_t \\ \hat{\pi}_t \end{bmatrix} = AE_t \left\{ \begin{bmatrix} \tilde{y}_{t+1} \\ \hat{\pi}_{t+1} \end{bmatrix} \right\} + B \left(E_t \left\{ \hat{r}^n_{t+1} \right\} - v_t \right)$$

where letting $\Omega = \frac{1}{\gamma+\phi_y+\kappa\phi_\pi}$,

$$A = \Omega \begin{bmatrix} \gamma & 1 - \beta\phi_\pi \\ \gamma\kappa & \kappa + \beta \left(\gamma + \phi_y \right) \end{bmatrix} \text{ and } B = \Omega \begin{bmatrix} 1 \\ \kappa \end{bmatrix}$$

- 2 non-predetermined variables, 0 endogenous state variables.
    - Solve forward.
- Unique solution if both eigenvalues of A in unit circle:

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

which holds if $\phi_\pi > 1$ and $\phi_y \geq 0$.

- Taylor principle still holds (and we assume it).

Solving the Model: Monetary Policy Shocks

- Assume:

$$v_t = \rho_v v_{t-1} + \varepsilon_t \text{ and } \hat{r}^n_{t+1} = 0$$

- Guess reduced form policy functions:

$$\tilde{y}_t = \psi_{yv} v_t \text{ and } \tilde{\pi}_t = \psi_{\pi v} v_t$$

- This gives:

$$\begin{aligned} \psi_{\pi v} &= \kappa \psi_{yv} + \beta \rho_v \psi_{\pi v} \\ \psi_{\pi v} &= -\sigma \left(\phi_\pi \psi_{\pi v} + \phi_y \psi_{yv} - \rho_v \psi_{\pi v} \right) + \rho_v \psi_{yv} \end{aligned}$$

- Solving by method of undetermined coeffs:

$$\psi_{yv} = -\left(1 - \beta \rho_v\right) \Lambda_v \text{ and } \psi_{\pi v} = -\kappa \Lambda_v$$

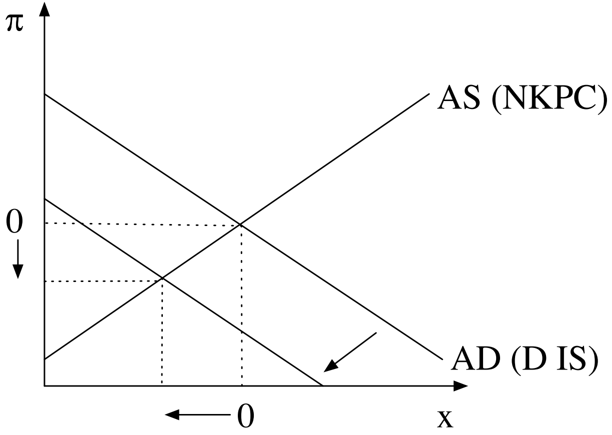
$$\text{where } \Lambda_v = \frac{1}{\left(1 - \beta \rho_v\right) \left[\gamma \left(1 - \rho_v\right) + \phi_y\right] + \kappa \left(\phi_\pi - \rho_v\right)} > 0$$

Solving the Model: Monetary Policy Shocks

- Contractionary monetary shock ($\uparrow i_t$) reduces $\tilde{y}_t$ and π_t.
- Consider a temporary shock ($\rho_v = 0$):
  - By Fisher, increase in i_t raises real interest rate above its natural level.
  - Consumption and output gap fall due to inter-temporal substitution.
  - Economy is aggregate demand determined so output falls.
  - Marginal costs fall and markups rise. Resetters cut prices to get back to desired markup. Inflation falls.

Solving the Model: Monetary Policy Shocks

- Other way to see it is with AD-AS diagram.
  - Monetary shock shifts AD curve in, AS unaffected.



