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14 October 2011

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October 2011

Abstract

This study demonstrates that a model with efficiency wages and imperfect information produces a Phillips curve relationship. Equations are derived for labor demand and the efficiency wage-setting condition, and shifts in these curves in response to aggregate demand shocks result in a relationship with the characteristics of a Phillips curve. The Phillips curve differs from the efficiency wage-setting condition in that the Phillips curve is a more parsimonious expression and has a coefficient on expected inflation equal to 1. Also derived from this model is the counterpart curve to the Phillips curve in unemployment – inflation space.

Keywords: Phillips curve; Efficiency wages
JEL codes: E24; E31

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I. Introduction

The Phillips curve was originally developed as a relationship between unemployment and the rate of either wage or price inflation.[1] Subsequent work by Friedman (1968) and Phelps (1968) argued that expected inflation should be included as an independent variable in a Phillips curve, with a predicted coefficient of 1. While researchers have found empirical evidence for the expectations-augmented Phillips curve,[2] it has been much more difficult to provide theoretical justification for it. For example, Fuhrer (1995, p. 43) states, "Perhaps the greatest weakness of the Phillips curve is its lack of theoretical underpinnings: No one has derived a Phillips curve from first principles, beginning with the fundamental concerns and constraints of consumers and firms." In a similar vein, Mankiw (2001, p. C46) writes, "The [Phillips curve] tradeoff remains mysterious, however, for the economics profession has yet to produce a satisfactory theory to explain it."

In addition, the Phillips curve does not have a counterpart curve in unemployment – inflation space. Thus, the Phillips curve framework shows the combinations of unemployment and inflation that are possible but does make predictions about the actual values of inflation and unemployment.

This study demonstrates that a downward-sloping Phillips curve results from the profit-maximizing behavior of firms, under the assumptions that firms pay efficiency wages and that workers have imperfect information about average wages or about the aggregate price level. A wage-wage Phillips curve is obtained if workers' efficiency depends on their wages relative to the average wage, and a price-price Phillips curve is obtained if workers' efficiency depends on their real wages. These Phillips curves, however, are not directly derived from the first-order conditions of the firm's maximization problem. Rather, they are obtained by substituting one first-order condition into another. In addition, this study derives the counterpart to the Phillips curve (referred to as the dynamic labor demand curve) in inflation – unemployment space from the same framework used to derive the Phillips curve. This curve is upward sloping when the dependent variable is wage inflation and is downward sloping when the dependent variable is price inflation. Shifts in the Phillips curve and the dynamic labor demand curve trace out the paths of inflation and unemployment in response to demand or technology shocks.

For both the case in which efficiency depends on relative wages (in Section III) and the case in which efficiency depends on real wages (in Section IV), the profit function is differentiated with respect to wages and employment, and the production function and the unemployment equation are substituted into the first-order conditions. The resulting equations are the labor demand curve and the efficiency wage-setting condition, expressed as relationships between unemployment and wages (when efficiency depends on relative wages) or prices (when efficiency depends on real wages). Taking first differences yields the dynamic labor demand (DLD) curve and the dynamic efficiency wage-setting (DEWS) condition, in which the left-hand side variable is the rate of wage or price inflation.

In response to shocks to the growth rate of nominal demand, shifts in the DLD curve and DEWS condition trace out the paths of inflation (either of wages or prices) and unemployment. An increase (decrease) in demand growth initially reduces (raises) unemployment and raises (reduces) inflation by less than the change in the growth rate of demand. Over time, however, unemployment returns to its original level, and inflation equals the new growth rate of demand. Thus, the model is characterized by a natural rate of unemployment in response to nominal demand shocks. The framework developed here can also be used to analyze the effects of technology shocks. These shocks affect unemployment when efficiency depends on real wages, but not when efficiency depends on relative wages.

There is another way to derive the transition paths of inflation and unemployment in response to exogenous shocks. If labor demand is substituted into the efficiency wage-setting condition, a third relationship is obtained. The transition can be illustrated by the intersections between the dynamic labor demand curve and this new relationship. This third relationship has the characteristics of a Phillips curve. When efficiency depends on relative wages, wage inflation depends on unemployment and expected wage inflation. When efficiency depends on real wages, price inflation depends on unemployment, technology shocks, and expected price inflation. In both cases, the coefficient on expected inflation equals 1.

While the economy's transition path can be illustrated either by the dynamic labor demand curve and the dynamic efficiency wage-setting condition or by the dynamic labor demand curve and the Phillips curve, the latter is a more parsimonious and convenient specification. The Phillips curve depends on just expected inflation, the unemployment rate, and technology shocks (when efficiency depends on real wages), and the coefficient on expected inflation equals one. In contrast, the dynamic efficiency wage-setting condition depends on more variables, including the change in nominal demand (which is nearly impossible to observe), and the coefficient on expected inflation will generally not equal one.

This study expands upon the work of Campbell (2010), which develops a barebones version of the model in this study. This previous study derives equations for the wage-wage and price-price Phillips curves, but does not derive the dynamic labor demand curve or the dynamic efficiency wage-setting condition. The present study shows how a Phillips curve results from shifts of the dynamic labor demand curve and the dynamic efficiency wage-setting condition, and thus provides intuition for why the Phillips curve is obtained from a model with efficiency wages and imperfect information. In addition, the present study includes the maximization problem for workers, as well as firms, and it derives the counterpart to the Phillips curve.

The model developed in this study suggests a possible reason why researchers have found empirical evidence for the Phillips curve but have had difficulty in deriving a Phillips curve from microeconomic principles. The model predicts that there is a stable relationship between unemployment and the difference between actual and expected inflation, so a Phillips curve should be observed in macroeconomic data. However, this Phillips curve is derived indirectly from profit maximization by substituting one first-order condition into another.

II. Previous Phillips Curve Models

Two models of the Phillips curve that have been developed in recent years are the New Keynesian Phillips curve and the sticky information Phillips curve. Roberts (1995) shows that the New Keynesian Phillips curve can be derived from the staggered contract models of Taylor (1979, 1980) and Calvo (1983) and from the quadratic adjustment cost model of Rotemberg (1982). Roberts demonstrates that these models all yield the prediction that inflation depends on expectations of future inflation and on the output gap.

While the sticky price model is widely used in policy analysis,[3] it has been criticized on several grounds. Fuhrer and Moore (1995) find that it cannot explain why inflation is so persistent, and Ball (1994) shows that this model predicts that announced, credible disinflations may cause booms instead of recessions. The sticky price model predicts that inflation depends on output and expected future inflation, yet many studies find that lagged inflation is an important determinant of current inflation, even when controlling for future inflation.[4] Also, it assumes that firms follow a time-dependent rather than a state-dependent pricing policy. However, the assumption that firms can make price adjustments at only certain specified times is not grounded in economic theory. In addition, the New Keynesian Phillips curve is a relationship between inflation and output, whereas the Phillips curve was initially specified as a relationship between inflation and unemployment.

Another variant of the sticky price Phillips curve is Galí and Gertler's (1999) model, which derives a Phillips curve specification in which price inflation depends on expectations of future marginal cost. They measure marginal cost by labor's share of national income and demonstrate that their model outperforms a conventional sticky price model in which inflation depends on the output gap. However, while Galí and Gertler show that price inflation depends on the behavior of wages, their study does not analyze the factors that determine wages.

In the sticky information of Mankiw and Reis (2002), a firm's optimal price depends on the aggregate price level and on aggregate output. It is assumed that a fraction of firms receives information in each period that enables them to compute optimal prices, while the remaining firms set prices based on out-of-date information. The present model is similar to Mankiw and Reis's model in that economic fluctuations result from imperfect information. However, it differs from Mankiw and Reis by assuming a different type of imperfect information. In the Mankiw-Reis model, firms have imperfect information about the optimal price of their products, and this imperfect information affects their pricing and output decisions. In contrast, the present study assumes that workers' decisions that affect their efficiency are made with imperfect information about average wages or about the price level and that this imperfect information affects the wage decisions (and hence employment decisions) of firms.

It seems more realistic to attribute economic fluctuations to workers' imperfect information about aggregate wages or prices than to firms' imperfect information about prices and output. Firms have more resources to obtain macroeconomic data, and they have a greater incentive to collect these data, since the revenues of a typical firm are much larger than earnings of a typical individual. According to Kobe (2007), 49.3% of U.S. private nonfarm GDP was produced by firms with at least 500 employees in 2004 (the most recent year for which data were available), and it is particularly unclear why these firms would find it optimal to operate with out-of-date information, since a small deviation from the optimal price can have a large effect on profits for firms of this size. For individual workers, on the other hand, information about average wages or prices is needed to make decisions about how much effort to provide and how much on-the-job search to undertake, and incorrect information would probably have a small effect on their utility. Thus, it is reasonable to expect that individuals are more likely than firms to operate with imperfect information.

In addition, Mankiw and Reis consider firms' pricing and output decisions but do not consider their wage and employment decisions, and there is no reason why firms in their model would not continually set wages at their market-clearing level. Also, like the New Keynesian Phillips curve, the sticky information Phillips curve is a relationship between inflation and output, rather than between inflation and unemployment.

III. The Wage-Wage Phillips Curve

Assumptions about individuals' behavior

It is assumed that individuals' utility depends positively on their consumption (c) and their leisure (X), with μ representing the relative weight placed on leisure in their utility functions. As in Dixit and Stiglitz (1977), total consumption is the composite of the purchases of the output produced by individual firms. Assuming a continuity of firms, indexed from 0 to 1, this implies that

$$c_{t+i} = \left[\int_0^1 c_{t+i}(f)^{\frac{\gamma-1}{\gamma}} df \right]^{\frac{\gamma}{\gamma-1}}.$$

Utility is also assumed to depend on workers' effort (e), with the marginal utility being negative in equilibrium. The effort exerted in the current period affects the probability that the individual is employed in future periods and thus affects future utility, as well as current utility.

A worker seeks to maximize

$$U = \sum_{i=0}^{\infty} \left(\frac{1}{1+\delta} \right)^i \Big\{ \log(c_{t+i}) + \mu \Pr[Emp_{t+i}]^e \log(X_{t+i}) + (T - X_{t+i}) \Pr[Emp_{t+i}]^e [\alpha e_{t+i} - \eta e_{t+i}^2] + \mu (1 - \Pr[Emp_{t+i}]^e) \log(T) \Big\} \tag{1}$$

$$\text{s.t. } \sum_{i=0}^{\infty} \frac{1}{\prod_{j=1}^{i} (1 + r_{t+j-1})} \overline{P}_{t+i}^{e} c_{t+i} = \sum_{i=0}^{\infty} \frac{1}{\prod_{j=1}^{i} (1 + r_{t+j-1})} W_{t+i}^{e} (T - X_{t+i}) \Pr[Emp_{t+i}]^e \ ,$$

where δ is the discount rate, $\Pr[Emp_{t+i}]$ is the probability that the worker is employed in period $t+i$, the superscript e represents individuals' expectations, T is time allotment, α and η are parameters representing the utility or disutility of effort, r is the interest rate, $\overline{P}$ is the price level, and W is the wage. The first term in the utility function is the utility from consumption, the second is the utility from leisure when the employee is working, the third is the utility or disutility of effort when the employee is working, and the fourth is the utility from leisure when the individual is not working.

