6 Money in the Short Run: Nominal Price and Wage Rigidities

6.1 Introduction

In this chapter, the focus shifts away from models with flexible wages and prices to models of sticky wages and prices. It starts with a simple example of a model with nominal wage rigidities that last for one period. Then it reviews models that account for the observation that prices and wages may take several periods to adjust to changes in macroeconomic conditions. Time-dependent and state-dependent models of price adjustment are discussed. Time-dependent pricing models assume the probability that a firm changes its price is a function only of time, and state-dependent models make this probability a function of the current state of the economy.

The focus in this chapter is on various models of nominal rigidities. In chapter 8, the new Keynesian Phillips curve developed in section 6.3.2 is incorporated into a general equilibrium framework so that the implications of price and wage rigidities for monetary policy can be studied.

6.2 Sticky Prices and Wages

Most macroeconomic models attribute the short-run real effects of monetary disturbances not to imperfect information or limited participation in financial markets but to the presence of nominal wage and/or price rigidities. These rigidities mean that nominal wages and prices fail to adjust immediately and completely to changes in the nominal quantity of money. In the 1980s it was common to model nominal rigidities by imposing the assumption that prices (or wages) were fixed for one period. This approach is illustrated in section 6.2.1 and employed extensively in chapter 7. This modification increases the impact that monetary disturbances have on real output but cannot account for persistent real effects of monetary policy. The model of staggered multiperiod nominal wage contracts due to Taylor (1979; 1980) can generate the persistent output responses observed in the data, but Taylor's model was not based on an explicit model of optimizing behavior by workers or firms. The literature in recent years has turned to models of monopolistic competition and price stickiness in which the decision problem faced by firms in setting prices can be made explicit. The objective in this section is to review some of the standard models of nominal rigidities and their implications. The new generation of dynamic stochastic general equilibrium (DSGE) models based on nominal rigidites and their implications for monetary policy analysis is the chief focus of chapter 8.

6.2.1 An Example of Nominal Rigidities in General Equilibrium

The first model considered adds a one-period nominal wage rigidity to the MIU model of chapter 2. This approach is not based on optimizing behavior by wage setters, but it leads to a reduced-form model that has been widely used in monetary economics. This model plays an important role in the analysis of time inconsistency in chapter 7.

Wage Rigidity in an MIU Model

One way to introduce nominal price stickiness is to modify a flexible-price model, such as an MIU model, by simply assuming that prices and/or wages are set at the start of each period and are unresponsive to developments within the period. In chapter 2 a linear approximation was used to examine the time series implications of an MIU model. Wages and prices were assumed to adjust to ensure market equilibrium, and consequently the behavior of the money supply mattered only to the extent that anticipated inflation was affected. A positive disturbance to the growth rate of money would, assuming that the growth rate of money was positively serially correlated, raise the expected rate of inflation, leading to a rise in the nominal rate of interest that affects labor supply and output. These last effects depended on the form of the utility function; if utility was separable in money, changes in expected inflation had no effect on labor supply or real output. Introducing wage stickiness into an MIU model serves to illustrate the effect such a modification has on the impact of monetary disturbances.

Consider the linear approximation to the Sidrauski MIU model developed in chapter 2. To simplify the model, assume utility is separable in consumption and money holdings ($b = \Phi$, or $\Omega_2 = 0$ in terms of the parameters of the model used in chapter 2). This implies that money and monetary shocks have no effect on output when prices are perfectly flexible.[1] In addition, the capital stock is treated as fixed, and investment is zero. This follows McCallum and Nelson (1999), who argued that for most monetary policy and business cycle analyses, fluctuations in the stock of

1. From (5.32), money surprises also have no effect on employment and output when $\Omega_2 = 0$ in Lucas's imperfect-information model.