Solving the Model: Technology Shocks

- Assume

$$v_t = 0 \text{ and } a_t = \rho_a a_{t-1} + \varepsilon_t$$

- Natural rate is

$$\begin{aligned} \hat{r}^n_{t+1} &= \gamma \frac{1+\varphi}{\gamma+\varphi} E_t \left\{ \Delta \hat{a}_{t+1} \right\} \\ &= -\gamma \frac{1+\varphi}{\gamma+\varphi} \left(1-\rho_a\right) \hat{a}_t \end{aligned}$$

- $\hat{r}^n_t$ is linear function of a_t and hence follows an AR(1) process.
- And it enters with opposite sign to v_t, so same solution:

$$\tilde{y}_t = \left(1 - \beta\rho_a\right) \Lambda_a \hat{r}^n_{t+1} \text{ and } \hat{\pi}_t = \kappa \Lambda_a \hat{r}^n_{t+1}$$

- Note: This is for *persistent* tech shocks.

Solving the Model: Technology Shocks

- Technology shock causes output gap and inflation to fall.
  - But flexible output rises: $\hat{y}_t^{flex} = \left(\frac{1+\varphi}{\gamma+\varphi}\right)\hat{a}_t$.
- So what happens to output and employment?

$$\begin{aligned} \hat{y}_t &= \hat{y}_t^{flex} + \tilde{y}_t \\ \hat{n}_t &= \hat{y}_t - \hat{a}_t \end{aligned}$$

- If $\gamma = 1$, then $\hat{y}_t^{flex} = \hat{a}_t$ and $\hat{r}_t^n = -(1-\rho_a)\,\hat{a}_t$ so:

$$\begin{aligned} \hat{y}_t &= \rho_a(1-\beta\rho_a)\Lambda_a\hat{a}_t \\ \hat{n}_t &= -(1-\rho_a)(1-\beta\rho_a)\Lambda_a\hat{a}_t \end{aligned}$$

- Technology shocks are contractionary for labor.
  - Consistent with Gali (1999) and Basu et al. (2006)!

Solving the Model: Demand Shocks

- Gali incorporates demand shocks into NK model through shocks to discount rate:

$$E_t \left\{ \sum_{s=0}^{\infty} Z_t \beta^s \left(\frac{C_{t+s}^{1-\gamma}}{1-\gamma} - \chi \frac{N_{t+s}^{1+\varphi}}{1+\varphi} \right) \right\}$$

  where Z_t follows an AR(1).
    - Z_t is a shock to the marginal utility of consumption.
    - Forces people to consume more today $\Rightarrow$ demand shock.
- Dynamic IS becomes:

$$\tilde{y}_t = -\sigma E_t \left\{ \hat{i}_t - \hat{\pi}_{t+1} - r_{t+1}^n \right\} + E_t \left\{ \tilde{y}_{t+1} \right\} + \frac{1}{\sigma} \left(1 - \rho_z\right) \hat{z}_t$$

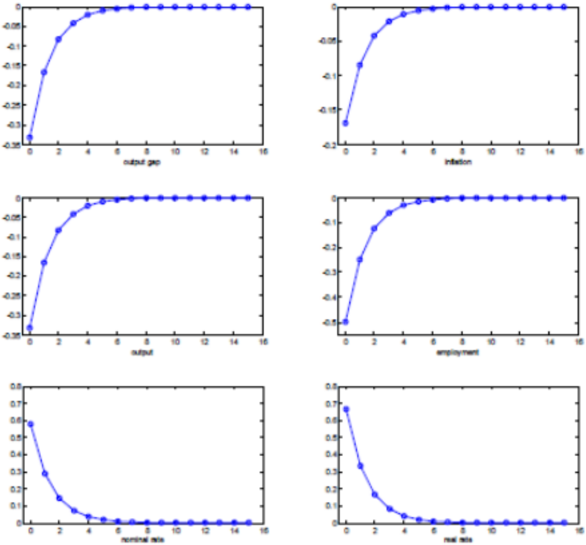
- $\hat{z}_t$ becomes part of natural rate:

$$\hat{r}_{t+1}^n = -\gamma \frac{1+\varphi}{\gamma+\varphi} \left(1 - \rho_a\right) \hat{a}_t + \left(1 - \rho_z\right) \hat{z}_t$$

