An efficiency wage - imperfect information model of the aggregate supply curve

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Abstract

This study derives a reduced-form equation for the aggregate supply curve from a model in which firms pay efficiency wages and workers have imperfect information about average wages at other firms. If specific assumptions are made about workers' expectations of average wages and about aggregate demand, the model predicts how the aggregate demand and supply curves shift and how output and prices adjust in response to demand shocks and supply shocks. The model also provides an alternative explanation for Lucas' (1973) finding that the AS curve is steeper in countries with greater inflation variability.

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I. Introduction

The aggregate demand (AD) – aggregate supply (AS) framework has been developed to analyze the effects of demand shocks and supply shocks on output and the price level. The aggregate supply curve is generally assumed to be upward sloping in the short run and vertical in the long run.[1] Explanations for an upward-sloping short-run AS curve include imperfect information about the price level, sticky prices, and rigid nominal wages.

This study takes a different approach and derives an aggregate supply curve from an efficiency wage model in which workers have imperfect information about average wages. The profit-maximization problem of firms yields a reduced-form equation that relates the difference between actual output and potential output to technology shocks, input price (e.g., oil) shocks, wages, workers' expectations of average wages, and the price level. Under reasonable conditions, the coefficient on the price level is positive, which means that the economy is characterized by an upward-sloping short-run AS curve. The value of this coefficient (and thus the slope of the AS curve) depends on the model's microeconomic parameters. In addition, the model provides an alternative explanation for Lucas' (1973) finding that the AS curve is steeper in countries in which inflation is more variable.

Section II reviews previous work on the aggregate supply curve and discusses undesirable features of various models. In addition, it is shown that a common specification for the AS curve implies that adverse supply shocks are likely to lower unemployment. It is argued that the model in the present study is based on a more realistic set of assumptions than previous models and that its predictions are more in line with the behavior of the economy.

In Section III, an expression for the aggregate supply curve is derived under the assumptions that firms pay efficiency wages and that workers have imperfect information about average wages at other firms. Then, in Section IV specific assumptions are made about aggregate demand and workers' expectations of average wages. With these assumptions, the model predicts how the AD and AS curves shift over time in response to demand shocks, technology shocks, and input price shocks, yielding expressions for the paths that output and prices follow over time in response to these shocks. As expected, output and prices initially rise when aggregate demand increases, but output eventually returns to potential output as the aggregate supply curve shifts. In the transition between the economy's initial equilibrium and new equilibrium, real wages can be procyclical, acyclical, or countercyclical, depending on the model's parameters. In response to technology and input price shocks, both the long-run and short-run AS curves shift, and it is theoretically ambiguous whether the change in short-run output is greater or less than the change in long-run output. However, under reasonable conditions, supply shocks affect short-run output more than they affect long-run output, which means that adverse supply shocks initially raise unemployment and favorable supply shocks initially lower it. In the long run, unemployment returns to its initial value.

Section V provides another explanation for Lucas' (1973) finding that the AS curve is steeper in countries with greater inflation variability. In Section VI the model is generalized to make efficiency a function of the ratio between a worker's actual wage and his or her reference wage, and it is argued that this modification enables the model to explain a wider set of phenomena. A brief conclusion is provided in Section VII.

II. Relation to Previous Literature

Economists have developed several explanations for an upward-sloping aggregate supply curve. In Lucas (1973) firms observe their own price but do not observe the aggregate price level, and they view changes in their own price as partly general and partly idiosyncratic. When the overall price level rises, each firm views this rise as partly idiosyncratic and raises output accordingly, so that a higher price level is associated with higher aggregate output. A second explanation for an upward-sloping AS curve is that prices are sticky because firms adjust prices infrequently and these adjustments are not synchronized, as in Rotemberg (1982) and Calvo (1983). When aggregate demand rises, prices adjust slowly to their new equilibrium values, resulting in an increase in output and a positive association between the price level and real GDP. A third reason for this positive relationship is the sticky nominal wage model of Keynes (1936), in which a rise in the price level reduces the real wage and induces firms to increase employment and output.

A common specification for the AS curve is $Y_t = \overline{Y} + \alpha(P_t - P_t^e)$, where Y_t is actual output, $\overline{Y}$ is full-employment output, P_t is the actual price level, P_t^e is the expected price level, and α is the slope of the AS curve. In fact, Mankiw (2007) demonstrates that an equation of this form can be derived from all three of the previously discussed models.