capital do not play a major role. The equations characterizing equilibrium in the resulting MIU model are

$$y_t = (1-\alpha)n_t + e_t \tag{6.1}$$

$$y_t = c_t \tag{6.2}$$

$$y_t - n_t = w_t - p_t \tag{6.3}$$

$$\Phi \mathrm{E}_t(c_{t+1} - c_t) - r_t = 0 \tag{6.4}$$

$$\eta\left(\frac{n^{ss}}{1-n^{ss}}\right)n_t + \Phi c_t = w_t - p_t \tag{6.5}$$

$$m_t - p_t = c_t - \left(\frac{1}{bi^{ss}}\right)i_t \tag{6.6}$$

$$i_t = r_t + \mathrm{E}_t p_{t+1} - p_t \tag{6.7}$$

$$m_t = \rho_m m_{t-1} + s_t. \tag{6.8}$$

All variables are expressed as log derivations from steady state. The system is written in terms of the log price level p rather than the inflation rate, and in contrast to the notation of chapter 2, m represents the nominal stock of money. Equation (6.1) is the economy's production function in which output deviations from the steady state are a linear function of the deviations of labor supply from steady state and a productivity shock. Equation (6.2) is the resource constraint derived from the condition that in the absence of investment or government purchases, output equals consumption. Labor demand is derived from the condition that labor is employed up to the point where the marginal product of labor equals the real wage. With the Cobb-Douglas production function underlying (6.1), this condition, expressed in terms of percentage deviations from the steady state, can be written as (6.3).[2] Equations (6.4)–(6.6) are derived from the representative household's first-order conditions for consumption, leisure, and money holdings. Equation (6.7) is the Fisher equation linking the nominal and real rates of interest. Finally, (6.8) gives the exogenous process for the nominal money supply.[3]

When prices are flexible, (6.1)–(6.5) form a system of equations that can be solved for the equilibrium time paths of output, labor, consumption, the real wage, and the

2. If $Y = \bar{K}^{\alpha}N^{1-\alpha}$, then the marginal product of labor is $(1-\alpha)Y/N$, where $\bar{K}$ is the fixed stock of capital. In log terms, the real wage is then equal to $\ln W - \ln P = \ln(1-\alpha) + \ln Y - \ln N$, or, in terms of deviations from steady state, $w - p = y - n$.

3. Alternatively, the nominal interest rate i_t could be taken as the instrument of monetary policy, with (6.6) then determining m_t.

real rate of interest. Equations (6.6)–(6.8) then determine the evolution of real money balances, the nominal interest rate, and the price level. Thus, realizations of the monetary disturbance s_t have no effect on output when prices are flexible. This version of the MIU model displays the *classical dichotomy* (Modigliani 1963; Patinkin 1965); real variables such as output, consumption, investment, and the real interest rate are determined independently of both the money supply process and money demand factors.[4]

Now suppose the nominal wage rate is set prior to the start of the period, and that it is set equal to the level *expected* to produce the *real* wage that equates labor supply and labor demand. Since workers and firms are assumed to have a real wage target in mind, the nominal wage will adjust fully to reflect expectations of price level changes held at the time the nominal wage is set. This means that the information available at the time the wage is set, and on which expectations will be based, will be important. If unanticipated changes in prices occur, the actual real wage will differ from its expected value. In the standard formulation, firms are assumed to determine employment on the basis of the actual, realized real wage. If prices are unexpectedly low, the actual real wage will exceed the level expected to clear the labor market, and firms will reduce employment.[5]

The equilibrium level of employment and the real wage with flexible prices can be obtained by equating labor supply and labor demand (from (6.5) and (6.3)) and then using the production function (6.1) and the resource constraint (6.2) to obtain

$$n_t^* = \left[\frac{1-\Phi}{1+\bar{\eta}+(1-\alpha)(\Phi-1)}\right]e_t = b_0 e_t$$

and

$$\omega_t^* = \left[\frac{\bar{\eta}+\Phi}{1+\bar{\eta}+(1-\alpha)(\Phi-1)}\right]e_t = b_1 e_t,$$

where n^* is the flexible-wage equilibrium employment, ω^* is the flexible-wage equilibrium real wage, and $\bar{\eta} \equiv \eta n^{ss}/(1-n^{ss})$.

The contract nominal wage w^c will satisfy

$$w_t^c = \mathrm{E}_{t-1}\omega_t^* + \mathrm{E}_{t-1}p_t. \tag{6.9}$$

4. This is stronger than the property of monetary superneutrality, in which the real variables are independent of the money supply process. For example, Lucas's model does not display the classical dichotomy as long as $\Omega_2 \neq 0$ because the production function, the resource constraint, and the labor supply condition cannot be solved for output, consumption, and employment without knowing the real demand for money, since real balances enter (5.4).

5. This implies that the real wage falls in response to a positive money shock. Using a VAR approach based on U.S. data, Christiano, Eichenbaum, and Evans (1997) found that an expansionary monetary policy shock actually leads to a slight increase in real wages.