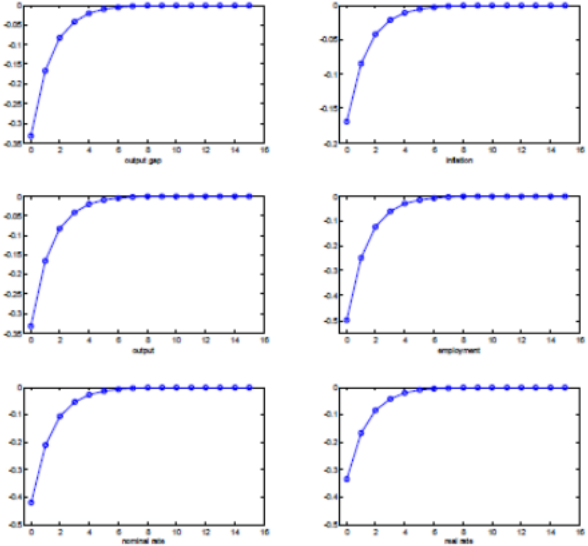
Solving the Model: Demand Shocks

- Demand shocks enter in opposite way as tech shocks and same way as expansionary monetary shocks.
  - Increase output gap and inflation.
  - Demand shocks are expansionary!
- Reason: Aggregate demand channel.
  - Prices are somewhat fixed.
  - So if demand goes up, markups fall and marginal costs rise, accommodate by producing more, but raise prices when have opportunity to do so causing inflation.
- Let's go one step further and look at impulse responses (you should be able to draw!)

Impulse Response: Monetary Shock



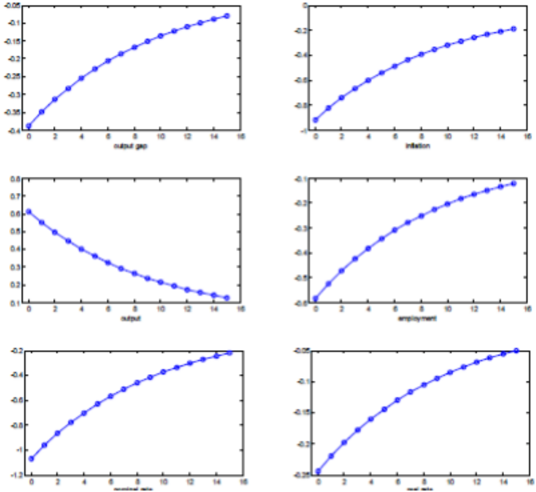
Impulse Response: Discount Rate Shock



Demand Shock vs. Monetary Shock

- Demand shocks have an effect on the natural rate of interest, while monetary policy shocks do not.
- Monetary policy shocks lead to changes in the nominal interest rate for a given level of inflation and output, whereas discount factor shocks do not.
- But they go in similar directions.
  - Monetary policy can stabilize *both* output and inflation.
  - This turns out to be a special case.
- Note: Impulse responses depend crucially on Central Bank response function.
  - Theme of NK literature.
  - Somewhat unsatisfying.

Impulse Response: Tech Shocks



Critiquing the New Keynesian Model

- The New Keynesian model will be our laboratory to study monetary policy.
  - But does it make sense? Do we like it?
  - How well does it perform, qualitatively and quantitatively?

Ball (1994): Deflation vs. Disinflation

- What happens when the central bank credibly tightens monetary policy?
- Ball (1994): It depends on *how* they do so.
  - Credible deflation (change in *level* of money): Recession.
    - Accords with evidence, e.g. from 1720s France.
  - Credible disinflation (change in *growth rate* of money): Boom!
- Credible disinflation result seems to fly in the face of the evidence from the early 1980s, when Volcker caused a disinflation and a recession!