However, there are shortcomings with each of these models and with the specification $Y_t = \overline{Y} + \alpha(P_t - P_t^e)$. The imperfect information model of Lucas (1973) attributes output fluctuations to firms' lack timely information about the aggregate price level. In reality, however, data on the price level are published monthly by the Bureau of Labor Statistics and are readily available on the internet. Given the ease of accessing these statistics, it is not obvious why imperfect information about the price level could cause large fluctuations in output. In addition, Lucas does not consider the labor market, which means that his model does not provide a rationale for unemployment and does not treat output as being determined from a production function involving labor input. Furthermore, aggregate supply shocks are not considered in Lucas' model.

Models with sticky prices (e.g. Calvo (1983) and Rotemberg (1982)) explain why prices are sticky and why decreases in demand reduce output. However, while the price level is sticky in these model, the inflation rate can adjust quickly to shocks, so disinflationary demand shocks do not necessarily lower output. In fact, Ball (1994) demonstrates that the sticky price model predicts that announced, credible disinflations may actually raise output. In addition, Fuhrer and Moore (1995) show that the sticky price model cannot explain the persistence of inflation observed in U.S. data.[2]

In addition, the sticky price models of Calvo (1983) and Rotemberg (1982) do not consider involuntary unemployment. Calvo's model does not incorporate a labor market and assumes that firms produce output at zero variable cost up to a certain level, so that supply is demand-determined up to this level. In one version of Rotemberg's model, production is a function of labor, but the labor market is assumed to be competitive so there is no involuntary unemployment.[3] Also, Calvo's and Rotemberg's models consider only demand shocks and do not analyze the response of the economy to aggregate supply shocks.

A criticism of the sticky wage model of Keynes (1936) is its predictions concerning the cyclical behavior of real wages. As discussed in Romer (2006) and Mankiw (2007), this model predicts that real wages should be countercyclical. However, when Bils (1985) and Solon, Barsky, and Parker (1994) analyze the behavior of real wages with individual data, they find that real wages are significantly procyclical. Another version of the sticky nominal wage model is Taylor (1979), in which overlapping contracts result in slow adjustment of nominal wages. In this model, the behavior of the price level and the supply of labor are not considered. Because labor supply is not modeled, it is not clear whether the slow adjustment of wages results in involuntary unemployment.

As previously discussed, Mankiw (2007) demonstrates that all three of these models yield the specification, $Y_t = \overline{Y} + \alpha(P_t - P_t^e)$. However, this specification implies that adverse supply shocks are likely to lower unemployment. Suppose that an adverse supply shock raises the price level. If price expectations do not fully adjust (i.e., P_t^e rises less than P_t), then Y_t initially exceeds the new value of $\overline{Y}$, meaning that unemployment is initially below the natural rate. Even if P_t^e increases as much as P_t, output will equal the new value of $\overline{Y}$, implying that unemployment will not rise. Adverse supply shocks would raise unemployment only if P_t^e rises more than P_t, which would appear to imply irrationality on the part of workers. However, historical evidence suggests that adverse supply shocks do tend to raise unemployment. For example, unemployment rose significantly following large increases in oil prices in 1973-74 and 1979-80.

The present study takes a different approach in modeling aggregate supply. It is assumed that workers' efficiency depends on their relative wages (because of the effect of relative wages on workers' effort and quit propensities) and that workers have imperfect information about average wages.[4] These assumptions are then used to derive a closed-form equation for the aggregate supply curve. This approach provides a framework for analyzing both demand shocks and supply shocks. It is argued below that a model with efficiency wages and imperfect information is based on a more realistic set of assumptions than previous models of aggregate supply and that its predictions appear to be more in line with observed macroeconomic data.

In terms of assumptions, this model incorporates a labor market in which labor is an input in the production function and in which there is involuntary unemployment. Unlike in models involving overlapping contracts, firms in the efficiency wage – imperfect information model are free to set wages and prices each period. While firms can set wages and prices each period, they find it optimal to adjust wages and prices slowly to their new equilibrium level in response to aggregate demand and aggregate supply shocks.