The Lagrangian for the worker's utility maximization is

$$L = \sum_{i=0}^{\infty}\left(\frac{1}{1+\delta}\right)^{i}\{\log(c_{t+i}) + \mu\Pr[Emp_{t+i}]^{e}\log(X_{t+i}) + (T - X_{t+i})\Pr[Emp_{t+i}]^{e}[\alpha e_{t+i} - \eta e_{t+i}^{2}] + \mu(1-\Pr[Emp_{t+i}]^{e})\log(T)\}$$

$$+ \lambda\left[\sum_{i=0}^{\infty}\frac{1}{\prod_{j=1}^{i}(1+r_{t+j-1})}\left(\frac{W}{\overline{P}}\right)_{t+i}^{e}(T - X_{t+i})\Pr[Emp_{t+i}]^{e} - \sum_{i=0}^{\infty}\frac{1}{\prod_{j=1}^{i}(1+r_{t+j-1})}c_{t+i}\right].$$

The first-order conditions with respect to c, X, and λ are

$$\frac{dL}{dc_{t+i}} = 0 = \left(\frac{1}{1+\delta}\right)^{i}\frac{1}{c_{t+i}} - \lambda\frac{1}{\prod_{j=1}^{i}(1+r_{t+j-1})}, \tag{2a}$$

$$\frac{dL}{dX_{t+i}} = 0 = \left(\frac{1}{1+\delta}\right)^{i}\left(\frac{\mu}{X_{t+i}} - \alpha e_{t+i} + \eta e_{t+i}^{2}\right) - \lambda\frac{1}{\prod_{j=1}^{i}(1+r_{t+j-1})}\left(\frac{W}{\overline{P}}\right)_{t+i}^{e}, \tag{2b}$$

and

$$\frac{dL}{d\lambda} = 0 = \sum_{i=0}^{\infty}\frac{1}{\prod_{j=1}^{i}(1+r_{t+j-1})}\left(\frac{W}{\overline{P}}\right)_{t+i}^{e}(T - X_{t+i})\Pr[Emp_{t+i}]^{e} - \sum_{i=0}^{\infty}\frac{1}{\prod_{j=1}^{i}(1+r_{t+j-1})}c_{t+i}\,. \tag{2c}$$

If the first-order conditions are approximated around their steady-state equilibria (in which it is assumed that the interest rate equals the discount rate), the Appendix demonstrates that the following equation for labor supply is obtained:

$$X_{t+i} = \frac{\mu}{\alpha e^* - \eta(e^*)^2 + \lambda_1\left[\left(\frac{W_{t+i}}{\overline{P}^e_{t+i}}\right)\Big/\left(\frac{W^*}{\overline{P}^*}\right)\right]},$$

where e^*, W^*, and $\overline{P}^*$ represent the steady-state values of effort, wages, and prices, and λ_1 is defined in the Appendix. Since labor supply equals $T - X_{t+i}$, the above equation for X_{t+i} implies that labor supply can be expressed as

$$N\left(\frac{W_{t+i}/\overline{P}^e_{t+i}}{W^*/\overline{P}^*}\right), \text{ with } N' > 0.$$

The short-run labor-supply elasticity (i.e., N'/N) will be denoted by ψ.

The Lagrangian is not differentiated with respect to effort, because the effect of effort on utility is quite complicated. Current effort not only affects currently utility but also affects expected future utility through its effect on the probability that a worker is employed in each future period. To derive an expression for the optimal level of effort, it is necessary to make assumptions about the probability that a worker is dismissed (as a function of his or her effort) and the probability that an unemployed worker is hired. Campbell (2006) develops a model of workers' effort with a similar utility function and budget constraint and makes assumptions about the probability of dismissal and the probability of hire.[5] It is demonstrated that workers' efficiency depends on the ratio of their current wage to the average wage at other firms and on the unemployment rate, such that

$$e = e[W_t / \overline{W}_t^{\,e}, u_t] \qquad \text{with } e_W > 0, \quad e_u > 0, \quad e_{WW} < 0, \quad e_{Wu} < 0, \tag{3}$$

where W_t is the wage at a worker's current firm, $\overline{W}_t^{\,e}$ denotes workers' expectations of the average wage rate, and u_t is the unemployment rate.[6]

As in Dixit and Stiglitz's (1977) model, the demand curve facing each firm can be expressed as

$$Q_t^D = Y_t \left(\frac{P_t}{\overline{P}_t} \right)^{-\gamma}, \tag{4}$$

where P is the firm's price, $\overline{P}$ is the aggregate price level, γ is the price elasticity of demand, and Y is real aggregate demand per firm.

Thus, given the assumptions about workers' utility functions and the constraints they face, equations are derived for labor supply, effort, and the demand for the output of individual firms. In addition, it will be assumed that wages vary across firms and that workers do not know the average wage with certainty.[7] If information on average wages is costly, workers' expectations may not necessarily satisfy the criteria for rational expectations and may be based partly on old information. This assumption could be incorporated into (1) by assuming that workers suffer a utility loss from incorrect information about average wages and incur a cost to acquire information, and thus find it optimal to acquire a limited amount of information.[8] (However, incorporating this assumption into (1) would significantly complicate the model, without yielding any insights beyond the current discussion.)

Assumptions about firms' behavior

1. Firms produce output (Q) with the Cobb-Douglas production function,

$$Q_t = A_t^{\phi} L_t^{\phi} K_0^{1-\phi} e\left[W_t / \overline{W}_t^{\,e}, u_t\right]^{\phi}, \tag{5}$$

where A represents technology (assumed to be exogenous and labor augmenting), L represents labor, and K represents capital (assumed to be fixed).

2. Real aggregate demand per firm is determined from the constant velocity specification,

$$Y_t = M_t / \overline{P}_t, \tag{6}$$

where M is nominal demand.

3. Parameters are such that firms pay efficiency wages, yielding excess supply of labor.[9] The unemployment rate can be expressed as

$$u_t = \frac{N\left(\dfrac{W_t / \overline{P}_t^{\,e}}{W^* / \overline{P}^*}\right) - L_t}{N\left(\dfrac{W_t / \overline{P}_t^{\,e}}{W^* / \overline{P}^*}\right)}. \tag{7}$$

Derivations of the DLD, DEWS, and Phillips curves

Solving (4) for P_t and multiplying by Q_t yields the following equation for total revenue:

$$P_t Q_t = Y_t^{\frac{1}{\gamma}} Q_t^{\frac{\gamma-1}{\gamma}} \overline{P}_t.$$

Thus, profits in period t are

$$\Pi = Y_t^{\frac{1}{\gamma}} \left[A_t^{\phi} L_t^{\phi} K_0^{1-\phi} e[W_t / \overline{W}_t^{\,e}, u_t]^{\phi}\right]^{\frac{\gamma-1}{\gamma}} \overline{P}_t - W_t L_t - r K_0. \tag{8}$$

Differentiating the profit function yields the following first-order conditions:

$$\frac{d\Pi}{dL_t} = 0 = \frac{\phi(\gamma-1)}{\gamma} Y_t^{\frac{1}{\gamma}} A_t^{\frac{\phi(\gamma-1)}{\gamma}} L_t^{\frac{\phi(\gamma-1)}{\gamma}-1} K_0^{\frac{(1-\phi)(\gamma-1)}{\gamma}} e[\bullet]^{\frac{\phi(\gamma-1)}{\gamma}} \overline{P}_t - W_t, \tag{9a}$$

and

$$\frac{d\Pi}{dW_t} = 0 = \frac{\phi(\gamma-1)}{\gamma} Y_t^{\frac{1}{\gamma}} A_t^{\frac{\phi(\gamma-1)}{\gamma}} L_t^{\frac{\phi(\gamma-1)}{\gamma}} K_0^{\frac{(1-\phi)(\gamma-1)}{\gamma}} e[\bullet]^{\frac{\phi(\gamma-1)}{\gamma}-1} e_W[\bullet] \frac{1}{\overline{W}_t^e} \overline{P}_t - L_t. \tag{9b}$$

Combining (9a) and (9b) and taking steady-state values (i.e., $W = \overline{W}$) yields the following equilibrium condition:

$$e_W[1,u]e^{-1}[1,u] = 1. \tag{10}$$

The steady-state condition, $e_W e^{-1} = 1$, determines the economy's natural rate of unemployment. In addition, this condition will be used to simplify equations expressed in terms of deviations from steady-state values.

Equation (9a) is the labor demand curve, and equation (9b) is the efficiency wage-setting condition. If (9a) and (9b) are totally differentiated and divided by the original equations, the following expressions are obtained:

$$\begin{aligned}\hat{W}_t &= \frac{1}{\gamma}\hat{Y}_t + \frac{\phi(\gamma-1)}{\gamma}\hat{A}_t + \frac{\phi\gamma-\phi-\gamma}{\gamma}\hat{L}_t + \frac{\phi(\gamma-1)}{\gamma} e_W e^{-1}\frac{W_t}{W_t^e}\hat{W}_t \\ &\quad - \frac{\phi(\gamma-1)}{\gamma} e_W e^{-1}\frac{W_t}{W_t^e}\hat{\overline{W}}_t^e + \frac{\phi(\gamma-1)}{\gamma} e_u e^{-1} du_t + \hat{\overline{P}}_t,\end{aligned} \tag{11}$$

and

$$\begin{aligned}\frac{\phi+\gamma-\phi\gamma}{\gamma}\hat{L}_t &= \frac{1}{\gamma}\hat{Y}_t + \frac{\phi(\gamma-1)}{\gamma}\hat{A}_t + \frac{\phi\gamma-\phi-\gamma}{\gamma} e^{-1}\left[e_W \frac{W_t}{W_t^e}\hat{W}_t - e_W\frac{W_t}{W_t^e}\hat{\overline{W}}_t^e + e_u du_t \right] \\ &\quad + e_{WW}e^{-1}\frac{W_t}{W_t^e}\hat{W}_t - e_{WW}e^{-1}\frac{W_t}{W_t^e}\hat{\overline{W}}_t^e + e_{Wu}e^{-1}du_t - \hat{W}_t^e + \hat{\overline{P}}_t,\end{aligned} \tag{12}$$

where $\hat{W}_t = dW_t / W_t$ and $\hat{\overline{W}}_t^e = d\overline{W}_t^e / \overline{W}_t^e$. The above equations can be viewed as the relationships between percentage deviations in W_t, percentage deviations in $\overline{W}_t^e$, and absolute deviations in u_t (in percentage-point terms) from their steady-state equilibrium values. If small deviations of W, $\overline{W}^e$, and u from their steady-state values are considered, the coefficients on these variables can be treated as constants, with these constants determined by the steady-state values of W_t, $\overline{W}_t^e$, e, e_W, e_u, e_{WW}, and e_{Wu}.