Credible Deflation

$$
\begin{aligned}
\tilde{y}_t &= -\sigma E_t \left\{ \hat{i}_t - \hat{\pi}_{t+1} - \hat{r}^n_{t+1} \right\} + E_t \left\{ \tilde{y}_{t+1} \right\} \\
\hat{\pi}_t &= \kappa \tilde{y}_t + \beta E_t \left\{ \hat{\pi}_{t+1} \right\}
\end{aligned}
$$

- Central bank tightens money supply, or equivalently raises nominal interest rate
    - Standard monetary shock.
    - Real interest rate rises, increasing savings and reducing consumption today. Output gap falls.
    - In response to fall in output gap, inflation falls. Intuitively, markups are too high and producing too little, so cut prices toward optimal markup.
- Prices and markups are "too high" when money supply falls immediately but prices adjust gradually
    - So output falls until prices are at the right level.

Credible Disinflation

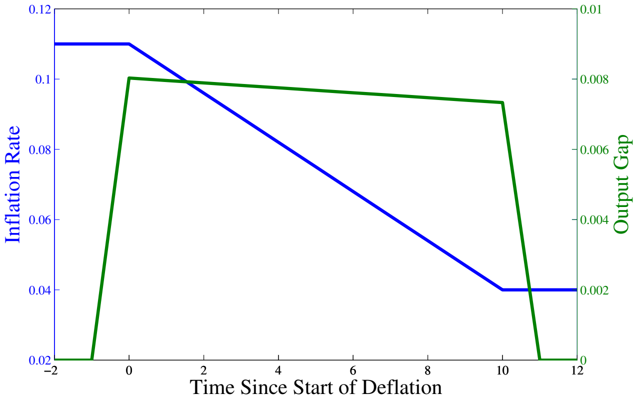
$$\hat{\pi}_t \quad = \quad \kappa \tilde{y}_t + \beta E_t \{\hat{\pi}_{t+1}\}$$

- Central bank is going to gradually reduce the inflation *rate.*
- Since credible, $\hat{\pi}_{t+1}$ is known for certain and:

$$\tilde{y}_t = \frac{1}{\kappa}(\pi_t - \beta\pi_{t+1})$$

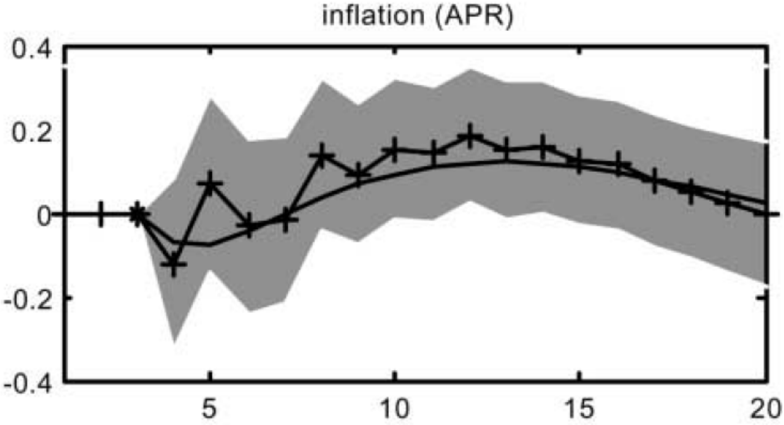
  - The output gap is positive during the disinflation if it is not too fast as $\beta\pi_{t+1} < \pi_t$.
- Anticipating lower inflation, firms cut prices today.
  - Prices and markups are "too low" until the disinflation finishes, so output *rises*.
- Reconciling with Volcker: Goodfriend and King (2005) argue it was "incredible" at the time, but could be issue with model.

Credible Disinflation



- Example: Linear Disinflation from $\bar{\pi}$ to $\underline{\pi}$ over T periods.
  - Reduces inflation $\mu = (\bar{\pi} - \underline{\pi}) / T$ per period.
  - Since credible, $\pi_t = \bar{\pi} - \mu t$ until $t = T$ and $\underline{\pi}$ thereafter.