The efficiency wage – imperfect information model differs from the imperfect information model in that the former assumes that workers have imperfect information about average wages, while the latter assumes that firms have imperfect information about the aggregate price level. The assumption that workers have imperfect information about average wages seems to be more realistic than the assumption that firms have imperfect information about the price level. The variable that affects firms' output in Lucas (1973) is the aggregate price level, and this variable is published monthly and is available on the internet. In contrast, the variable that matters for a worker's effort and quit decisions is the average wage for workers with similar characteristics (e.g., age, experience, and education) in the same narrowly defined occupational group, and this type of data is not easily obtainable.[5] Also, the profits of the typical firm are much higher than the wages of a typical worker, so the cost of incorrect expectations is probably much greater for firms than for workers,[6] giving workers less incentive than firms to acquire the relevant information. In fact, employers in Bewley's (1999) survey believed that their workers did not have a very precise idea of wages at other firms. Thus, it seems more reasonable to construct a theory on the assumption that workers have imperfect information about average wages than on the assumption that firms have imperfect information about the price level.

Relative to other models of aggregate supply, the efficiency wage – imperfect information model appears to make more reasonable predictions about macroeconomic variables. First, unlike aggregate supply models in which $Y_t = \overline{Y} + \alpha(P_t - P_t^e)$, the efficiency wage – imperfect information model predicts that, given realistic parameter values, adverse supply shocks will initially raise unemployment. Second, the efficiency wage – imperfect information model predicts that real wages can be procyclical, acyclical, or countercyclical, depending on the model's parameters. In contrast, the real wage is countercyclical in the sticky wage model of Keynes (1936), contrary to empirical evidence.

The models that are most similar to the efficiency wage – imperfect information model are Mankiw and Reis (2002) and Blanchard (2003). In Mankiw and Reis' "sticky information" model, each period a fraction of firms receives information that enables them to compute optimal prices for their products; the other firms set prices based on out-of-date information. The present study differs from Mankiw and Reis in two respects. First, Mankiw and Reis' model does not incorporate a labor market, so involuntary unemployment is not considered. Second, the informational imperfection is firms' expectations of optimal prices (which depend on the price level and aggregate output) in Mankiw and Reis, and is workers' expectations of average wages in the present model. Since data on the price level and GDP are easily available, it is not obvious why some firms would operate with out-of-date information. On the other hand, as previously discussed, there are good reasons why workers may have imperfect information about the relevant average wage.

Blanchard (2003) assumes a wage-setting relationship of the form, $W = P^e F(u, z)$, where u is the unemployment rate and z represents other variables that may affect the wage-setting process. While Blanchard states that this type of wage-setting relationship can be obtained from either a bargaining model or an efficiency wage model, either of these theories would predict that wages should depend on workers' expectations of average wages rather than on their expectations of the price level. Also, Blanchard assumes a constant markup of wages over prices, while the present study assumes the markup is endogenously determined and allows it to vary over the business cycle.

III. A Model of the Aggregate Supply Curve

In deriving the AS curve, the following assumptions are made:

1. Workers' efficiency (e) depends on the ratio of their current wage to their expectations of wages at other firms and on the unemployment rate, so that

$$e = e[W_t / \overline{W}_t^e, u_t], \qquad \text{with } e_W > 0, \quad e_u > 0, \quad e_{Wu} < 0, \quad \text{and } e_{WW} < 0,$$ [7]

   where W_t is a worker's current wage, $\overline{W}_t^e$ denotes workers' expectations of the average wage rate, and u_t is the unemployment rate.[8] Explanations for why efficiency may depend positively on wages and unemployment include the shirking model of Shapiro and Stiglitz (1984); the gift-exchange/fair wage models of Akerlof (1982, 1984) and Akerlof and Yellen (1990); the labor turnover models of Stiglitz (1974), Schlicht (1978), and Salop (1979); and the adverse selection model of Weiss (1980). The function $e[W_t / \overline{W}_t^e, u_t]$ can be viewed as incorporating all of these explanations.

2. Each firm produces output (Y) with the production function,

$$Y_t = A_t^{\phi} L_t^{\phi} I_t^{\beta} K_t^{1-\phi-\beta} e[W_t / \overline{W}_t^{\,e}, u_t]^{\phi},$$

where A represents technology (assumed to be labor augmenting), L is labor input, I is an input in the production process (e.g., oil), K is the capital stock, and e is defined above. It is assumed that the capital stock is exogenously determined.

