

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

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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 Inflation Persistence
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:

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

- 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

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

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

- 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

$$\frac{W_t}{P_t} = \frac{\chi N_t^\varphi}{C_t^{-\gamma}}$$

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

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

$$P_t^* = (1+\mu) E_t \left\{ \sum_{s=0}^{\infty} \frac{\theta^s \Lambda_{t,t+s}^n P_{t+s}^\varepsilon Y_{t+s}}{E_t \left\{ \sum_{k=0}^{\infty} \theta^k \Lambda_{t,t+k}^n P_{t+k}^\varepsilon Y_{t+k} \right\}} \frac{W_{t+s}}{A_{t+s}} \right\}$$

$$Y_t = C_t$$

$$Y_t = A_t N_t \left[ \int_0^1 \left( \frac{N_t(i)}{N_t} \right)^{\frac{\varepsilon-1}{\varepsilon}} \right]^{\frac{\varepsilon}{\varepsilon-1}}$$

## 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 **fictitious 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  $\varphi$ )
      - Shift in labor supply due to wealth effect (controlled by  $\gamma$ )
    - 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:

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

- Log-linearize marginal costs and flex price equilibrium:

$$\begin{aligned} \hat{m}c_t &= (\gamma + \varphi) \hat{y}_t - (1 + \varphi) \hat{a}_t \\ (\gamma + \varphi) \hat{y}_t^{flex} &= (1 + \varphi) \hat{a}_t \end{aligned}$$

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

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

- Slope determined by:
  - $\theta$ : More reseters (lower  $\theta$ ), more inflation immediately.
  - $\varphi$ : More inelastic labor supply, more  $\pi$  for given  $\tilde{y}_t$ .
  - $\gamma$ : Lower IES, stronger wealth effect, more  $\pi$  for given  $\tilde{y}_t$ .

## Log Linearization: The Aggregate Demand Block

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

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

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

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

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

- 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 in flex price equilibrium with no capital.

## Dynamic IS In Terms of the Output Gap

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

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

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

# The Three Equation NK Model

- The basic NK model boils down to three equations:

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

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

$$\hat{i}_t = \phi_\pi \hat{\pi}_t + \phi_y \tilde{y}_t + v_t$$

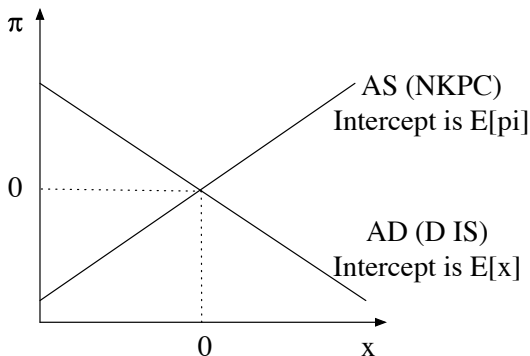
with three unknowns:  $\hat{i}_t$ ,  $\tilde{y}_t$ , and  $\hat{\pi}_t$  and an exogenous driving process for the natural rate:

$$\hat{r}_t^n = \gamma \frac{1 + \varphi}{\gamma + \varphi} E_t \{ \Delta \hat{a}_{t+1} \}.$$

- Key new ingredient is NK Phillips curve:
  - $\beta E_t \{ \pi_{t+1} \}$ : 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:

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

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

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

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

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

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:

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

- Guess reduced form policy functions:

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

- This gives:

$$\psi_{\pi v} = \kappa \psi_{yv} + \beta \rho_v \psi_{\pi v}$$

$$\psi_{\pi v} = -\sigma (\phi_\pi \psi_{\pi v} + \phi_y \psi_{yv} - \rho_v \psi_{\pi v}) + \rho_v \psi_{yv}$$

- Solving by method of undetermined coeffs:

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

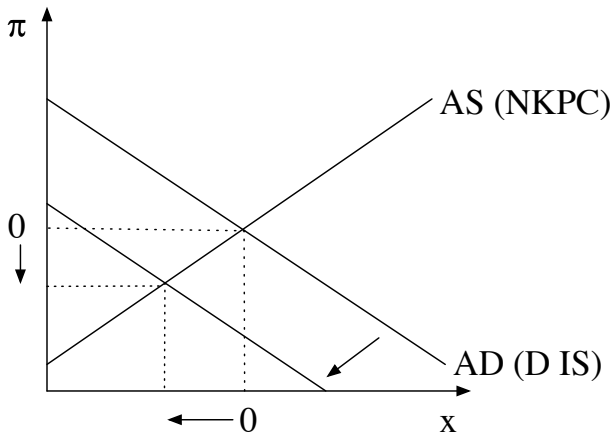
$$\text{where } \Lambda_v = \frac{1}{(1 - \beta \rho_v) [\gamma (1 - \rho_v) + \phi_y] + \kappa (\phi_\pi - \rho_v)} > 0$$

## Solving the Model: Monetary Policy Shocks

- Contractionary monetary shock ( $\uparrow i_t$ ) reduces  $\tilde{y}_t$  and  $\pi_t$ .
- 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

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

- $\hat{r}_t^n$  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:

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

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

## Technology Shocks and Output

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

$$\hat{y}_t = \hat{y}_t^{flex} + \tilde{y}_t$$

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

$$\hat{y}_t = [1 - (1 - \rho_a)(1 - \beta\rho_a)] \Lambda_a \hat{a}_t$$

and output rises!

- Intuition: Non-price reseters are demand constrained
  - When technology improves, demand does not expand and so non-reseters produce same amount. Price reseters increase how much they produce so output rises some
  - But output rises by less than it would have if everyone could have reset prices, so output gap falls

## Technology Shocks and Employment

- What happens to 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 Galí (1999) and Basu et al. (2006)!
  - Intuition: Non-resetters are demand constrained and produce same output, but technology has improved so need less labor
  - Resetters produce more and hire more, so as more and more firms reset, this goes away

## Solving the Model: Demand Shocks

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

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

where  $Z_t$  follows an AR(1).

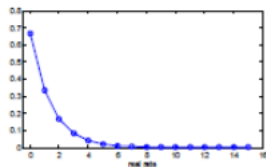
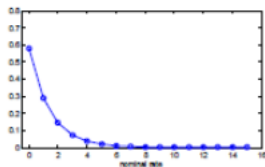
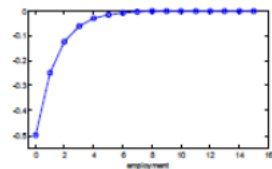
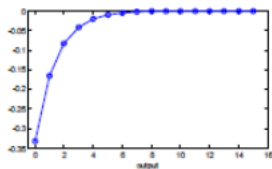
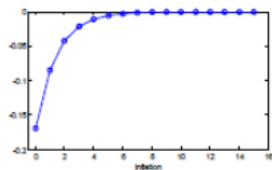
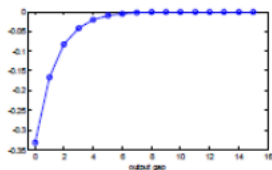
- $Z_t$  is a shock to the marginal utility of consumption.
- Forces people to consume more today  $\Rightarrow$  demand shock.
- Dynamic IS becomes:
$$\tilde{y}_t = -\sigma E_t \left\{ \hat{i}_t - \hat{\pi}_{t+1} - r_{t+1}^n \right\} + E_t \{ \tilde{y}_{t+1} \} + \sigma (1 - \rho_z) \hat{z}_t$$
- $\hat{z}_t$  becomes part of natural rate:

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

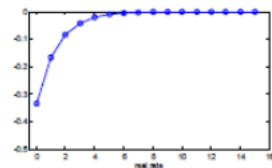
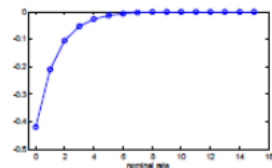
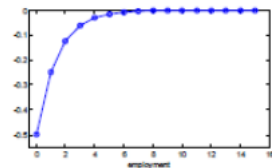
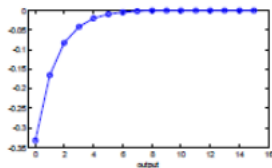
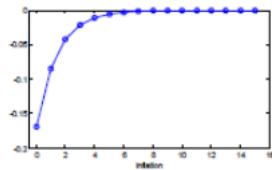
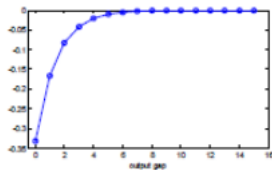
## Solving the Model: Demand Shocks