Inflation Persistence: Hump-Shaped IRFs in Data



- See Fuhrer (2011) for more evidence on inflation persistence

Inflation Persistence

- In the baseline Calvo model, $|\hat{\pi}_t|$ jumps to its highest level *immediately* in response to a shock and gradually mean reverts.
  - # of firms that have not adjusted previously is highest initially.
  - # of firms adjusting for first time decays geometrically.
- Generalize two key equations with persistent output gap:

$$
\begin{aligned}
\tilde{y}_t &= -\sigma E_t \left\{ \hat{i}_t - E_t \{\hat{\pi}_{t+1}\} - \hat{r}^n_{t+1} \right\} + \rho_y E_t \{\tilde{y}_{t+1}\} \\
\hat{\pi}_t &= \kappa \tilde{y}_t + \beta E_t \{\hat{\pi}_{t+1}\}
\end{aligned}
$$

  - Persistence of inflation equal to that of output gap.
  - But inflation is more persistent in data.

Inflation Persistence: Backward-Looking Phillips

- To get persistent inflation, need "backward-looking" component in Phillips curve:

$$\hat{\pi}_t = \kappa \tilde{y}_t + (1-\mu)\, \beta E_t \left\{ \hat{\pi}_{t+1} \right\} + \mu \hat{\pi}_{t-1}$$

- Also fixes credible disinflation issue if sufficiently backward-looking.
  - Prices fall slowly when central bank deflates slowly and prices are never "too low."
- Several ways to obtain backward-looking Phillips.

Inflation Persistence: Obtaining a Backward-Looking Phillips

1. Fraction of Backward-Looking Firms (Gali and Gertler, 1999).
2. Indexation (Christiano, Eichenbaum, and Evans, 2005):
   Prices automatically update by lagged inflation if passive.

$$P_{t+k|t} = P_{t+k-1|t}\Pi_{t+k-1}$$

3. Sticky Information (Mankiw and Reis, 2002)
   - Prices set freely; Calvo updates firms information sets.
   - Past expectations of current conditions rather than current expectations of future conditions matter, creating persistence.

$$\hat{\pi}_t = \frac{1-\beta\theta}{\beta\theta}\kappa\tilde{y}_t + (1-\theta)\sum_{j=0}^{\infty}(\beta\theta)^j E_{t-1-j}\left\{\hat{\pi}_t + \kappa\Delta\tilde{y}_t\right\}$$

Limitations of "Simple" NK Models

- "Simple" New Keynesian models like the one we have studied have limitations.
  - For starters, no capital!
  - No inflation persistence (without fix).
  - No wage stickiness (which makes marginal costs sticky and prices stickier).
  - Little amplification of Calvo friction (price level has adjusted once the time most firms have reset price).
- Big literature adding many features back into basic NK model.

Medium-Scale NK Models

- "State of the Art" for NK literature (absent financial frictions) is "Medium-Scale" models of Christiano, Eichenbaum, and Evans (2005) and Smets and Wouters (2007).
- Goal: Quantitative parameterized model that can be used for...
  - Forecasting (like a VAR).
  - But also, structural model so can be use for shock decompositions, policy experiments, and other counterfactuals.
- Consequently, as add features to RBC to fit data, add features to NK to fully fit data.
  - Then use GMM or Bayesian methods to fit model to match VAR impulse responses in simulated data.
- Parameterized models do a remarkably good job.
  - As good at forecasting over 1-2 years as VAR.
  - Allow for shock decompositions and counterfactuals.
  - Used at many central banks.

Medium-Scale NK Models: Smets and Wouters

- Example: Smets and Wouters (2007) has...
  - Calvo prices and inflation indexation.
  - Calvo wages.
  - Capital and investment adjustment costs.
  - Habit formation in consumption.
  - Variable capital utilization.
  - Fixed costs in production.
  - Strategic complementarity in price setting.
- And *seven* shocks:
  1. TFP
  2. Risk premium shock.
  3. Investment technology shocks.
  4. Wage markup shocks.
  5. Price markup shocks.
  6. Government spending shock.
  7. Monetary policy shock.
- When people say "New Keynesian" often mean these models.