3. The demand curve facing an individual firm can be expressed as

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

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

$$P_t = \theta_t^{\frac{1}{\gamma}} Q_t^{-\frac{1}{\gamma}} \overline{P}_t,$$

and its total revenue is

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

4. Labor supply is inelastic and equals N times the number of firms. Parameters are chosen so that there is excess supply of labor.[9] Since parameters are chosen so that firms maximize profits by paying efficiency wages, wages and employment are determined by differentiating the profit function with respect to both W and L.

Given these assumptions, profits in period t can be expressed as

(1) $$\Pi_t = \theta_t^{1/\gamma}\left[A_t^{\phi}L_t^{\phi}I_t^{\beta}K_t^{1-\phi-\beta}e[W_t/\overline{W}_t^{e}, u_t]^{\phi}\right]^{\frac{\gamma-1}{\gamma}}\overline{P}_t - W_tL_t - (\delta+i)K_t - z_t\overline{P}_tI_t,$$

where i is the interest rate, δ is the depreciation rate, and z is the real price of the input.

In deriving the aggregate supply curve, we first obtain expressions for the profit function and production function that include the price of the input rather than the quantity of the input. The optimal amount of the input is determined from the condition,

$$\frac{d\Pi_t}{dI_t} = 0 = \frac{\beta(\gamma-1)}{\gamma}\theta_t^{1/\gamma}A_t^{\frac{\phi(\gamma-1)}{\gamma}}L_t^{\frac{\phi(\gamma-1)}{\gamma}}I_t^{\frac{\beta(\gamma-1)}{\gamma}-1}K_t^{\frac{(1-\phi-\beta)(\gamma-1)}{\gamma}}e[\bullet]^{\frac{\phi(\gamma-1)}{\gamma}}\overline{P}_t - z_t\overline{P}_t.$$

Solving the above equation for I_t yields

$$I_t = \left(\frac{\gamma}{\beta(\gamma-1)}\right)^{-\frac{\gamma}{\gamma-\beta(\gamma-1)}}\theta_t^{\frac{1}{\gamma-\beta(\gamma-1)}}A_t^{\frac{\phi(\gamma-1)}{\gamma-\beta(\gamma-1)}}L_t^{\frac{\phi(\gamma-1)}{\gamma-\beta(\gamma-1)}}K_t^{\frac{(1-\phi-\beta)(\gamma-1)}{\gamma-\beta(\gamma-1)}}e[\bullet]^{\frac{\phi(\gamma-1)}{\gamma-\beta(\gamma-1)}\frac{\gamma}{\gamma-\beta(\gamma-1)}}z_t^{-\frac{\gamma}{\gamma-\beta(\gamma-1)}}.$$

As demonstrated in Appendix A, if this expression for I is substituted into equation (1), profits can be expressed as

(2) $$\begin{aligned}\Pi_t &= \theta_t^{\frac{1}{\gamma-\beta(\gamma-1)}}A_t^{\frac{\phi(\gamma-1)}{\gamma-\beta(\gamma-1)}}L_t^{\frac{\phi(\gamma-1)}{\gamma-\beta(\gamma-1)}}K_t^{\frac{(1-\phi-\beta)(\gamma-1)}{\gamma-\beta(\gamma-1)}}e[W_t/\overline{W}_t^{e}, u_t]^{\frac{\phi(\gamma-1)}{\gamma-\beta(\gamma-1)}}\overline{P}_tz_t^{-\frac{\beta(\gamma-1)}{\gamma-\beta(\gamma-1)}} \\ &\times\left(\frac{\gamma}{\beta(\gamma-1)}\right)^{-\frac{\gamma}{\gamma-\beta(\gamma-1)}}\frac{\gamma-\beta(\gamma-1)}{\beta(\gamma-1)} - W_tL_t - (\delta+i)K_t.\end{aligned}$$

In addition, substituting this expression for I into the production function yields the following equation for output:

$$Y_t = A_t^{\frac{\phi\gamma}{\gamma-\beta(\gamma-1)}} L_t^{\frac{\phi\gamma}{\gamma-\beta(\gamma-1)}} \left(\frac{\gamma}{\beta(\gamma-1)}\right)^{-\frac{\beta\gamma}{\gamma-\beta(\gamma-1)}} \theta_t^{\frac{\beta}{\gamma-\beta(\gamma-1)}} K_t^{\frac{\gamma(1-\phi-\beta)}{\gamma-\beta(\gamma-1)}}$$
$$\times e[W_t / \overline{W}_t^{\,e}, u_t]^{\frac{\phi\gamma}{\gamma-\beta(\gamma-1)}} z_t^{-\frac{\beta\gamma}{\gamma-\beta(\gamma-1)}}.$$