The Appendix demonstrates that calculating deviations in steady-state values in the production function (equation 5) and in the unemployment equation (equation 7) and substituting these expressions into the labor demand and efficiency wage setting equations yields

$$\hat{W}_t = \frac{1}{(1+\psi)}(\hat{M}_t + s_L^{-1} du_t + \psi \hat{\overline{P}}_t^e), \qquad \text{and} \tag{13a}$$

$$\hat{W}_t = \frac{-e_{WW} e^{-1} \hat{\overline{W}}_t^e + \left[s_L^{-1} - e_u e^{-1} + e_{Wu} e^{-1}\right] du_t + \psi \hat{\overline{P}}_t^e + \hat{M}_t}{1 - e_{WW} e^{-1} + \psi}. \tag{13b}$$

Equations (13a) and (13b) are, respectively, the labor demand curve and the efficiency wage-setting condition expressed as the relationships between wages and unemployment. If the lag of each equation is subtracted, the following equations are obtained for wage inflation:

$$\hat{W}_t - \hat{W}_{t-1} = \frac{1}{(1+\psi)}\left[(\hat{M}_t - \hat{M}_{t-1}) + s_L^{-1}(du_t - du_{t-1}) + \psi(\hat{\overline{P}}_t^e - \hat{\overline{P}}_{t-1}^e)\right], \tag{14a}$$

and

$$\hat{W}_t - \hat{W}_{t-1} = \frac{\begin{array}{c} -e_{WW} e^{-1}(\hat{\overline{W}}_t^e - \hat{\overline{W}}_{t-1}^e) + \left[s_L^{-1} - e_u e^{-1} + e_{Wu} e^{-1}\right](du_t - du_{t-1}) \\ + \psi(\hat{\overline{P}}_t^e - \hat{\overline{P}}_{t-1}^e) + (\hat{M}_t - \hat{M}_{t-1}) \end{array}}{1 - e_{WW} e^{-1} + \psi}. \tag{14b}$$

Equation (14a) will be called the dynamic labor demand (DLD) curve, and equation (14b) will be called the dynamic efficiency wage-setting (DEWS) condition. The dynamic efficiency wage-setting condition is a relatively complicated expression that includes the changes in the unemployment rate, expected wage inflation, expected price inflation, and nominal demand. Neither the coefficient on the change in expected wage inflation nor the coefficient on the change in expected price inflation will generally equal 1.

The DLD-DEWS framework can be used to illustrate how wage inflation and unemployment evolve over time in response to a shock to the growth rate of nominal demand ($\hat{M}_t$). In particular, it is assumed that demand is growing at a rate of g^o prior to period 1 and that the growth rate of demand falls to g^n in period 1 and remains at g^n indefinitely. To analyze the response of these variables to a shock to nominal demand, it is necessary to make assumptions about the nature of inflationary expectations and about the parameters in (14a) and (14b). There are several ways in which inflationary expectations can be modeled. It could be assumed that inflationary expectations are rational, in which case nominal demand shocks have no systematic effect on unemployment. However, as previously discussed, workers may choose not to acquire all available information if information is costly.

There are at least two approaches to modeling expectations when information is costly. One is to assume, in the spirit of Mankiw and Reis's (2002) sticky information model, that each period a fraction of workers receives new information about the current and future expected values of average wages, while the rest operate with out-of-date information. Let θ represent the proportion of workers who receive new information in each period. Suppose that workers whose information has not been updated expect wages to continue to grow at a rate of g^o, while workers who have received new information know that demand has grown and will continue to grow at a rate of g^n since period 1. Suppose also that these workers know that the fraction of workers receiving new information in each period is θ and know that workers whose information has not been updated since period 0 will expect wages to rise at a rate of g^o. Then these workers will have rational expectations about average wages from the time when they receive this information onwards.[10] Thus, overall expectations can be expressed as

$$\overline{W}_t^{\,e} = [1-(1-\theta)^t]\overline{W}_t + (1-\theta)^t\,\overline{W}_0(1+g^o)^t\ .$$

Given this expression for expectations, it can be demonstrated that nominal demand shocks will have systematic effects on employment and output.

A second approach to modeling workers' expectations when information about current average wages is costly is to assume, as in Campbell (2010), that expectations are a mixture of rational and adaptive expectations, so that

$$\overline{W}_t^{\,e} = \overline{W}_t^{\,\omega}\left[\overline{W}_{t-1}\left(\frac{\overline{W}_{t-1}}{\overline{W}_{t-2}}\right)^{\lambda_1}\left(\frac{\overline{W}_{t-2}}{\overline{W}_{t-3}}\right)^{\lambda_2}\cdots\left(\frac{\overline{W}_{t-T}}{\overline{W}_{t-T-1}}\right)^{\lambda_T}\right]^{1-\omega} \qquad \text{with } \lambda_1+\lambda_2+\cdots\lambda_T=1,$$

where ω represents the degree to which expectations are rational. A model providing justification for this assumption from the utility-maximizing behavior of workers is developed in Campbell (2011).[11]

Simulations are performed under the assumption that workers' expectations are a mixture of rational and adaptive expectations. (The assumptions of sticky information and of mixed rational and adaptive expectations give similar results, so only the latter case is considered.) In these simulations ω is set at 0.5 (i.e., expectations are assumed to be an equal mixture of rational and adaptive expectations). Consistent with empirical evidence, it is assumed that λ_1=1 and that $\lambda_2 = \lambda_3 = \cdots = \lambda_T = 0$.[12] In addition, the equilibrium unemployment rate is set at 5%, the steady-state values of e, e_W, e_u, and e_{Wu} are the same as those in Campbell (2008) with the micro-based efficiency function, and the short-run labor supply elasticity (ψ) is assumed to equal 0 since empirical studies find that this elasticity is low.[13] The value of e_{WW} is set so that the slope of the Phillips curve equals -1, in line with estimates with annual data from Blanchard and Katz (1997).

Figure 1 shows how wage inflation and unemployment respond over time to a decrease in the growth rate of demand from 5% to 0%. The DLD and the DEWS curves are shown for the initial equilibrium and the first three periods following the reduction in nominal demand growth.[14] Values of inflation and unemployment are denoted by dots (including values after period 3), and the initial and first five unemployment–inflation points are numbered. This demand shock initially causes a rise in unemployment and a fall in inflation. Over time, the path of the dots shows that the economy eventually reaches a new equilibrium in which unemployment returns to the natural rate and inflation equals the new growth rate of demand.

While the DLD-DEWS framework is one way to show the paths of wage inflation and unemployment in the transition between equilbria, there is another way to show the transition paths. If (13a) is solved for $\hat{M}_t$ and the resulting expression is substituted into (13b), the following equation is obtained:

$$\hat{W}_t = \hat{\overline{W}}_t^e + \frac{e_u - e_{Wu}}{e_{WW}} du_t . \qquad (15)$$

If $\hat{W}_{t-1}$ is subtracted from both sides of (15), the relationship can be expressed as

$$(\hat{W}_t - \hat{W}_{t-1}) = (\hat{W}_t^e - \hat{W}_{t-1}) + \frac{e_u - e_{Wu}}{e_{WW}} du_t \,. \tag{16}$$

Equation (16) has the characteristics of the Phillips curve (PC), as the coefficient on expected inflation equals 1, the level of the unemployment rate appears on the right-hand side with a negative sign (since $e_u > 0$, $e_{Wu} < 0$, and $e_{WW} < 0$) and the growth rate of demand is not an explanatory variable.

Figure 2 illustrates the response of wage inflation and unemployment to a decline in the growth rate of demand from 5% to 0%, using the DLD-PC framework.[15] (The thick line is the Phillips curve.) The DEWS condition is also included in Figure 2. A comparison of Figures 1 and 2 shows that the DLD-PC framework and the DLD-DEWS framework both predict the same paths of wage inflation and unemployment.

While the DLD-DEWS framework and the DLD-PC framework give the same results, the Phillips curve is a much more parsimonious specification than the dynamic efficiency wage-setting condition. The DEWS condition includes the changes in nominal demand and expected price inflation, variables that do not appear in the Phillips curve. The unemployment variable is the change in unemployment in the DEWS condition, but is the level of unemployment in the Phillips curve. In addition, the DEWS condition includes the change in wage expectations between periods *t*-1 and *t*, and the coefficient on this difference depends on the model's microeconomic parameters. Thus, it is likely to vary across countries and across time, and it is unlikely to equal 1. In contrast, the Phillips curve includes expected wage inflation, and the coefficient on this variable equals 1 for any set of microeconomic parameters.

Equation (16) predicts a stable relationship between unemployment and the difference between actual and expected inflation. Thus, a researcher with data on wage inflation and unemployment and with a reasonable proxy for expected wage inflation would likely find evidence for the Phillips curve.

The exogenous variable that causes the DLD and DEWS curves to shift, and thus causes changes in unemployment and inflation, is the growth rate of nominal demand (M). In deriving the Phillips curve, however, nominal demand drops out. Thus, the Phillips curve can be viewed as the relationship between two endogenous variables as they adjust in response to a nominal demand shock. The actual values of unemployment and wage inflation depend on the interaction between the Phillips curve and the DLD curve.

The relationship expressed in (16) is between wage inflation, unemployment, and expected wage inflation (i.e., a wage-wage Phillips curve). However, when economists estimate Phillips curves, the right-hand side variable is generally expected price inflation rather than expected wage inflation. While expected price inflation is the independent variable in the vast majority of Phillips curve studies, the right-hand side variable is expected wage inflation in Phelps's (1968) seminal paper, resulting in a wage-wage Phillips curve.[16]

Technology shocks ($\hat{A}$) do not appear in the dynamic labor demand curve or in the Phillips curve. The reason they do not appear in either equation is that technology shocks leave nominal wages and unemployment unchanged in both the short run and the long run. While technology shocks do not affect wages and unemployment, these shocks immediately and permanently change prices by -ϕ times the percentage change in technology.

IV. The Price-Price Phillips Curve

It is now assumed that workers' efficiency depends on the ratio between their wages and their expectations of the price level. If efficiency depends on price expectations, equations (4), (6), (7), and (8) become

$$Q_t = A_t^{\phi} L_t^{\phi} K_0^{1-\phi} e\left[W_t/\overline{P}_t^{\,e}, u_t\right]^{\phi}, \tag{17}$$

$$\Pi = Y_t^{\frac{1}{\gamma}} \left[A_t^{\phi} L_t^{\phi} K_0^{1-\phi} e[W_t / \overline{P}_t^{\,e}, u_t]^{\phi}\right]^{\frac{\gamma-1}{\gamma}} \overline{P}_t - W_t L_t - rK_0 , \tag{18}$$

$$\frac{d\Pi}{dL_t} = 0 = \frac{\phi(\gamma-1)}{\gamma} Y_t^{\frac{1}{\gamma}} A_t^{\frac{\phi(\gamma-1)}{\gamma}} L_t^{\frac{\phi(\gamma-1)}{\gamma}-1} K_0^{\frac{(1-\phi)(\gamma-1)}{\gamma}} e[W_t / \overline{P}_t^{\,e}, u_t]^{\frac{\phi(\gamma-1)}{\gamma}} \overline{P}_t - W_t , \tag{19}$$

and

$$\frac{d\Pi}{dW_t} = 0 = \frac{\phi(\gamma-1)}{\gamma} Y_t^{\frac{1}{\gamma}} A_t^{\frac{\phi(\gamma-1)}{\gamma}} L_t^{\frac{\phi(\gamma-1)}{\gamma}} K_0^{\frac{(1-\phi)(\gamma-1)}{\gamma}} e[W_t / \overline{P}_t^{\,e}, u_t]^{\frac{\phi(\gamma-1)}{\gamma}-1}$$

$$\times e_W [W_t / \overline{P}_t^{\,e}, u_t] \frac{1}{\overline{P}_t^{\,e}} \overline{P}_t - L_t . \tag{20}$$

Combining (19) and (20) and taking steady-state values yields the following equilibrium condition:

$$e_W\left[\frac{W}{\overline{P}^{\,e}}, u\right] e^{-1}\left[\frac{W}{\overline{P}^{\,e}}, u\right] \frac{W}{\overline{P}^{\,e}} = 1. \tag{21}$$

As in Section III, this steady-state condition determines the natural rate of unemployment and will be used to simplify equations expressed in terms of deviations from steady-state values.

