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Inflation Dynamics in the New Keynesian Model: Sticky Prices vs Sticky Information

1 Introduction

Inflation is persistent and responds slowly to monetary shocks. It takes a few quarters for inflation to fully react to monetary shocks - Christiano Eichenbaum and Evans (2005). Sticky price models have a problem explaining this fact, sticky information models generate a hump shape response of inflation to monetary shocks.

Money enters the model as a unit of account.

In the sticky price model the price level is sticky, not inflation.

The sticky information model is due to Mankiw and Reis (2002).

2 The Basic Sticky Prices Model

Consider an economy with households, firms, and a government. The households consume differentiated goods, supply labor to the firms, and hold risk-free government bonds. The firms produce the goods using labor. The labor market is competitive, but in the goods market firms enjoy monopolistic power. The government targets the nominal interest rate and issue risk-free bonds so as to defend its rate.

2.1 Households

There is a large number of identical infinitely lived households in the economy. The population size is normalized to 1 so household specific variables equal the aggregate level. Households consume a continuum of differentiated goods indexed by g, $g \in [0,1]$. The consumption index is given by:

$$C_t = \left[\int_0^1 c_t(g)^{\frac{\sigma-1}{\sigma}} dg \right]^{\frac{\sigma}{\sigma-1}} \qquad \sigma > 1$$

Given prices, $p_t(g)$, and for any arbitrary level of consumption, C_t, households allocate resources for each consumption good so as to minimize the cost of C_t. That is:

$$\begin{aligned} \{c_t(g)\} &= \arg\min \int_0^1 p_t(g)\, c_t(g)\, dg \\ & \quad s.t. \qquad C_t = \left[\int_0^1 c_t(g)^{\frac{\sigma-1}{\sigma}} dg \right]^{\frac{\sigma}{\sigma-1}} \end{aligned}$$

This results in the following demand function for $c_t(g)$:

$$c_t(g) = \left(\frac{p_t(g)}{P_t} \right)^{-\sigma} C_t \tag{1}$$

where P_t is the consumption price index:

$$P_t = \left[\int_0^1 p_t(g)^{1-\sigma} dg \right]^{\frac{1}{1-\sigma}} \tag{2}$$

Households also supply labor to the firms, hold risk-free nominal government bonds, and receive profits from the firms. The households' problem is given by:

$$\begin{aligned} & \underset{\{C_t, L_t, B_t\}}{Max} \qquad E_0 \textstyle\sum_{t=0}^{\infty} \beta^t U(C_t, L_t) \\ & s.t. \qquad P_t C_t + B_t \leq W_t L_t + I_{t-1} B_{t-1} + \Pi_t + T_t \end{aligned}$$

where L_t is labor effort; W_t is the nominal wage; B_t is the quantity of bonds purchased at time t, each pays I_t units of the currency in $t+1$ (I_t is the *gross* nominal interest rate);

Π_t is profits from the firms; and T_t is lump-sum transfers from the government (T_t may be negative).

The FOCs are given by:

$$-\frac{U_{L_t}}{U_{C_t}} = \frac{W_t}{P_t} \quad (3)$$

$$\frac{U_{C_t}}{P_t} = \beta I_t E_t \left\{ \frac{U_{C_{t+1}}}{P_{t+1}} \right\} \quad (4)$$

Notice that the second equation suggests that in steady state the real interest rate, r_{ss}, is determined by the subjective discount factor, $1 + r_{ss} = \beta^{-1}$.

2.2 Firms

There is a continuum of firms lying on the unit interval each produces a differentiated consumption good. We therefore assign firms the same index as the goods they produce - g, $g \in [0, 1]$. Each firm has two departments, production and sales.

The production department: The production department operates a technology that uses labor as the only input of production; specifically:

$$y_t(g) = A_t l_t(g)$$

$$A_t = A_{t-1}^{\rho_a} \exp(\varepsilon_t^a) \qquad \varepsilon_t^a \overset{iid}{\sim} N\left(0, \sigma_a^2\right)$$

where A_t is an aggregate productivity shock that affects all firms.