With firms equating the marginal product of labor to the actual real wage, actual employment will equal $n_t = y_t - (w_t^c - p_t) = y_t - \mathrm{E}_{t-1}\omega_t^* + (p_t - \mathrm{E}_{t-1}p_t)$, or using the production function and noting that $\mathrm{E}_{t-1}\omega_t^* = -\alpha\mathrm{E}_{t-1}n_t^* + \mathrm{E}_{t-1}e_t$,

$$n_t = \mathrm{E}_{t-1}n_t^* + \left(\frac{1}{\alpha}\right)(p_t - \mathrm{E}_{t-1}p_t) + \left(\frac{1}{\alpha}\right)\varepsilon_t, \tag{6.10}$$

where $\varepsilon_t = (e_t - \mathrm{E}_{t-1}e_t)$. Equation (6.10) shows that employment deviates from the expected flexible-wage equilibrium level in the face of unexpected movements in prices. An unanticipated increase in prices reduces the real value of the contract wage and leads firms to expand employment. An unexpected productivity shock ε_t raises the marginal product of labor and leads to an employment increase.

By substituting (6.10) into the production function, one obtains

$$y_t = (1-\alpha)\left[\mathrm{E}_{t-1}n_t^* + \left(\frac{1}{\alpha}\right)(p_t - \mathrm{E}_{t-1}p_t) + \left(\frac{1}{\alpha}\right)\varepsilon_t\right] + e_t,$$

which implies that

$$y_t - \mathrm{E}_{t-1}y_t^* = a(p_t - \mathrm{E}_{t-1}p_t) + (1+a)\varepsilon_t, \tag{6.11}$$

where $\mathrm{E}_{t-1}y^* = (1-\alpha)\mathrm{E}_{t-1}n_t^* + \mathrm{E}_{t-1}e_t$ is expected equilibrium output under flexible wages and $a = (1-\alpha)/\alpha$. Innovations to output are positively related to price innovations. Thus, monetary shocks which produce unanticipated price movements directly affect real output.

The linear approximation to the MIU model, augmented with one-period nominal wage contracts, produces one of the basic frameworks often used to address policy issues. This framework generally assumes serially uncorrelated disturbances, so $\mathrm{E}_{t-1}y^* = 0$ and the aggregate supply equation (6.11), often called a *Lucas supply function* (see chapter 5) becomes

$$y_t = a(p_t - \mathrm{E}_{t-1}p_t) + (1+a)\varepsilon_t. \tag{6.12}$$

The demand side often consists of a simple quantity equation of the form

$$m_t - p_t = y_t. \tag{6.13}$$

This model can be obtained from the model of the chapter appendix (section 6.5) by letting $b \to \infty$; this implies that the interest elasticity of money demand goes to zero. According to (6.12), a 1 percent deviation of p from its expected value will cause a $(1-\alpha)/\alpha \approx 1.8$ percent deviation of output if the benchmark value of 0.36 is used for α. To solve the model for equilibrium output and the price level, given the nominal quantity of money, note that (6.13) and (6.8) imply

$$p_t - \mathrm{E}_{t-1}p_t = m_t - \mathrm{E}_{t-1}m_t - (y_t - \mathrm{E}_{t-1}y_t) = s_t - y_t.$$

Substituting this result into (6.12), one obtains

$$y_t = \left(\frac{a}{1+a}\right)s_t + \left(\frac{1+a}{1+a}\right)\varepsilon_t = (1-\alpha)s_t + \varepsilon_t. \tag{6.14}$$

A 1 percent money surprise increases output by $1-\alpha \approx 0.64$ percent. Notice that in (6.12) the coefficient a on price surprises depends on parameters of the production function. This is in contrast to Lucas's misperceptions model, in which the impact on output of a price surprise depends on the variances of shocks (see section 5.2.2). The model consisting of (6.12) and (6.13) will play an important role in the analysis of monetary policy in chapter 7.