The Appendix demonstrates that the labor demand curve and the efficiency wage-setting condition are, respectively,

$$\hat{\bar{P}}_t = (1-\phi)\hat{M}_t - \phi\hat{A}_t + \phi\hat{\bar{P}}_t^e - \phi e_u e^{-1} du_t\,, \tag{22a}$$

and

$$\begin{aligned}\hat{\bar{P}}_t = {} & \frac{(1-\phi)(1+\psi) - e_{WW}e_W^{-1}\zeta}{1-e_{WW}e_W^{-1}\zeta+\psi}\hat{M}_t - \phi\hat{A}_t + \frac{\phi(1+\psi)}{1-e_{WW}e_W^{-1}\zeta+\psi}\hat{\bar{P}}_t^e \\ & - \frac{\phi[e_{Wu}e_W^{-1} + \psi e_{Wu}e_W^{-1} - e_{WW}e_W^{-1}\zeta e_u e^{-1} + e_{WW}e_W^{-1}\zeta s_L^{-1}]}{1-e_{WW}e_W^{-1}\zeta+\psi} du_t\,,\end{aligned} \tag{22b}$$

where ζ equals the equilibrium ratio between wages and prices. The dynamic labor demand curve and the dynamic efficiency wage-setting condition are derived by subtracting the lag of each equation, yielding

$$\hat{\bar{P}}_t - \hat{\bar{P}}_{t-1} = (1-\phi)(\hat{M}_t - \hat{M}_{t-1}) - \phi(\hat{A}_t - \hat{A}_{t-1}) + \phi(\hat{\bar{P}}_t^e - \hat{\bar{P}}_{t-1}^e) - \phi e_u e^{-1}(du_t - du_{t-1})\,, \tag{23}$$

and

$$\begin{aligned}\hat{\bar{P}}_t - \hat{\bar{P}}_{t-1} = {} & \frac{(1-\phi)(1+\psi) - e_{WW}e_W^{-1}\zeta}{1-e_{WW}e_W^{-1}\zeta+\psi}(\hat{M}_t - \hat{M}_{t-1}) - \frac{\phi[1-e_{WW}e_W^{-1}\zeta+\psi]}{1-e_{WW}e_W^{-1}\zeta+\psi}(\hat{A}_t - \hat{A}_{t-1}) \\ & + \frac{\phi(1+\psi)}{1-e_{WW}e_W^{-1}\zeta+\psi}(\hat{\bar{P}}_t^e - \hat{\bar{P}}_{t-1}^e) \\ & - \frac{\phi[e_{Wu}e_W^{-1} + \psi e_{Wu}e_W^{-1} - e_{WW}e_W^{-1}\zeta e_u e^{-1} + e_{WW}e_W^{-1}\zeta s_L^{-1}]}{1-e_{WW}e_W^{-1}\zeta+\psi}(du_t - du_{t-1}).\end{aligned} \tag{24}$$

The Appendix demonstrates that if (22a) is solved for $\hat{M}_t$ and the resulting expression is substituted into (22b), the following relationship is obtained:

$$\hat{\bar{P}}_t = \hat{\bar{P}}_t^e - \frac{(1-\phi)[e_{WW}\zeta^2 - (1+\psi)s_L(e_u - \zeta e_{Wu})] + \phi e_{WW}\zeta^2 e_u e^{-1} s_L}{e_{WW}\zeta^2 s_L} du_t - \phi\hat{A}_t\,. \tag{25}$$

Subtracting $\bar{P}_{t-1}$ from both yields

$$(\hat{\hat{P}}_t - \hat{\hat{P}}_{t-1}) = (\hat{\hat{P}}_t^e - \hat{\hat{P}}_{t-1}) - \frac{(1-\phi)[e_{WW}\zeta^2 - (1+\psi)s_L(e_u - \zeta e_{Wu})] + \phi e_{WW}\zeta^2 e_u e^{-1} s_L}{e_{WW}\zeta^2 s_L} du_t - \phi \hat{A}_t . \quad (26)$$

[17]

Equation (26) has the characteristics of a Phillips curve, as the coefficient on expected inflation equals 1 and the coefficient on the unemployment rate is negative (since 1-ϕ>0, e_u>0, e_{WW}<0, e_{Wu}<0, ψ≥0, ζ>0, and 1-ω>0). In addition, price inflation depends negatively on technology shocks.

Figure 3 shows the paths of unemployment and price inflation in response to a deceleration in the growth of nominal demand from g^o to g^n (where g^o=5% and g^n=0%), using the dynamic labor demand curve (23) and the Phillips curve (26) for the initial equilibrium and for three periods following the deceleration in demand. As before, values of unemployment and inflation are denoted by dots (including values after period 3). This deceleration initially causes a rise in the unemployment rate and a fall in inflation. In the long run, the economy returns to a new equilibrium in which unemployment equals the natural rate and inflation equals the new growth rate of nominal demand. While the transition path is not illustrated using the DLD curve and the DEWS condition, the same intersection points are obtained with the DLD–DEWS framework and the DLD–PC framework.

As before, the Phillips curve is a more parsimonious and convenient specification than the DEWS condition. The growth rate of nominal demand appears in the dynamic efficiency wage-setting condition but not in the Phillips curve, and the coefficient on expected inflation equals 1 in the Phillips curve, but not in the dynamic efficiency wage-setting condition.

The economy's response to a technology shock is illustrated in Figure 4 for the initial equilibrium and for four periods following the shock. In particular, it is assumed that technology decreases by 3% in period 1 and remains at this level indefinitely. (In these simulations it is assumed that nominal demand remains constant.) Initially, unemployment and inflation both rise, but then decrease as the economy adjusts to its new equilibrium.

Under the assumption that efficiency depends on real wages, a technology shock alters the equilibrium unemployment rate. A technology shock changes the equilibrium real wage, and equation (21) shows that a change in the equilibrium real wage is associated with a change in the economy's equilibrium unemployment rate. Thus, if efficiency depends on real wages, the economy is not characterized by a fixed natural rate of unemployment in response to technology shocks. However, as discussed in the next section, it is much more likely that efficiency depends on relative than on real wages in the long run. Because the assumption that efficiency depends on real wages probably does not describe the long run, points corresponding to inflation and unemployment after period 4 are not included in Figure 4.

V. Does Workers' Efficiency Depend on Relative or Real Wages?

In the model in Section III, workers' efficiency depends on their wage relative to average wages, while their efficiency depends on the real wage in Section IV. There is little empirical evidence concerning whether efficiency is a function of relative or real wages. Theoretical considerations seem to suggest that workers' efficiency is likely to depend more on relative wages than on real wages since quit decisions and effort decisions (based on the shirking model of Shapiro and Stiglitz (1984)) should depend on a worker's wage relative to wages elsewhere. However, there are reasons why efficiency may depend on real wages in the short run. First, in the fair wage model of Akerlof and Yellen (1990), workers may view the fair wage as a function of the real wage and thus feel that their employer has an obligation to compensate them for a rise in consumer prices. Second, even if workers are concerned about their relative wages, they may use information about price inflation to predict how rapidly wages are rising at other firms, since price inflation data are more widely publicized than wage inflation data, and these series are highly correlated. Thus, it is possible that, in the short run, both real and relative wages affect efficiency. In the long run, it is almost certain that efficiency depends on relative wages, since what ultimately matters for workers' quit and effort decisions are their wages relative to wages elsewhere. For example, real wages have risen dramatically since World War II, yet we have not observed a significant increase in effort or a significant decline in the quit rate.

Even if workers' efficiency is a function of relative wages, it is still likely that economists will find evidence for a price-price and wage-price Phillips curve, as well as for a wage-wage Phillips curve. Campbell (2009b) demonstrates that a model in which efficiency depends on relative wages yields asymptotic price-price and wage-price Phillip curves in response to stochastic aggregate demand shocks. In this model, equations are derived for the paths of wages, prices, and unemployment in response to nominal demand shocks, and these equations are used as data in a theoretical regression of either price inflation or wage inflation on unemployment and lagged price inflation. In such a regression it is demonstrated that inflation depends on the level of unemployment and that the coefficient on lagged price inflation asymptotically approaches 1 as the sample size increases, and it is close to 1 even when the sample size is small.

VI. Possible Extensions of the Model

There are several ways in which this model could be extended. One is to generalize the model to assume that workers' efficiency depends on the ratio between their wage and their reference wage (W_t^R), the wage to which workers compare their own wages in making decisions that affect their efficiency (e.g., deciding how hard to work or how much time to devote to job search, which affects their quit propensities). Under this assumption, efficiency can be expressed as

$$e = e[W_t / W_t^R, u_t].$$

An important determinant of the reference wage is workers' expectations of the average wage, as assumed in Section III. However, the reference wage may also depend on workers' perception of their fair wage.[18] Determinants of a worker's perceived fair wage may include the worker's past wage or past wage increases. For example, since last period's wage may be a determinant of the reference wage, firms may be reluctant to reduce nominal wages, even in times when workers know that economic conditions are poor, providing a possible explanation for nominal wage rigidity. In addition, if a worker has received x% wage increases for the past several years, he or she may view the fair wage as last period's wage plus an x% increase. Such a model can explain why wages generally increase in recessions, even if workers have rational expectations about average wages, since firms may have an incentive to continue to grant wage increases when unemployment is high.

A second possible extension is to assume that wages are set by multi-period overlapping contracts. In the models developed in this study, wages can be changed each period. Since the typical worker's wages are adjusted once a year (if at all), this implies that each period in these models corresponds to a year of actual time. However, to model short-run fluctuations it is often more convenient to treat a period as a quarter. If wages are set by 4-period overlapping contracts, firms that reset their wages in the current period will take into account the wages they expect to be set by firms who adjust their wages in the next three periods. In this case, wages will depend on expected future wage inflation, as well as on past inflation.[19]

VII. Conclusion

While the Phillips curve has been an important component of empirical macroeconomic modeling, it has been a challenge for economists to provide theoretical justification for this relationship. This study demonstrates that a Phillips curve can be derived from a model in which firms pay efficiency wages and workers have imperfect information about average wages or about the aggregate price level. Firms' maximization problem yields equations for the dynamic labor demand curve and the dynamic efficiency wage-setting condition, and shifts of these curves trace out the paths of unemployment and wage or price inflation in response to shocks.

If one of these first-order conditions is substituted into the other, a third equation is obtained. This third relationship has the characteristics of a Phillips curve, as the coefficient on expected inflation equals 1, inflation depends on the level of unemployment (rather than the change in unemployment), and the change in nominal demand does not appear. Shifts in the dynamic labor demand curve and the Phillips curve produce the same paths for inflation and unemployment as shifts in the dynamic labor demand curve and the dynamic efficiency wage-setting condition. However, the former is a more convenient framework because fewer variables appear in the Phillips curve than in the DEWS condition, and the coefficient on expected inflation is 1 in the Phillips curve but is generally not equal to 1 in the DEWS condition.