The production department is a price taker; given the wage level and prices in the goods market it must produce enough of its own good, $y_t(g)$, so as to satisfy demand (1). That is, output is demand determined, and given our specification labor is given by:[1]

$$l_t(g) = \left(\frac{p_t(g)}{P_t}\right)^{-\sigma} \frac{C_t}{A_t} \quad (5)$$

[1] In this setting the production department has no degrees of freedom for choosing the level of inputs. If, however, we introduce capital to the model then the production department would choose the optimal labor-capital mix so as to minimize cost of production.

The sales department: The sales department sets the price of its good, $p_t(g)$. However, price setting is staggered across firms a-la Calvo (1983). That is, in each period a firm can freely adjust its price only if it receives an idiosyncratic signal that allows it to do so, otherwise prices are automatically updated by the steady state gross inflation rate, π_{ss}. The probability of receiving the signal is ξ and it is iid across firms and time. Whenever a firm is able to reset its price it maximizes the present discounted value of its expected profits for the periods its new price is expected to be in effect. After substituting for labor (5) and demand (1), a sales department that can readjust its price at date t solves:

$$\underset{p_t(g)}{Max} \qquad E_t \sum_{s=0}^{\infty} Q_{t,t+s} (1-\xi)^s \left\{ \begin{array}{c} \pi_{ss}^s p_t(g) \left(\frac{\pi_{ss}^s p_t(g)}{P_{t+s}} \right)^{-\sigma} C_{t+s} \\ -W_{t+s} \left(\frac{\pi_{ss}^s p_t(g)}{P_{t+s}} \right)^{-\sigma} \frac{C_{t+s}}{A_{t+s}} \end{array} \right\}$$

where $Q_{t,t+s}$ is the discount factor between time t and $t+s$, specifically: $Q_{t,t+s} = \left[\prod_{\tau=0}^{s-1} I_{t+\tau} \right]^{-1}$ for $s > 0$, and $Q_{t,t} = 1$. The FOC gives:

$$p_t(g) = \frac{\sigma}{\sigma-1} \frac{E_t \left\{ \sum_{s=0}^{\infty} Q_{t,t+s} (1-\xi)^s \pi_{ss}^{-\sigma s} W_{t+s} \frac{P_{t+s}^{\sigma} C_{t+s}}{A_{t+s}} \right\}}{E_t \left\{ \sum_{s=0}^{\infty} Q_{t,t+s} (1-\xi)^s \pi_{ss}^{(1-\sigma)s} P_{t+s}^{\sigma} C_{t+s} \right\}}$$

Notice that if prices are fully flexible, that is $\xi \to 1$, then $p_t(g) = \frac{\sigma}{\sigma-1} \frac{W_t}{A_t}$; that is, the optimal price is set as a constant mark-up, $\frac{\sigma}{\sigma-1}$, over marginal cost.

An important feature of this pricing rule is that it depends only on aggregate quantities, this suggests that all firms that adjust their price in period t choose that same price. It is therefore sufficient to keep track of cohorts of firms identified by the last date of price adjustment rather than by their specific identity, g. From this point we will use the following notation:

Notation 1 *Let $p_t^{t-\tau}$ denote date t price of a firm that last revised its price in $t-\tau$.*

Using this notation we can now write:

$$\begin{aligned} p_t^t &= \frac{\sigma}{\sigma-1} \frac{E_t \left\{ \sum_{s=0}^{\infty} Q_{t,t+s} (1-\xi)^s \pi_{ss}^{-\sigma s} W_{t+s} \frac{P_{t+s}^{\sigma} C_{t+s}}{A_{t+s}} \right\}}{E_t \left\{ \sum_{s=0}^{\infty} Q_{t,t+s} (1-\xi)^s \pi_{ss}^{(1-\sigma)s} P_{t+s}^{\sigma} C_{t+s} \right\}} \qquad (6) \\ \text{and } p_t^{t-\tau} &= p_{t-\tau}^{t-\tau} \pi_{ss}^{\tau} \end{aligned}$$