When (6.13) is replaced with an interest-sensitive demand for money, the systematic behavior of the money supply can matter for the real effects of money surprises. For example, if money is positively serially correlated ($\rho_m > 0$), a positive realization of s_t implies that the money supply will be higher in the future as well. This leads to increases in $\mathrm{E}_t p_{t+1}$, expected inflation, and the nominal rate of interest. The rise in the nominal rate of interest reduces the real demand for money today, causing, for a given shock s_t, a larger increase in the price level today than occurs when $\rho_m = 0$. This means the price surprise today is larger and implies that the real output effect of s_t will be increasing in ρ_m.[6]

Bénassy (1995) shows how one-period wage contracts affect the time series behavior of output in a model similar to the one used here but in which capital is not ignored. However, the dynamics associated with consumption smoothing and capital accumulation are inadequate on their own to produce anything like the output persistence that is revealed by the data.[7] That is why real business cycle models assume that the productivity disturbance itself is highly serially correlated. Because it is assumed here that nominal wages are fixed for only one period, the estimated effects of a monetary shock on output die out almost completely after one period.[8] This would continue to be the case even if the money shock were serially correlated. While serial correlation in the s_t shock would affect the behavior of the price level, this will be incorporated into expectations, and the nominal wage set at the start of $t+1$ will adjust fully to make the expected real wage (and therefore employment and output) independent of the predictable movement in the price level. Just adding one-period

6. See problem 1 at the end of this chapter. I thank Henrik Jensen for pointing out this effect of systematic policy.

7. Cogley and Nason (1995) demonstrated this for standard real business cycle models.

8. With Bénassy's model and parameters ($\alpha = 0.40$ and $\delta = 0.019$), equilibrium output (expressed as a deviation from trend) is given by $y_t \approx 0.6 \times (1 + 0.006L - 0.002L^2 \ldots)(m_t - m_t^e)$, so that the effects of a money surprise die out almost immediately (Bénassy 1995, 313, eq. 51).

sticky nominal wages will not capture the persistent effects of monetary shocks, but it will significantly influence the effect of a money shock on the economy.

6.2.2 Early Models of Intertemporal Nominal Adjustment

The model just discussed assumes that wages remain fixed for one period. More interesting from the perspective of understanding the implications for macroeconomic dynamics of nominal rigidities are models that allow prices and/or wages to adjust gradually over several periods. Two such models are discussed here.

Taylor's Model of Staggered Nominal Adjustment
One of the first models of nominal rigidities that also assumed rational expectations is due to Taylor (1979; 1980). Because his model was originally developed in terms of nominal wage-setting behavior, that approach is followed here. Prices are assumed to be a constant markup over wage costs, so the adjustment of wages translates directly into a model of the adjustment of prices.

Assume that wages are set for two periods, with one-half of all contracts negotiated each period. Let x_t equal the log contract wage set at time t. The average wage faced by the firm is equal to $w_t = (x_t + x_{t-1})/2$ because in period t, contracts set in the previous period (x_{t-1}) are still in effect. Assuming a constant markup, the log price level is given by $p_t = w_t + \mu$, where μ is the log markup. For convenience, normalize so that $\mu = 0$.

For workers covered by the contract set in period t, the average expected real wage over the life of the contract is $\frac{1}{2}[(x_t - p_t) + (x_t - \mathrm{E}_t p_{t+1})] = x_t - \frac{1}{2}(p_t + \mathrm{E}_t p_{t+1})$.[9] In Taylor (1980), the expected average real contract wage is assumed to be increasing in the level of economic activity, represented by log output:

$$x_t = \frac{1}{2}(p_t + \mathrm{E}_t p_{t+1}) + k y_t. \tag{6.15}$$

With $p_t = 0.5(x_t + x_{t-1})$,

$$\begin{aligned} p_t &= \frac{1}{2}\left[\frac{1}{2}(p_t + \mathrm{E}_t p_{t+1}) + k y_t + \frac{1}{2}(p_{t-1} + \mathrm{E}_{t-1} p_t) + k y_{t-1}\right] \\ &= \frac{1}{4}[2p_t + \mathrm{E}_t p_{t+1} + p_{t-1} + \eta_t] + \frac{k}{2}(y_t + y_{t-1}), \end{aligned}$$

where $\eta_t \equiv \mathrm{E}_{t-1} p_t - p_t$ is an expectational error term. Rearranging,

9. It would be more appropriate to assume that workers care about the present discounted value of the real wage over the life of the contract. This would lead to a specification of the form $0.5(1+\beta)x_t - 0.5(p_t + \beta \mathrm{E}_t p_{t+1})$ for $0 < \beta < 1$, where β is a discount factor.