In conventional specifications, the Phillips curve shows the combinations of inflation and unemployment that are possible, but it does not predict the actual values of inflation and unemployment. The present study uses a consistent framework to derive both the Phillips curve and the dynamic labor demand curve from the profit-maximizing behavior of firms. The intersections of these two curves determine the values of inflation and unemployment that result from nominal demand shocks or technology shocks in the transition between the economy’s initial equilibrium and its new equilibrium. Thus, the model developed in this study not only shows the tradeoff between inflation and unemployment, but also predicts the paths of these variables over time.

Appendix

<u>Derivation of equation (3):</u>

If it is assumed that the interest rate equals the discount rate, then (2a) can be expressed as

$$c_{t+i} = \frac{1}{\lambda}. \tag{A1a}$$

In addition, (2b) can be approximated as (A1b)

$$X_{t+i} = \frac{\mu}{\alpha e^{*} - \eta (e^{*})^{2} + \lambda \left(\dfrac{W_{t+i}}{\overline{P}^{e}_{t+i}} \right)},$$

where *'s represent steady-state values of a variable. In equilibrium, the probability that an individual is employed in each period is 1-u*, where u* is the natural rate of unemployment. Substituting (A1a), (A1b), and Pr[*Emp*]=1-u* into (2c) yields

$$\left(\frac{W^{*}}{\overline{P}^{*}} \right) \left(T - \frac{\mu}{\alpha e^{*} - \eta (e^{*})^{2} + \lambda \left(\dfrac{W^{*}}{\overline{P}^{*}} \right)} \right) (1 - u^{*}) = \frac{1}{\lambda} \tag{A2}$$

The above equation can be rewritten as

$$\lambda \left(\frac{W^{*}}{\overline{P}^{*}} \right) (1 - u^{*}) T \left[\alpha e^{*} - \eta (e^{*})^{2} + \lambda \left(\frac{W^{*}}{\overline{P}^{*}} \right) \right] - \lambda \left(\frac{W^{*}}{\overline{P}^{*}} \right) (1 - u^{*}) \mu$$
$$= \alpha e^{*} - \eta (e^{*})^{2} + \lambda \left(\frac{W^{*}}{\overline{P}^{*}} \right)$$

$$0 = \lambda^2 \left(\frac{W^*}{\overline{P}^*}\right)^2 (1-u^*)T + \lambda \left(\frac{W^*}{\overline{P}^*}\right) \left[\left((1-u^*)T\right) \left[\alpha e^* - \eta (e^*)^2\right] - (1-u^*)\mu - 1 \right]$$
$$- \alpha e^* + \eta (e^*)^2.$$

The value of λ can be calculated from the quadratic equation:

$$\lambda = \frac{-\left(\frac{W^*}{\overline{P}^*}\right)\left[\left((1-u^*)T\right)\left[\alpha e^* - \eta(e^*)^2\right] - (1-u^*)\mu - 1\right] \pm \sqrt{\left(\frac{W^*}{\overline{P}^*}\right)^2 \left[\left((1-u^*)T\right)\left[\alpha e^* - \eta(e^*)^2\right] - (1-u^*)\mu - 1\right]^2 + 4\left(\frac{W^*}{\overline{P}^*}\right)^2 (1-u^*)T[\alpha e^* - \eta(e^*)^2]}}{2\left(\frac{W^*}{\overline{P}^*}\right)^2 (1-u^*)T}$$

$$\lambda = \frac{-\left[\left((1-u^*)T\right)\left[\alpha e^* - \eta(e^*)^2\right] - (1-u^*)\mu - 1\right] \pm \sqrt{\left[\left((1-u^*)T\right)\left[\alpha e^* - \eta(e^*)^2\right] - (1-u^*)\mu - 1\right]^2 + 4(1-u^*)T)[\alpha e^* - \eta(e^*)^2]}}{2\left(\frac{W^*}{\overline{P}^*}\right)(1-u^*)T}$$

Let

$$\lambda_1 = \frac{-\left[\left((1-u^*)T\right)\left[\alpha e^* - \eta(e^*)^2\right] - (1-u^*)\mu - 1\right] \pm \sqrt{\left[\left((1-u^*)T)\right)\left[\alpha e^* - \eta(e^*)^2\right] - (1-u^*)\mu - 1\right]^2 + 4(1-u^*)T[\alpha e^* - \eta(e^*)^2]}}{2(1-u^*)T}$$

Then,

$$X_{t+i} = \frac{\mu}{\alpha e^* - \eta(e^*)^2 + \lambda_1 \left[\left(\frac{W_{t+i}}{\overline{P}^e_{t+i}}\right) \Big/ \left(\frac{W^*}{\overline{P}^*}\right)\right]}.$$

Since labor supply equals $T - X_{t+i}$, the above expression for X_{t+i} implies that labor supply is a positive function of

$$\left(\frac{W_{t+i}}{\overline{P}^{e}_{t+i}}\right)\Bigg/\left(\frac{W^*}{\overline{P}^*}\right).$$

Derivation of the Wage-Wage Phillips Curve

Letting s_L equal the steady-state value of $L_t / N(W_t / \overline{P}_t^e)$ and ψ represent the steady-state value of the short-run labor supply elasticity (with $\psi \geq 0$), du_t can be approximated by

$$du_t = \frac{-dL_t}{N} + L_t N^{-2} N' \left[\frac{1}{\overline{P}_t^e} dW_t - \frac{W_t}{(\overline{P}_t^e)^2} d\overline{P}_t^e \right] \approx -s_L \hat{L}_t + s_L \psi \hat{W}_t - s_L \psi \hat{\overline{P}}_t^e . \quad \text{(A1)}$$

Solving the above equation for L_t yields

$$\hat{L}_t \approx -s_L^{-1} du_t + \psi \hat{W}_t - \psi \hat{\overline{P}}_t^e . \quad \text{(A2)}$$

Totally differentiating (4), dividing by the original equation, and using the fact that Q_t=Y_t results in the following expression for $\hat{Y}_t$:

$$\hat{Y}_t = \phi \hat{A}_t + \phi \hat{L}_t + \phi e_W e^{-1} \frac{W_t}{\overline{W}_t^e} \hat{W}_t - \phi e_W e^{-1} \frac{W_t}{\overline{W}_t^e} \hat{\overline{W}}_t^e + \phi e_u e^{-1} du_t . \quad \text{(A3)}$$

Since $W / \overline{W}^e = 1$ in the steady state and since (from equation (8)) $e_W e^{-1} = 1$, the above equation can be expressed as

$$\hat{Y}_t = \phi \hat{A}_t + \phi (1 - e_u e^{-1} s_L) \hat{L}_t + \phi (1 + e_u e^{-1} s_L \psi) \hat{W}_t - \phi \hat{\overline{W}}_t^e - \phi e_u e^{-1} s_L \psi \hat{\overline{P}}_t^e . \quad \text{(A4)}$$

To derive the labor demand equation, eq. (A1) and the relationships $\hat{\overline{P}}_t = \hat{M}_t - \hat{Y}_t$, $W / \overline{W}^e = 1$, and $e_W e^{-1} = 1$ are substituted into (9) yielding,

$$\hat{W}_t = \frac{1-\gamma}{\gamma}\hat{Y}_t + \frac{\phi(\gamma-1)}{\gamma}\hat{A}_t + \frac{\phi(\gamma-1)}{\gamma}(1-e_u e^{-1}s_L)\hat{L}_t - \hat{L}_t + \frac{\phi(\gamma-1)}{\gamma}(1+e_u e^{-1}s_L\psi)\hat{W}_t - \frac{\phi(\gamma-1)}{\gamma}\hat{\overline{W}}{}_t^e - \frac{\phi(\gamma-1)}{\gamma}e_u e^{-1}s_L\psi\hat{\overline{P}}{}_t^e + \hat{M}_t. \tag{A5}$$

If (A4) is substituted into (A5), the equation simplifies to

$$\hat{W}_t = \hat{M}_t - \hat{L}_t. \tag{A6}$$

From (A2), (A6) can be expressed as

$$(1+\psi)\hat{W}_t = \hat{M}_t + s_L^{-1}du_t + \psi\hat{\overline{P}}{}_t^e.$$

Solving for $\hat{W}_t$ yields the following equation for labor demand:

$$\hat{W}_t = \frac{1}{(1+\psi)}(\hat{M}_t + s_L^{-1}du_t + \psi\hat{\overline{P}}{}_t^e). \tag{A7}$$

To derive the efficiency wage-setting condition, (A4) is substituted into (10), yielding

$$\frac{\phi+\gamma-\phi\gamma}{\gamma}\hat{L}_t = \frac{1-\gamma}{\gamma}\hat{Y}_t + \frac{\phi(\gamma-1)}{\gamma}\hat{A}_t + \frac{\phi\gamma-\phi-\gamma}{\gamma}e^{-1}\left[e_W\hat{W}_t - e_W\hat{\overline{W}}{}_t^e + e_u du_t\right] + e_{WW}e^{-1}\hat{W}_t - e_{WW}e^{-1}\hat{\overline{W}}{}_t^e + e_{Wu}e^{-1}du_t - \hat{\overline{W}}{}_t^e + \hat{M}_t. \tag{A8}$$

If (A2) and (A4) are substituted into (A8) (along with the facts that $W/\overline{W}^e = 1$ and $e_W e^{-1} = 1$) and the equation is solved for $\hat{W}_t$, the following equation for the efficiency wage-setting condition is obtained:

$$\hat{W}_t = \frac{-e_{WW}e^{-1}\hat{\overline{W}}{}_t^e + \left[s_L^{-1} - e_u e^{-1} + e_{Wu}e^{-1}\right]du_t + \psi\hat{\overline{P}}{}_t^e + \hat{M}_t}{1 - e_{WW}e^{-1} + \psi}. \tag{A9}$$

Price-Price Phillips Curve

Totally differentiating (17) and dividing by the original equation yields

$$\hat{Y}_t = \phi\hat{A}_t + \phi\hat{L}_t + \phi e_W e^{-1}\frac{W_t}{\overline{P}_t^e}\hat{W}_t - \phi e_W e^{-1}\frac{W_t}{\overline{P}_t^e}\hat{\overline{P}}_t^e + \phi e_u e^{-1} du_t\,. \tag{A10}$$

Substituting (21) and (A2) into (A10) yields

$$\hat{Y}_t = \phi\hat{A}_t + \phi(1+\psi)\hat{W}_t - \phi(1+\psi)\hat{\overline{P}}_t^e + \phi(e_u e^{-1} - s_L^{-1})du_t\,. \tag{A11}$$