2.3 Government

The government sets the nominal interest rate following a policy rule:

$$\begin{aligned} \frac{I_t}{I_{ss}} &= \chi_t \left(\frac{Y_t}{Y_{ss}}\right)^{\phi} \left(\frac{\pi_{t-1}}{\pi_{ss}}\right)^{1+\phi} \\ \chi_t &= \chi_{t-1}^{\rho_\chi} \exp\left(\varepsilon_t^{\chi}\right) \qquad \varepsilon_t^{\chi} \overset{iid}{\sim} N\left(0, \sigma_\chi^2\right) \end{aligned} \tag{7}$$

where I_{ss} is set arbitrarily by the government; Y_t is aggregate output measured in consumption units, i.e. $Y_t = \int_0^1 \frac{p_t(g)}{P_t} y_t(g)\, dg$; π_t is gross inflation between $t-1$ and t, $\pi_t = \frac{P_t}{P_{t-1}}$, and χ_t is a policy shock.

The government budget constraint is given by:

$$B_t = I_{t-1} B_{t-1} + T_t$$

2.4 Market Clearing

Equilibrium in the labor market:

$$L_t = \int_0^1 l_t(g)\, dg$$

Market clearing in the goods market requires:

$$c_t(g) = y_t(g)$$

This, together with the definition of Y_t, P_t, and (1) suggests:

$$C_t = Y_t$$

Note that this can be also derived by combining the households budget constraint together with the government budget constraint and firms' profits.

2.5 Aggregation and Log-Linearization

2.5.1 The Sticky-Price New-Keynesian Phillips Curve

Recall the consumption price index (2):

$$P_t = \left[\int_0^1 p_t(g)^{1-\sigma}\, dg\right]^{\frac{1}{1-\sigma}}$$

Since all firms of the same cohort share the same price this can be written as (after using the law of large numbers):

$$P_t = \left[\sum_{s=0}^{\infty} \xi \left(1-\xi\right)^s \left(p_t^{t-s}\right)^{1-\sigma}\right]^{\frac{1}{1-\sigma}}$$

Log-linearize to get:

$$\widetilde{P}_t = \sum_{s=0}^{\infty} \xi \left(1-\xi\right)^s \widetilde{p}_t^{t-s}$$

Which can be re-written as:

$$\widetilde{P}_t = \xi \widetilde{p}_t^t + \left(1-\xi\right) \widetilde{P}_{t-1} \tag{8}$$

Log-linearizing pricing equation (6) gives:

$$\frac{\widetilde{p}_t^t}{1-\beta\left(1-\xi\right)} = \sum_{s=0}^{\infty} \beta^s \left(1-\xi\right)^s E_t\left(\widetilde{W}_{t+s} - \widetilde{A}_{t+s}\right) \tag{9}$$

where we used $\frac{I_{ss}}{\pi_{ss}} = \beta^{-1}$. Rewrite this equation for period $t+1$, take expectations conditional on date t information, and multiply by $\beta\left(1-\xi\right)$, to get:

$$\frac{\beta\left(1-\xi\right)}{1-\beta\left(1-\xi\right)} E_t\left(\widetilde{p}_{t+1}^{t+1}\right) = \sum_{s=1}^{\infty} \beta^s \left(1-\xi\right)^s E_t\left(\widetilde{W}_{t+s} - \widetilde{A}_{t+s}\right) \tag{10}$$

Now subtract (10) from (9):

$$\frac{1}{1-\beta\left(1-\xi\right)} \widetilde{p}_t^t - \frac{\beta\left(1-\xi\right)}{1-\beta\left(1-\xi\right)} E_t\left(\widetilde{p}_{t+1}^{t+1}\right) = \widetilde{W}_t - \widetilde{A}_t$$

Using (8), and noting that $\widetilde{\pi}_t = \widetilde{P}_{t+1} - \widetilde{P}_t$, we get:

$$\widetilde{\pi}_{t-1} = \beta E_t\left(\widetilde{\pi}_t\right) + \frac{\xi}{1-\xi}\left[1-\beta\left(1-\xi\right)\right]\left(\widetilde{W}_t - \widetilde{P}_t - \widetilde{A}_t\right)$$

Finally, notice that the last expression is the log-deviation of the real marginal cost from steady state ($\widetilde{RMC}_t$), therefore:

$$\widetilde{\pi}_{t-1} = \beta E_t\left(\widetilde{\pi}_t\right) + \frac{\xi}{1-\xi}\left[1-\beta\left(1-\xi\right)\right]\widetilde{RMC}_t \tag{11}$$

Equation (11) is the sticky prices New-Keynesian Phillips Curve. According to this equation, current inflation increases with expected inflation and with the real marginal cost.