This expression for Y_t can be simplified by noting that $\theta_t = Y_t^D = Y_t$.[10] This substitution enables the production function to be expressed as

$$\text{(3)} \qquad Y_t = A_t^{\frac{\phi}{1-\beta}} L_t^{\frac{\phi}{1-\beta}} \left(\frac{\gamma}{\beta(\gamma-1)}\right)^{-\frac{\beta}{1-\beta}} K_t^{\frac{1-\phi-\beta}{1-\beta}} e[W_t / \overline{W}_t^{\,e}, u_t]^{\frac{\phi}{1-\beta}} z_t^{-\frac{\beta}{1-\beta}}.$$

The first-order conditions are obtained by differentiating (2) with respect to *L* and *W*. One first-order condition is

$$\frac{d\Pi_t}{dL_t} = 0 = \frac{\phi(\gamma-1)}{\gamma-\beta(\gamma-1)} \theta_t^{\frac{1}{\gamma-\beta(\gamma-1)}} A_t^{\frac{\phi(\gamma-1)}{\gamma-\beta(\gamma-1)}} L_t^{\frac{\phi(\gamma-1)}{\gamma-\beta(\gamma-1)}-1} K_t^{\frac{(1-\phi-\beta)(\gamma-1)}{\gamma-\beta(\gamma-1)}}$$
$$\times e[W_t / \overline{W}_t^{\,e}, u_t]^{\frac{\phi(\gamma-1)}{\gamma-\beta(\gamma-1)}} \overline{P}_t z_t^{-\frac{\beta(\gamma-1)}{\gamma-\beta(\gamma-1)}} \left(\frac{\gamma}{\beta(\gamma-1)}\right)^{-\frac{\gamma}{\gamma-\beta(\gamma-1)}} \frac{\gamma-\beta(\gamma-1)}{\beta(\gamma-1)} - W_t.$$

Solving this equation for L_t yields the following equation for labor demand:

$$\text{(4)} \qquad L_t = W_t^{\frac{\gamma-\beta(\gamma-1)}{(\phi+\beta)(\gamma-1)-\gamma}} \left(\frac{\beta}{\phi}\right)^{\frac{\gamma-\beta(\gamma-1)}{(\phi+\beta)(\gamma-1)-\gamma}} \theta_t^{-\frac{1}{(\phi+\beta)(\gamma-1)-\gamma}} A_t^{-\frac{\phi(\gamma-1)}{(\phi+\beta)(\gamma-1)-\gamma)}} K_t^{-\frac{(1-\phi-\beta)(\gamma-1)}{(\phi+\beta)(\gamma-1)-\gamma}}$$
$$\times e[W_t / \overline{W}_t^{\,e}, u_t]^{-\frac{\phi(\gamma-1)}{(\phi+\beta)(\gamma-1)-\gamma}} \overline{P}_t^{\frac{-\gamma+\beta(\gamma-1)}{(\phi+\beta)(\gamma-1)-\gamma}} z_t^{\frac{\beta(\gamma-1)}{(\phi+\beta)(\gamma-1)-\gamma}} \left(\frac{\gamma}{\beta(\gamma-1)}\right)^{\frac{\gamma}{(\phi+\beta)(\gamma-1)-\gamma}}.$$

The other first-order condition is

$$\text{(5)}\quad \begin{aligned} \frac{d\Pi_t}{dW_t} = 0 = \frac{\phi(\gamma-1)}{\gamma-\beta(\gamma-1)} \theta_t^{\frac{1}{\gamma-\beta(\gamma-1)}} A_t^{\frac{\phi(\gamma-1)}{\gamma-\beta(\gamma-1)}} L_t^{\frac{\phi(\gamma-1)}{\gamma-\beta(\gamma-1)}} K_t^{\frac{(1-\phi-\beta)(\gamma-1)}{\gamma-\beta(\gamma-1)}} e[W_t / \overline{W}_t^{\,e}, u_t]^{\frac{\phi(\gamma-1)}{\gamma-\beta(\gamma-1)}-1} \\ \times \frac{e_W}{\overline{W}_t^{\,e}} \overline{P}_t z_t^{-\frac{\beta(\gamma-1)}{\gamma-\beta(\gamma-1)}} \left(\frac{\gamma}{\beta(\gamma-1)}\right)^{-\frac{\gamma}{\gamma-\beta(\gamma-1)}} \frac{\gamma-\beta(\gamma-1)}{\beta(\gamma-1)} - L_t . \end{aligned}$$