To obtain the labor demand curve, (19) is totally differentiated and divided by the original equation, yielding

$$\begin{aligned}\hat{W}_t = {}& \frac{1}{\gamma}\hat{Y}_t + \frac{\phi(\gamma-1)}{\gamma}\hat{A}_t + \frac{\phi\gamma-\phi-\gamma}{\gamma}\hat{L}_t + \frac{\phi(\gamma-1)}{\gamma}e_W e^{-1}\frac{W_t}{\overline{P}_t^e}\hat{W}_t \\ & - \frac{\phi(\gamma-1)}{\gamma}e_W e^{-1}\frac{W_t}{\overline{P}_t^e}\hat{\overline{P}}_t^e + \frac{\phi(\gamma-1)}{\gamma}e_u e^{-1}du_t + \hat{\overline{P}}_t.\end{aligned} \tag{A12}$$

If (21) and (A2) are substituted into (A12), the following equation is obtained:

$$\begin{aligned}\left[1 - \frac{\phi(\gamma-1)}{\gamma} - \frac{\phi\gamma-\phi-\gamma}{\gamma}\psi\right]\hat{W}_t = {}& \frac{1}{\gamma}\hat{Y}_t + \frac{\phi(\gamma-1)}{\gamma}\hat{A}_t \\ & - \left[\frac{\phi(\gamma-1)}{\gamma} + \frac{\phi\gamma-\phi-\gamma}{\gamma}\psi\right]\hat{\overline{P}}_t^e + \left[\frac{\phi(\gamma-1)}{\gamma}e_u e^{-1} - \frac{\phi\gamma-\phi-\gamma}{\gamma}s_L^{-1}\right]du_t + \hat{\overline{P}}_t.\end{aligned} \tag{A13}$$

If (A13) is solved for $\hat{W}_t$ and the resulting expression is substituted into (A11), $\hat{Y}_t$ can be expressed as

$$\begin{aligned}\hat{Y}_t = {}& \phi\hat{A}_t + \phi(1+\psi)\frac{1}{\eta\gamma}\hat{Y}_t + \phi(1+\psi)\frac{1}{\eta}\frac{\phi(\gamma-1)}{\gamma}\hat{A}_t + \phi(1+\psi)\frac{\eta-1}{\eta}\hat{\overline{P}}_t^e \\ & + \phi(1+\psi)\frac{1}{\eta}\left[\frac{\phi(\gamma-1)}{\gamma}e_u e^{-1} - \frac{\phi\gamma-\phi-\gamma}{\gamma}s_L^{-1}\right]du_t + \phi(1+\psi)\frac{1}{\eta}\hat{\overline{P}}_t \\ & - \phi(1+\psi)\hat{\overline{P}}_t^e + \phi(e_u e^{-1} - s_L^{-1})du_t,\end{aligned} \tag{A14}$$

where $\eta = 1 - \frac{\phi(\gamma-1)}{\gamma} - \frac{\phi\gamma-\phi-\gamma}{\gamma}\psi$.

The above equation simplifies to

$$\hat{Y}_t[1-\phi-\phi\psi+\psi] = \phi(1+\psi)\hat{A}_t - \phi(1+\psi)\hat{\overline{P}}_t^e + \phi[e_u e^{-1} + e_u e^{-1}\psi]du_t + \phi(1+\psi)\hat{\overline{P}}_t$$

$$\hat{Y}_t = \frac{\phi}{1-\phi}\hat{A}_t - \frac{\phi}{1-\phi}\hat{\overline{P}}_t^e + \frac{\phi e_u e^{-1}}{1-\phi}du_t + \frac{\phi}{1-\phi}\hat{\overline{P}}_t. \tag{A15}$$

Since $\hat{\overline{P}}_t = \hat{M}_t - \hat{Y}_t$, the price level can be expressed as

$$\hat{\overline{P}}_t = \hat{M}_t - \frac{\phi}{1-\phi}\hat{A}_t + \frac{\phi}{1-\phi}\hat{\overline{P}}_t^e - \frac{\phi e_u e^{-1}}{1-\phi}du_t - \frac{\phi}{1-\phi}\hat{\overline{P}}_t$$

$$\hat{\overline{P}}_t = (1-\phi)\hat{M}_t - \phi\hat{A}_t + \phi\hat{\overline{P}}_t^e - \phi e_u e^{-1}du_t. \tag{A16}$$

Eq. (A16) is the equation for the labor demand curve. To obtain the efficiency wage-setting condition for the case in which efficiency depends on real wages, (20) is totally differentiated and divided by the original equation, yielding

$$\begin{aligned}\hat{L}_t &= \frac{1}{\gamma}\hat{Y}_t + \frac{\phi(\gamma-1)}{\gamma}\hat{A}_t + \frac{\phi(\gamma-1)}{\gamma}\hat{L}_t + \frac{\phi\gamma-\phi-\gamma}{\gamma}e_W e^{-1}\frac{W_t}{\overline{P}_t^e}\hat{W}_t \\ &- \frac{\phi\gamma-\phi-\gamma}{\gamma}e_W e^{-1}\frac{W_t}{\overline{P}_t^e}\hat{\overline{P}}_t^e + \frac{\phi\gamma-\phi-\gamma}{\gamma}e_u e^{-1}du_t + e_{WW}e_W^{-1}\frac{W_t}{\overline{P}_t^e}\hat{W}_t \\ &- e_{WW}e_W^{-1}\frac{W_t}{\overline{P}_t^e}\hat{\overline{P}}_t^e + e_{Wu}e_W^{-1}du_t - \overline{P}_t^e + \hat{\overline{P}}_t.\end{aligned} \tag{A17}$$

Let $\zeta = W/\overline{P}^e$. Then if (21) and (A2) are substituted into (A17), the following equation is obtained:

$$\begin{aligned}&\left[\frac{\phi+\gamma-\phi\gamma}{\gamma} - e_{WW}e_W^{-1}\zeta - \frac{\phi\gamma-\phi-\gamma}{\gamma}\psi\right]\hat{W}_t = \frac{1}{\gamma}\hat{Y}_t + \frac{\phi(\gamma-1)}{\gamma}\hat{A}_t \\ &\quad -\left[1 + \frac{\phi\gamma-\phi-\gamma}{\gamma} + e_{WW}e_W^{-1}\zeta + \frac{\phi\gamma-\phi-\gamma}{\gamma}\psi\right]\hat{\overline{P}}_t^e \\ &\quad +\left[\frac{\phi\gamma-\phi-\gamma}{\gamma}e_u e^{-1} + e_{Wu}e_W^{-1} - \frac{\phi\gamma-\phi-\gamma}{\gamma}s_L^{-1}\right]du_t + \hat{\overline{P}}_t\end{aligned}$$

$$\hat{W}_t = \frac{1}{\kappa\gamma}\hat{Y}_t + \frac{\phi(\gamma-1)}{\kappa\gamma}\hat{A}_t - \frac{1}{\kappa}\left[1 + \frac{\phi\gamma-\phi-\gamma}{\gamma} + e_{WW}e_W^{-1}\zeta + \frac{\phi\gamma-\phi-\gamma}{\gamma}\psi\right]\hat{\bar{P}}_t^e$$
$$+\frac{1}{\kappa}\left[\frac{\phi\gamma-\phi-\gamma}{\gamma}e_u e^{-1} + e_{Wu}e_W^{-1} - \frac{\phi\gamma-\phi-\gamma}{\gamma}s_L^{-1}\right]du_t + \frac{1}{\kappa}\hat{\bar{P}}_t, \qquad \text{(A18)}$$

where $\kappa = -\frac{\phi\gamma-\phi-\gamma}{\gamma} - e_{WW}e_W^{-1}\zeta - \frac{\phi\gamma-\phi-\gamma}{\gamma}\psi$.

If (A18) is substituted into (A11), output can be expressed as

$$\hat{Y}_t = \phi\hat{A}_t + \phi(1+\psi)\frac{1}{\kappa\gamma}\hat{Y}_t + \phi(1+\psi)\frac{\phi(\gamma-1)}{\kappa\gamma}\hat{A}_t - \phi(1+\psi)\frac{1}{\kappa}[1-\kappa]\hat{\bar{P}}_t^e$$
$$+\phi(1+\psi)\frac{1}{\kappa}\left[\frac{\phi\gamma-\phi-\gamma}{\gamma}e_u e^{-1} + e_{Wu}e_W^{-1} - \frac{\phi\gamma-\phi-\gamma}{\gamma}s_L^{-1}\right]du_t$$
$$+\phi(1+\psi)\frac{1}{\kappa}\hat{\bar{P}}_t - \phi(1+\psi)\hat{\bar{P}}_t^e + \phi(e_u e^{-1} - s_L^{-1})du_t$$

$$[(1-\phi)(1+\psi) - e_{WW}e_W^{-1}\zeta]\hat{Y}_t = \phi[1+\psi - e_{WW}e_W^{-1}\zeta]\hat{A}_t - \phi(1+\psi)\hat{\bar{P}}_t^e$$
$$+\phi[(1+\psi)e_{Wu}e_W^{-1} - e_{WW}e_W^{-1}\zeta e_u e^{-1} + e_{WW}e_W^{-1}\zeta s_L^{-1}]du_t + \phi(1+\psi)\hat{\bar{P}}_t$$

$$\hat{Y}_t = \frac{\phi[1+\psi-e_{WW}e_W^{-1}\zeta]}{(1-\phi)(1+\psi)-e_{WW}e_W^{-1}\zeta}\hat{A}_t - \frac{\phi(1+\psi)}{(1-\phi)(1+\psi)-e_{WW}e_W^{-1}\zeta}\hat{\bar{P}}_t^e$$
$$+\frac{\phi[(1+\psi)e_{Wu}e_W^{-1} - e_{WW}e_W^{-1}\zeta e_u e^{-1} + e_{WW}e_W^{-1}\zeta s_L^{-1}]}{(1-\phi)(1+\psi)-e_{WW}e_W^{-1}\zeta}du_t \qquad \text{(A19)}$$
$$+\frac{\phi(1+\psi)}{(1-\phi)(1+\psi)-e_{WW}e_W^{-1}\zeta}\hat{\bar{P}}_t.$$

From the relationship, $\hat{\bar{P}}_t = \hat{M}_t - \hat{Y}_t$, the price level is

$$\hat{\bar{P}}_t = \frac{(1-\phi)(1+\psi) - e_{WW}e_W^{-1}\zeta}{1-e_{WW}e_W^{-1}\zeta+\psi}\hat{M}_t - \frac{\phi[1-e_{WW}e_W^{-1}\zeta+\psi]}{1-e_{WW}e_W^{-1}\zeta+\psi}\hat{A}_t$$
$$+\frac{\phi(1+\psi)}{1-e_{WW}e_W^{-1}\zeta+\psi}\hat{\bar{P}}_t^e$$
$$-\frac{\phi[e_{Wu}e_W^{-1}+\psi e_{Wu}e_W^{-1}-e_{WW}e_W^{-1}\zeta e_u e^{-1}+e_{WW}e_W^{-1}\zeta s_L^{-1}]}{1-e_{WW}e_W^{-1}\zeta+\psi}du_t.$$

<u>Derivation of equation (25)</u>

Solving (22a) for $\hat{M}_t$ yields

$$\hat{M}_t = \frac{1}{1-\phi}\hat{\bar{P}}_t + \frac{\phi}{1-\phi}\hat{A}_t - \frac{\phi}{1-\phi}\hat{\bar{P}}_t^e + \frac{\phi}{1-\phi}e_u e^{-1}du_t. \tag{A20}$$