Even though prices are sticky, inflation is not. It is a forward looking variable and it is unaffected by past inflation. This suggests that the model delivers low persistency in inflation, which is counter-factual.

2.5.2 The Aggregate Supply Curve

In what follows assume that:

$$U(C_t, L_t) = \frac{C_t^{1-\gamma} - 1}{1-\gamma} - \psi \frac{L_t^{1+\eta}}{1+\eta} \qquad \gamma, \psi, \eta > 0$$

Aggregating equation (5), log-linearizing and using $Y_t = C_t$ we get:

$$\widetilde{L}_t = \widetilde{Y}_t - \widetilde{A}_t \tag{12}$$

Log linearizing (3) and using equilibrium in the goods market gives:

$$\eta \widetilde{L}_t + \gamma \widetilde{Y}_t = \widetilde{W}_t - \widetilde{P}_t$$

Using (12) to substitute for $\widetilde{L}_t$, and rearranging gives the aggregate supply curve:

$$\widetilde{RMC}_t = (\eta + \gamma) \widetilde{Y}_t - (1 + \eta) \widetilde{A}_t \tag{13}$$

Notice that by log-linearizing the process for productivity gives:

$$\widetilde{A}_t = \rho_a \widetilde{A}_{t-1} + \varepsilon_t^a \qquad \varepsilon_t^a \overset{iid}{\sim} N\left(0, \sigma_a^2\right) \tag{14}$$

2.5.3 The IS Curve

Log-linearize (4) and use $Y_t = C_t$ to get the IS curve:

$$\widetilde{Y}_t = -\frac{1}{\gamma} \left[\widetilde{I}_t - E_t(\widetilde{\pi}_t) \right] + E_t\left(\widetilde{Y}_{t+1}\right) \tag{15}$$

That is, output demand falls with the real interest rate, $\widetilde{I}_t - E_t(\widetilde{\pi}_t)$, and increases with future output.

2.5.4 The Interest Rate Policy Rule

Log-linearize (7):

$$\begin{aligned} \widetilde{I}_t &= \phi \widetilde{Y}_t + (1+\phi)\, \widetilde{\pi}_{t-1} + \widetilde{\chi}_t \\ \widetilde{\chi}_t &= \rho_\chi \widetilde{\chi}_{t-1} + \varepsilon_t^\chi \qquad \varepsilon_t^\chi \overset{iid}{\sim} N\left(0, \sigma_\chi^2\right) \end{aligned} \tag{16}$$

Note that the fact that the coefficient on inflation is greater than one means that the government pursue an activist stabilization policy. That is, an increase in inflation leads the government to raise the nominal interest rate by even a greater amount so as to increase the *real* rate. This is known as the Taylor principle.

2.6 System of Equations

The model boils down to a dynamic system in $\widetilde{Y}_t$, $\widetilde{RMC}_t$, $\widetilde{I}_t$, and $\widetilde{\pi}_t$, and a process for the exogenous shocks, $\widetilde{A}_t$ and $\widetilde{\chi}_t$.

Equilibrium is characterized by the Phillips curve, (11), aggregate supply, (13), the IS curve, (15), and the policy rule, (16). The model can be solved numerically using one of the methods for solving linear rational expectations models.

3 The Sticky Information Model

The sticky information model differs from the sticky price model only in the price setting mechanism. That is, the behavior and resulting equations of all agents are identical to the one in the sticky price model except for the behavior of the sales department and its pricing equation.