- 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: Contractionary Monetary Shock



# Impulse Response: Negative Discount Rate Shock

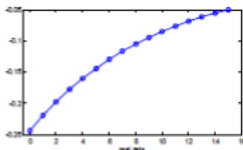
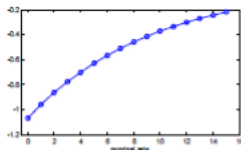
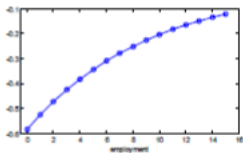
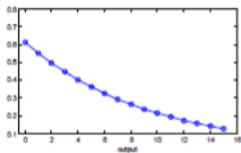
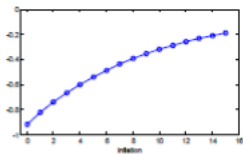
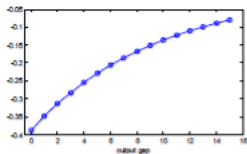


## Demand Shock vs. Monetary Shock

- 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 that we discussed in Lecture 3.
  - 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

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

- 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 central bank raises nominal interest rate and prices adjust gradually
  - So output falls until prices are at the right level.

## Credible Disinflation

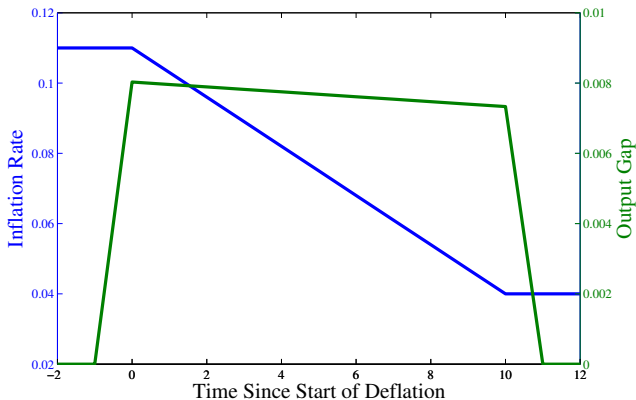
$$\hat{\pi}_t = \kappa \tilde{y}_t + \beta E_t \{\hat{\pi}_{t+1}\}$$

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

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

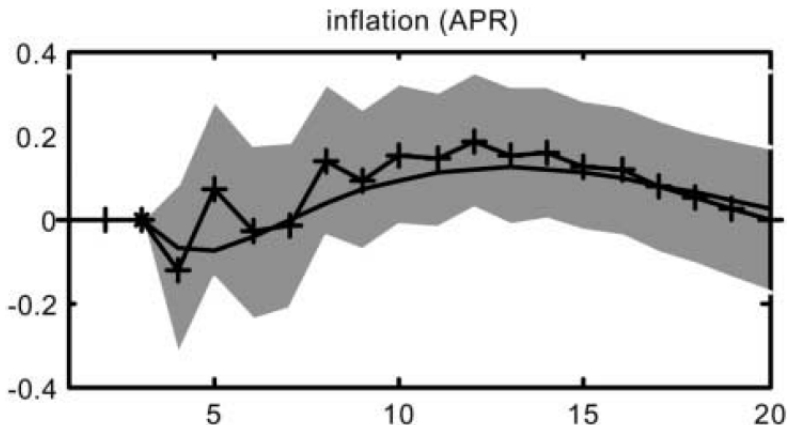
- The output gap is positive during the disinflation if it is not too fast as  $\beta \pi_{t+1} < \pi_t$ .
- Anticipating lower inflation, firms cut prices today.
  - Prices and markups are “too low” until the disinflation finishes, so output *rises*.
- Reconciling with Volcker: Goodfriend and King (2005) 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 assuming an exogenously persistent output gap with persistence  $\rho_y$ :

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

- 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:

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

- 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.

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

## 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.
- For capital, need adjustment costs and increasing marginal cost of producing capital.
  - Otherwise negative demand shock causes an increase in savings and a subsequent boom!

## 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 McGrattan (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:

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

- 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:

$$\frac{W_t}{P_t} = MC_t \alpha \frac{Y_t(i)}{N_t(i)}$$

$$Z_t = MC_t (1 - \alpha) \frac{Y_t(i)}{K_t(i)}$$

## 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...