If (A20) is substituted into (22b), the following equation is obtained:

$$\hat{\bar{P}}_t = \frac{(1-\phi)(1+\psi) - e_{WW}e_W^{-1}\zeta}{1-e_{WW}e_W^{-1}\zeta+\psi}\left[\frac{1}{1-\phi}\hat{\bar{P}}_t + \frac{\phi}{1-\phi}\hat{A}_t - \frac{\phi}{1-\phi}\hat{\bar{P}}_t^e + \frac{\phi}{1-\phi}e_u e^{-1}du_t\right]$$
$$-\frac{\phi[1-e_{WW}e_W^{-1}\zeta+\psi]}{1-e_{WW}e_W^{-1}\zeta+\psi}\hat{A}_t + \frac{\phi(1+\psi)}{1-e_{WW}e_W^{-1}\zeta+\psi}\hat{\bar{P}}_t^e$$
$$-\frac{\phi[e_{Wu}e_W^{-1}+\psi e_{Wu}e_W^{-1}-e_{WW}e_W^{-1}\zeta e_u e^{-1}+e_{WW}e_W^{-1}\zeta s_L^{-1}]}{1-e_{WW}e_W^{-1}\zeta+\psi}du_t$$

$$(1-\phi)(1-e_{WW}e_W^{-1}\zeta+\psi)\hat{\bar{P}}_t = [(1-\phi)(1+\psi)-e_{WW}e_W^{-1}\zeta]\left[\hat{\bar{P}}_t + \phi\hat{A}_t - \phi\hat{\bar{P}}_t^e + \phi e_u e^{-1}du_t\right]$$
$$-\phi(1-\phi)[1-e_{WW}e_W^{-1}\zeta+\psi]\hat{A}_t + \phi(1-\phi)(1+\psi)\hat{\bar{P}}_t^e$$
$$-\phi(1-\phi)[e_{Wu}e_W^{-1}+\psi e_{Wu}e_W^{-1}-e_{WW}e_W^{-1}\zeta e_u e^{-1}+e_{WW}e_W^{-1}\zeta s_L^{-1}]du_t$$

$$\hat{\bar{P}}_t = \hat{\bar{P}}_t^e - \frac{(1-\phi)[e_{WW}e_W^{-1}\zeta s_L^{-1} - (1+\psi)(e_u e^{-1} - e_{Wu}e_W^{-1})] + \phi e_{WW}e_W^{-1}\zeta e_u e^{-1}}{e_{WW}e_W^{-1}\zeta}du_t - \phi\hat{A}_t.$$

Since $\zeta = W / \overline{P}^e = ee_W^{-1}$, if the numerator and denominator of the coefficient on du_t are multiplied by s_L and e, the above equation can be rewritten as

$$\hat{\overline{P}}_t = \hat{\overline{P}}_t^e - \frac{(1-\phi)[e_{WW}\zeta^2 - (1+\psi)s_L(e_u - \zeta e_{Wu})] + \phi e_{WW}\zeta^2 e_u e^{-1} s_L}{e_{WW}\zeta^2 s_L} du_t - \phi \hat{A}_t . \quad \text{(A21)}$$

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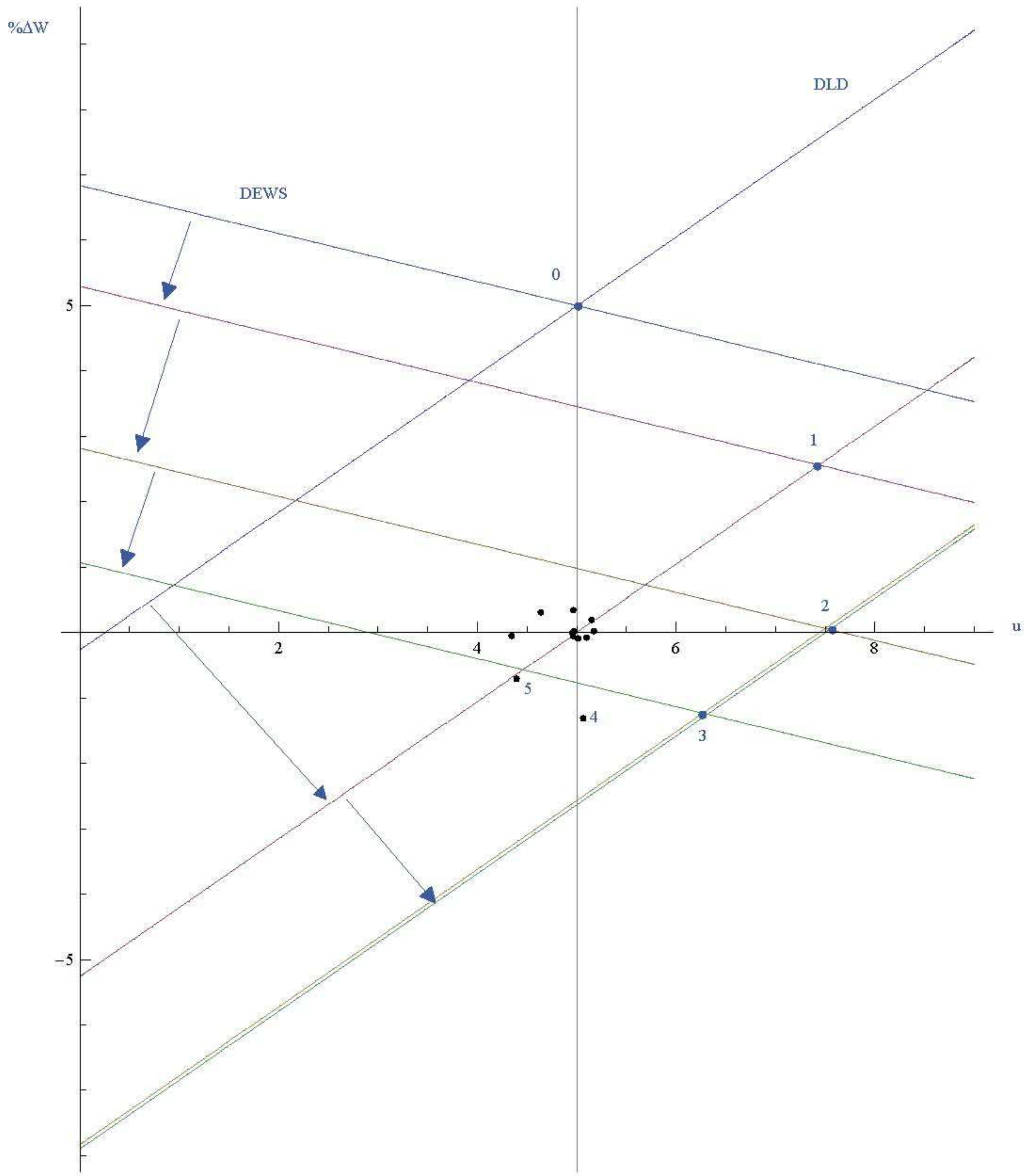