3.1 Price Setting in the Sticky Information Model

In this model prices are fully flexible as the sales department is free to change prices in every period. However, the information available for doing so may be outdated. In every period a firm can update its information only if it receives an idiosyncratic signal that allows it to do so, otherwise it revises its price based on old information. The probability of receiving the signal is ξ and it is iid across firms and time.

In each period a sales department that last updated its information τ periods ago chooses its current price, $p_t(g)$, so as to maximize expected profits conditional on the information in hand. After substituting for labor (5) and demand (1), the sales department solves:

$$\underset{p_t(g)}{Max} \qquad E_{t-\tau}\left\{p_t(g)\left(\frac{p_t(g)}{P_t}\right)^{-\sigma}C_t - W_t\left(\frac{p_t(g)}{P_t}\right)^{-\sigma}\frac{C_t}{A_t}\right\}$$

The FOC gives:

$$p_t(g) = \frac{\sigma}{\sigma-1}\frac{E_{t-\tau}\left\{W_t\frac{P_t^{\sigma}C_t}{A_t}\right\}}{E_{t-\tau}\left\{P_t^{\sigma}C_t\right\}}$$

Notice that for firms with current information the pricing equation reads $p_t(g) = \frac{\sigma}{\sigma-1}\frac{W_t}{A_t}$; that is, the optimal price is set as a constant mark-up, $\frac{\sigma}{\sigma-1}$, over marginal cost.

Notice that this pricing rule depends only on aggregate quantities, this suggests that all firms that adjust their information in period t choose the same price. As before, it is sufficient to keep track of cohorts of firms identified by the last date of information adjustment rather than by their specific identity, g. We will therefore use the same notation to the sticky price model.

Notation 2 *Let $p_t^{t-\tau}$ denote date t price of a firm that last revised its information in $t-\tau$.*

Using this notation we can now write:

$$p_t^{t-\tau} = \frac{\sigma}{\sigma-1}\frac{E_{t-\tau}\left\{W_t\frac{P_t^{\sigma}C_t}{A_t}\right\}}{E_{t-\tau}\left\{P_t^{\sigma}C_t\right\}} \tag{17}$$

3.2 Aggregation and Log-Linearization

The aggregate system of equations differs only in the Phillips curve, aggregate supply, equation (13), the IS curve, equation (15), and the policy rule, equation (16), are identical to the sticky price model.

3.2.1 The Sticky-Information New-Keynesian Phillips Curve

Log-linearizing the pricing equation (17) gives:

$$\widetilde{p}_t^{t-\tau} = E_{t-\tau}\left(\widetilde{W}_t - \widetilde{A}_t\right)$$

which can be rewritten as:

$$\widetilde{p}_t^{t-\tau} = E_{t-\tau}\left(\widetilde{P}_t + \widetilde{RMC}_t\right)$$

Substitute into the linearized aggregate price index to get:

$$\widetilde{P}_t = \textstyle\sum_{s=0}^{\infty} \xi\left(1-\xi\right)^s E_{t-s}\left(\widetilde{P}_t + \widetilde{RMC}_t\right)$$

Now lag one period and subtract $\widetilde{P}_{t-1}$ from $\widetilde{P}_t$ to get:

$$\begin{aligned}\widetilde{\pi}_{t-1} &= \xi\left(\widetilde{P}_t + \widetilde{RMC}_t\right) + \textstyle\sum_{s=1}^{\infty} \xi\left(1-\xi\right)^s E_{t-s}\left(\widetilde{\pi}_{t-1} + \Delta\widetilde{RMC}_t\right) \\ & \quad -\xi\underbrace{\frac{1}{1-\xi}\textstyle\sum_{s=1}^{\infty} \xi\left(1-\xi\right)^s E_{t-s}\left(\widetilde{P}_{t-1} + \widetilde{RMC}_{t-1}\right)}_{\widetilde{P}_{t-1}}\end{aligned}$$

where $\widetilde{\pi}_{t-1} = \widetilde{P}_t - \widetilde{P}_{t-1}$ and $\Delta\widetilde{RMC}_t = \widetilde{RMC}_t - \widetilde{RMC}_{t-1}$. Rearrange and get:

$$\widetilde{\pi}_{t-1} = \frac{\xi}{1-\xi}\widetilde{RMC}_t + \frac{1}{1-\xi}\textstyle\sum_{s=1}^{\infty} \xi\left(1-\xi\right)^s E_{t-s}\left(\widetilde{\pi}_{t-1} + \Delta\widetilde{RMC}_t\right) \tag{18}$$