Minnesota Critique: Chari et al. (2009)

- Chari, Kehoe, and McGratten (2009) argue medium-scale NK models are not suitable for quantitative policy analysis.
  - Minnesota is mecca of quantitative macro.
  - Shared view of tools (rational expectations DSGE) and need for frictions.
  - But they dislike medium-scale NK models.
- Main critique: Too many shocks and parameters!
  - In particular, wage markup shock, price markup shock, are basically inserting exogenous labor wedge into model.
  - These are not "primitive, interpretable shocks" and are critical to quantitative model fit (explain almost 90% of inflation).
  - Also do not like indexation and generally think NK has not figured out persistence.
- However, strongest policy prescriptions of three equation model continue to hold.
  - Although need these shocks for quantitative fit, in this sense still useful for policy.

Cochrane (2011) Critique

- Discussed this in context of price level determinacy, but worth reviewing in context of NK model.
- Determinacy comes from $\phi_\pi > 1$ holding *both on and off equilibrium path*.
  - Off equilibrium path, central bank pushes prices off to infinity.
  - Cochrane does not find this method of "trimming equilibria" appealing.
- But critique loses some power with monetary non-neutrality.
  - By raising nominal rate more than one for one, central bank contracts the output gap (via IS curve) which pulls down marginal costs and inflation.
  - Point that threat has to hold off equilibrium path remains, but now an economic reason to do so.

For Next Class

- We will continue critiquing the New Keynesian model and start using it to analyze policy (being mindful of its shortcomings).
    - Read Clarida et al. (1999), Gali 5.1-5.3 for next two classes.
- See below appendix for model with capital.

Adding Capital Appendix: Households

- Adding capital turns out to be surprisingly simple (but adds equations to three-equation model).
  - Here: A sketch so you understand conceptually.
- Households own capital which has real price Q_t and real rental rate Z_t.
  - Just here: Nominal bond return now I_t (sorry for change).
  - Same optimization with budget constraint:

$$\begin{aligned} C_t \quad = \quad & \frac{W_t}{P_t} N_t + PR_t + TR_t + Z_t K_t - Q_t \left(K_{t+1} - (1-\delta) K_t \right) \\ & - \frac{B_t - I_{t-1} B_{t-1}}{P_t} - \frac{M_t - M_{t-1}}{P_t} \end{aligned}$$

  - Same FOCs with additional capital FOC:

$$C_t^{-\gamma} = \beta E_t \left\{ \frac{Z_{t+1} + (1-\delta) Q_{t+1}}{Q_t} C_{t+1}^{-\gamma} \right\}$$

Adding Capital Appendix: Intermediate Firms

- Production Function: $Y_t(i) = A_t N_t(i)^{\alpha} K_t(i)^{1-\alpha}$.
- Trick: Split firm problem into price setting problem conditional on marginal costs and cost minimization problem to obtain minimum marginal cost from N and K.
  - Price setting is *exactly the same as before, both in flex and sticky price equilibria.*
- Cost min:

$$\min_{N_t(i),K_t(i)} \frac{W_t}{P_t} N_t(i) + Z_t K_t(i) \text{ s.t. } Y_t(i) = A_t N_t(i)^{\alpha} K_t(i)^{1-\alpha}$$

- Multiplier is MC, so FOCs are:

$$\begin{aligned} \frac{W_t}{P_t} &= MC_t \alpha \frac{Y_t(i)}{N_t(i)} \\ Z_t &= MC_t (1-\alpha) \frac{Y_t(i)}{K_t(i)} \end{aligned}$$

Adding Capital Appendix: Intermediate Firms and K Production

- Solving for $N_t(i)$ and $K_t(i)$ and plugging in,

$$MC_t = \frac{1}{A_t}\left(\frac{W_t/P_t}{\alpha}\right)^{\alpha}\left(\frac{Z_t}{1-\alpha}\right)^{1-\alpha}$$

- Finally, we need a production function for capital and solve that firm's problem to get the price of capital.
  - Usually simple Q model with increasing marginal cost of producing capital (DRS tech).
- Add these equations to equilibrium, log linearize, combine, etc...