Figure 1
Wage Inflation and Unemployment with the DLD and DEWS curves

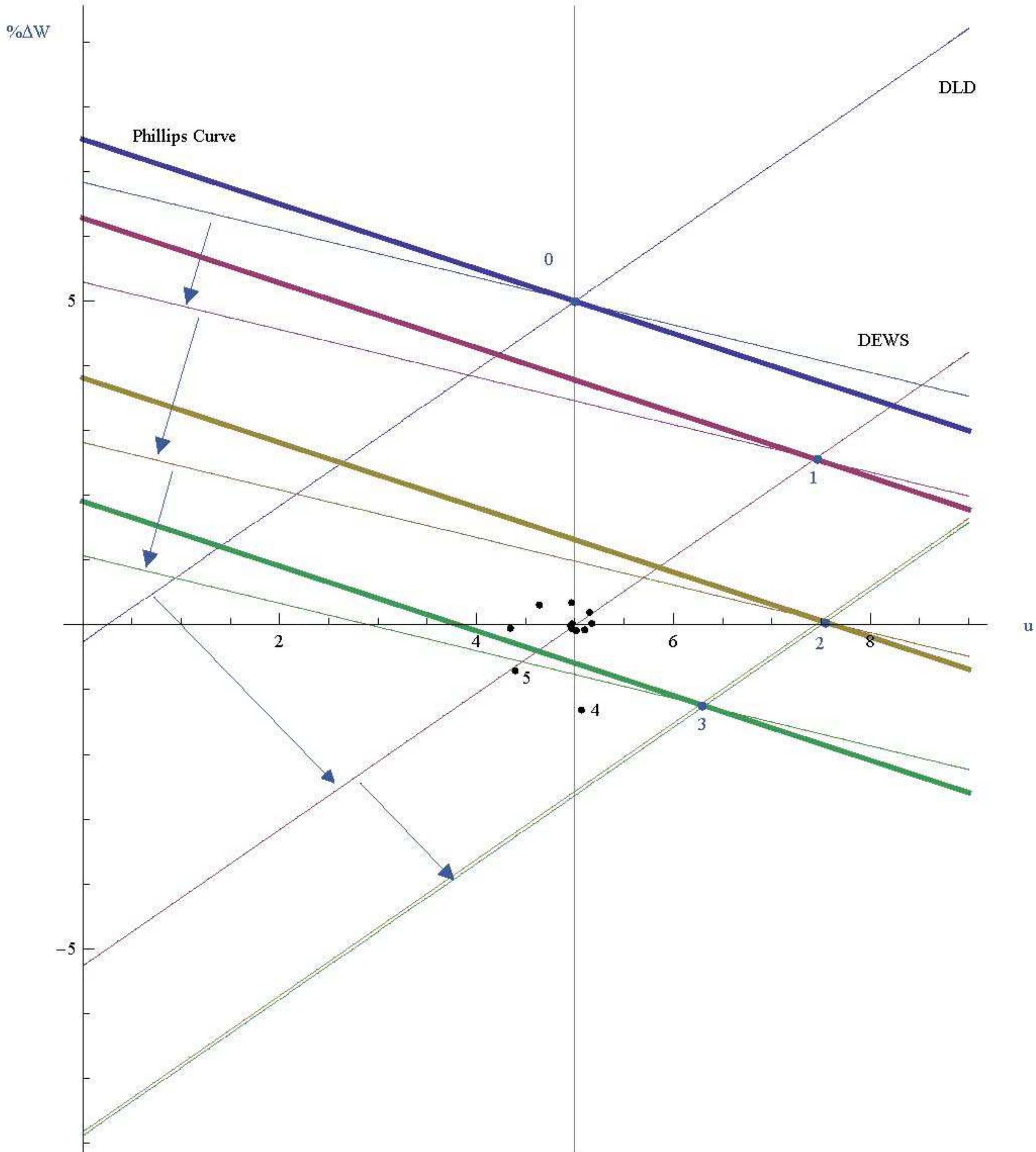

Figure 2
Wage Inflation and Unemployment with the DLD, DEWS, and Phillips Curves

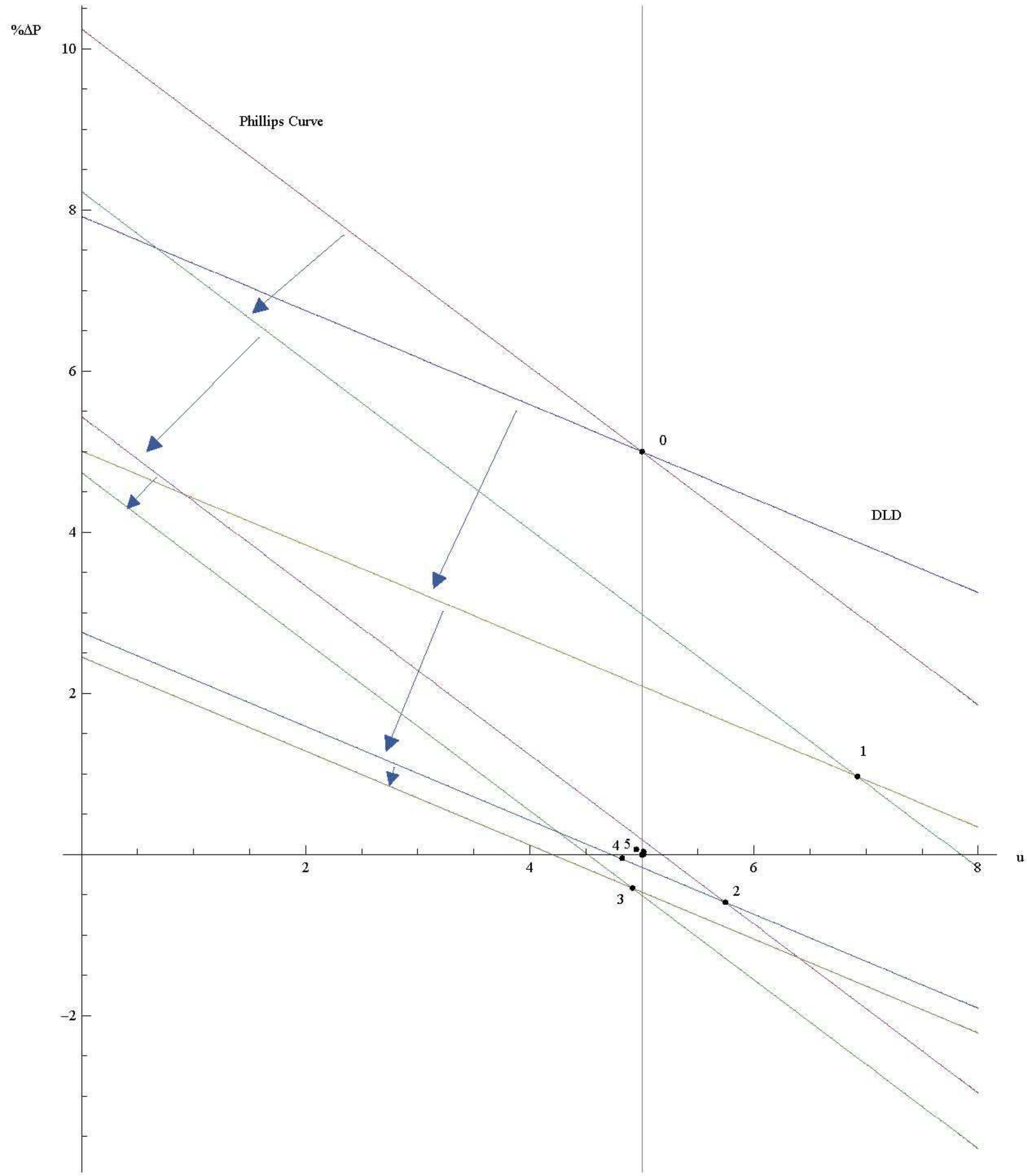

Figure 3
Price Inflation and Unemployment with the DLD and Phillips Curves

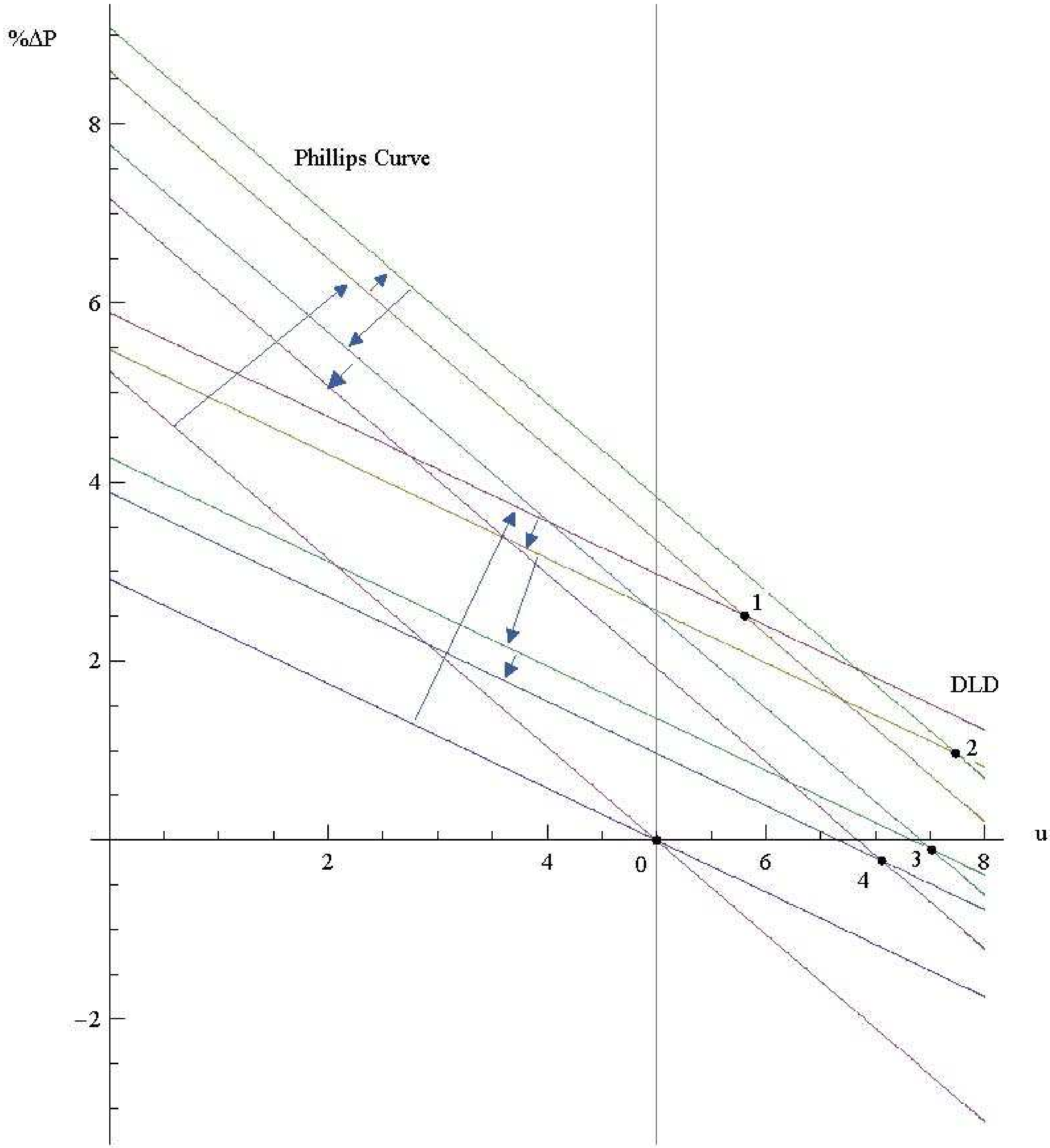

Figure 4

Footnotes

[1] Phillips (1958) finds an inverse relationship between wage inflation and unemployment with British data from 1861-1957. Samuelson and Solow (1960) show that a similar relationship can be derived between price inflation and unemployment.

[2] See King and Watson (1994) and Fuhrer (1995) for empirical evidence for the Phillips curve.

[3] According to McCallum (1997), the Calvo-Rotemberg model of the Phillips curve, has become "the closest thing there is to a standard specification."

[4] See, for example, Fuhrer (1997) and Rudd and Whelan (2005).

[5] The model of Campbell (2006) differs from the model in the present study in that Campbell (2006) does not consider the utility from leisure (X), allows individuals to hold non-labor wealth, and assumes that unemployed individuals receive benefits. Since the first-order conditions in the present study are approximated around their steady-state values and the last two differences are minor, the qualitative predictions of Campbell (2006) will be valid for the model in the present study. In Campbell (2006), the probability of dismissal is $PD = m(1-e)^2$, where m is the firm's monitoring intensity, and the probability of hire is $h = [(PD+q)(1-u)]/[(PD+q)(1-u)+u]$. In the hiring equation, q represents the probability of an exogenous separation, the numerator is the number of new hires in a period, and the denominator is the pool of the unemployed at the beginning of the period.

[6] In this model, wages have a positive effect on efficiency through their effect on workers' effort. Another reason why wages may affect efficiency is by reducing turnover.

[7] Wages could vary across firms if the profit-maximizing wage is set on average, but firms make random errors in setting wages.

[8] Incorrect information about average wages is costly because it results in suboptimal levels of effort. For example, a worker who overestimates average wages will exert less than optimal effort, so that on average, the loss of future earnings resulting from the increased probability of dismissal will exceed the utility gain from lower effort. A worker underestimating average wages will suffer the opposite type of utility loss.

[9] Assuming a positive relationship between wages and efficiency does not guarantee that there will be excess supply of labor. Whether a firm operates on its labor supply curve or to the left of its labor supply curve (i.e., pays an efficiency wage) depends on the elasticity of output with respect to the wage, calculated at the market-clearing wage. It is assumed that parameters are chosen so that firms maximize profits by operating to the left of their labor supply curves.

[10] This information would enable these workers to form correct expectations about the wage expectations of the average worker. Knowing the firm's profit function would enable them to use this information to form correct expectations of average wages.

[11] In Campbell (2011), workers use a Kalman filtering process to form their expectations, looking at an infinite number of lags (i.e., $T=\infty$), with exponentially declining values of λ.

[12] Using annual data from the Employment Cost Index, current wage inflation was regressed on five values of lagged wage inflation. The coefficient on the first lag was close to 1, and the coefficients on further lags were close to 0. It is reasonable to use annual data to calibrate the model, since the model assumes that wages are set once each period, and most people's wages are adjusted once each year.

[13] See, for example, Blundell and MaCurdy (1999) and Card (1991). Assuming that $\psi=0$ means that it is not necessary to model the formation of price expectations.

[14] Figure 1 includes arrows to show the shifts of the DLD and DEWS curves. However, an arrow is not used to show the leftward shift of the DLD curve between periods 2 and 3 since the distance between the lines is too small.

[15] In Figure 2, the Phillips curve shifts between periods 0 and 1 because inflationary expectations are partly rational, so these expectations partly decrease along with actual inflation. If expectations are assumed to be completely adaptive, the Phillips curve does not shift between periods 0 and 1.

[16] See equation 25 on p. 698 of Phelps (1968).

[17] This is the same equation for the price-price Phillips curve that was derived in Campbell (2010), except it was implicitly assumed that ζ was normalized to 1 in Campbell (2010).

[18] See Akerlof and Yellen (1990) for a discussion of the fair wage-effort hypothesis.

[19] If efficiency is assumed to depend on real wages, a firm's wage decision will depend on expectations of the price level over the next three periods.