Equation (18) is the sticky information New-Keynesian Phillips Curve. As oppose to the sticky price Phillips Curve, this equation does not involve any future variables. Instead, current inflation is determined by a mixture of current real marginal cost and some lagged expectations. Since these expectations are based on outdated information they do not react to new shocks; as a result, inflation in this model is expected to display greater persistence, relative to the sticky prices version, as it reacts slowly to new information.

3.3 System of Equations

As in the sticky prices case, the model boils down to a dynamic system in $\widetilde{Y}_t$, $\widetilde{RMC}_t$, $\widetilde{I}_t$, and $\widetilde{\pi}_t$, and a process for the exogenous shocks, $\widetilde{A}_t$ and $\widetilde{\chi}_t$.

Equilibrium is characterized by the Phillips curve, (18), aggregate supply, (13), the IS curve, (15), and the policy rule, (16).

It should be noted that although it is possible to solve the model using one of the numerical methods we already reviewed, none of them is efficient in doing so and they all require a long computation time. The next lecture notes describe a method for solving linear rational expectations models with lagged expectations such as the sticky information model.

4 Parameter Values and Impulse Response Functions

To summarize the basic New-Keynesian model boils down to the following system of equations:

$$\begin{aligned} \text{Aggregate Supply:} \qquad & \widetilde{RMC}_t = (\eta+\gamma)\,\widetilde{Y}_t - (1+\eta)\,\widetilde{A}_t \\ \text{IS Curve:} \qquad & \widetilde{Y}_t = -\frac{1}{\gamma}\left[\widetilde{I}_t - E_t(\widetilde{\pi}_t)\right] + E_t\left(\widetilde{Y}_{t+1}\right) \\ \text{Interest Policy Rule:} \qquad & \widetilde{I}_t = \phi\widetilde{Y}_t + (1+\phi)\,\widetilde{\pi}_{t-1} + \widetilde{\chi}_t \end{aligned}$$

and a Phillips Curve. Under sticky prices:

$$\widetilde{\pi}_{t-1} = \beta E_t(\widetilde{\pi}_t) + \frac{\xi}{1-\xi}\left[1-\beta(1-\xi)\right]\widetilde{RMC}_t$$

while under sticky information:

$$\widetilde{\pi}_{t-1} = \frac{\xi}{1-\xi}\widetilde{RMC}_t + \frac{1}{1-\xi}\sum\nolimits_{s=1}^{\infty}\xi(1-\xi)^s E_{t-s}\left(\widetilde{\pi}_{t-1} + \Delta\widetilde{RMC}_t\right)$$

In addition the exogenous shocks evolve according to:

$$\begin{aligned} & \widetilde{A}_t = \rho_a\widetilde{A}_{t-1} + \varepsilon_t^a \qquad \varepsilon_t^a \overset{iid}{\sim} N\left(0,\sigma_a^2\right) \\ \text{and} \qquad & \widetilde{\chi}_t = \rho_\chi\widetilde{\chi}_{t-1} + \varepsilon_t^\chi \qquad \varepsilon_t^\chi \overset{iid}{\sim} N\left(0,\sigma_\chi^2\right) \end{aligned}$$

We take a period in the model to represent one quarter, and assign parameters values as follows. Let $\beta = 0.99$, this corresponds to an annual real intereste rate of 4 percents. Let

$\xi = 0.25$, this value suggests that on average prices (or information) are updated once every 4 quarters ($\frac{1}{\xi}$). We set the relative risk aversion coefficient, γ, to 2. The Frisch elasticity of labor supply, $\frac{1}{\eta}$, is 0.5, so $\eta = 2$.[2] Following to Taylor (1993), we take $\phi = 0.5$. Finally, we take $\rho_a = 0.95$ and $\rho_\chi = 0.5$.

$$y_t = \left[\begin{array}{cccccccc} \widetilde{\pi}_{t-1} & E_t\left(\widetilde{\pi}_t\right) & \widetilde{Y}_t & E_t\left(\widetilde{Y}_{t+1}\right) & \widetilde{RMC}_t & \widetilde{I}_t & \widetilde{A}_t & \widetilde{\chi}_t \end{array} \right]'$$

$$\begin{aligned} \Gamma_0 &= \Gamma_1 = zeros\,(8,8) \\ \Psi &= zeros\,(8,2) \\ \Pi &= zeros\,(8,2) \end{aligned}$$

$$\begin{aligned} \widetilde{RMC}_t &= (\eta+\gamma)\,\widetilde{Y}_t - (1+\eta)\,\widetilde{A}_t \\ \Gamma_0\,(1,3) &= -\,(\eta+\gamma) \\ \Gamma_0\,(1,5) &= 1 \\ \Gamma_0\,(1,7) &= 1+\eta \end{aligned}$$

$$\begin{aligned} \widetilde{Y}_t &= -\frac{1}{\gamma}\left[\widetilde{I}_t - E_t\left(\widetilde{\pi}_t\right)\right] + E_t\left(\widetilde{Y}_{t+1}\right) \\ \Gamma_0\,(2,2) &= -\frac{1}{\gamma} \\ \Gamma_0\,(2,3) &= 1 \\ \Gamma_0\,(2,4) &= -1 \\ \Gamma_0\,(2,6) &= \frac{1}{\gamma} \end{aligned}$$

[2]The Frisch elasticity of labor supply is defined as the elasticity of labor supply with respect to real wage, leaving constant the marginal utility of consumption.

$$\begin{aligned}
\widetilde{I}_t &= \phi \widetilde{Y}_t + (1+\phi)\,\widetilde{\pi}_{t-1} + \widetilde{\chi}_t \\
\Gamma_0\,(3,1) &= 1+\phi \\
\Gamma_0\,(3,3) &= \phi \\
\Gamma_0\,(3,6) &= -1 \\
\Gamma_0\,(3,8) &= 1
\end{aligned}$$

$$\begin{aligned}
\widetilde{\pi}_{t-1} &= \beta E_t\,(\widetilde{\pi}_t) + \frac{\xi}{1-\xi}\,[1-\beta\,(1-\xi)]\,\widetilde{RMC}_t \\
\Gamma_0\,(4,1) &= -1 \\
\Gamma_0\,(4,2) &= \beta \\
\Gamma_0\,(4,5) &= \frac{\xi}{1-\xi}\,[1-\beta\,(1-\xi)]
\end{aligned}$$

$$\begin{aligned}
\widetilde{A}_t &= \rho_a \widetilde{A}_{t-1} + \varepsilon_t^a \\
\Gamma_0\,(5,7) &= 1 \\
\Gamma_1\,(5,7) &= \rho_a \\
\Psi\,(5,1) &= 1
\end{aligned}$$

$$\begin{aligned}
\widetilde{\chi}_t &= \rho_\chi \widetilde{\chi}_{t-1} + \varepsilon_t^\chi \\
\Gamma_0\,(6,8) &= 1 \\
\Gamma_1\,(6,8) &= \rho_\chi \\
\Psi\,(6,2) &= 1
\end{aligned}$$

$$
\begin{aligned}
\widetilde{\pi}_{t-1} &= E_{t-1}\left(\widetilde{\pi}_{t-1}\right) + \eta_{1,t} \\
\widetilde{Y}_t &= E_{t-1}\left(\widetilde{Y}_t\right) + \eta_{2,t} \\
\Gamma_0\left(7,1\right) &= 1 \\
\Gamma_1\left(7,2\right) &= 1 \\
\Pi\left(7,1\right) &= 1 \\
\Gamma_0\left(8,3\right) &= 1 \\
\Gamma_1\left(8,4\right) &= 1 \\
\Pi\left(8,2\right) &= 1
\end{aligned}
$$

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