Substituting (4) into (5) yields

$$\text{(6)}\qquad W_t e[W_t / \overline{W}_t^{\,e}, u_t]^{-1} e_W [W_t / \overline{W}_t^{\,e}, u_t] \frac{1}{\overline{W}_t^{\,e}} = 1 ,$$

which is analogous to the Solow (1979) condition.[11]

The economy's long-run aggregate supply curve is obtained from setting $\overline{W}_t^{\,e} = W_t$ in (6). Thus, in equilibrium the following condition must be satisfied:

$$\text{(7)}\qquad e[1, u_t]^{-1} e_W [1, u_t] = 1 .$$

This condition determines the economy's equilibrium unemployment rate (i.e., the natural rate of unemployment). If u^* represents the value of u that solves (7), the long-run AS curve can be expressed as

$$\text{(8)}\qquad Y = A^{\frac{\phi}{1-\beta}} [N(1-u^*)]^{\frac{\phi}{1-\beta}} \left(\frac{\gamma}{\beta(\gamma-1)}\right)^{-\frac{\beta}{1-\beta}} K^{\frac{1-\phi-\beta}{1-\beta}} e[1, u^*]^{\frac{\phi}{1-\beta}} z^{-\frac{\beta}{1-\beta}} .$$

An equation for the short-run AS curve can be derived by substituting the labor demand equation into the production function. However, equation (4) is not a closed-form solution for labor demand, since u_t (which depends on L_t) is a variable on the right-hand side. However, a closed-form solution for labor demand can be obtained by expressing variables as deviations from steady-state values. Differentiating (4) and dividing by the original equation yields the following relationship:

$$
\begin{aligned}
\hat{L}_t = {} & \frac{\gamma-\beta(\gamma-1)}{(\phi+\beta)(\gamma-1)-\gamma}\hat{W}_t - \frac{1}{(\phi+\beta)(\gamma-1)-\gamma}\hat{\theta}_t - \frac{\phi(\gamma-1)}{(\phi+\beta)(\gamma-1)-\gamma)}\hat{A}_t \\
& - \frac{(1-\phi-\beta)(\gamma-1)}{(\phi+\beta)(\gamma-1)-\gamma}\hat{K}_t - \frac{\phi(\gamma-1)}{(\phi+\beta)(\gamma-1)-\gamma}e^{-1}[e_W\hat{W}_t - e_W\hat{\overline{W}}_t^{\,e} + e_u du_t] \\
& - \frac{\gamma-\beta(\gamma-1)}{(\phi+\beta)(\gamma-1)-\gamma)}\hat{\overline{P}}_t + \frac{\beta(\gamma-1)}{(\phi+\beta)(\gamma-1)-\gamma}\hat{z}_t,
\end{aligned}
\tag{9}
$$

where variables with “^’s” over them represent percentage deviations. This equation can be viewed as representing deviations (the absolute deviation in *u* and the percentage deviations in the other variables) from their steady-state values. If small deviations of these variables from their steady-state values are considered, the coefficients on these variables can be treated as constants, with these constants determined by steady-state values of e, e_W, and e_u.

The value of du_t in (9) can be expressed as a function of $\hat{L}_t$. The fourth assumption implies that

$$u_t = \frac{N-L_t}{N}.$$

Letting $s_L = L^*/N$ (where L^* is the equilibrium value of L), du_t can be approximated by

$$du_t = \frac{-dL_t}{N} = \frac{-dL_t}{(L^*/s_L)} \approx -s_L\hat{L}_t.$$

Substituting $du_t = -s_L\hat{L}_t$ and $e^{-1}e_W = 1$ (from (7)) into (9) yields the following equation for $\hat{L}_t$:

$$
\begin{aligned}
\hat{L}_t &= \frac{(\phi+\beta)(\gamma-1)-\gamma}{\eta}\hat{W}_t + \frac{1}{\eta}\hat{\theta}_t + \frac{\phi(\gamma-1)}{\eta}\hat{A}_t + \frac{(1-\phi-\beta)(\gamma-1)}{\eta}\hat{K}_t \\
&\quad - \frac{\phi(\gamma-1)}{\eta}\hat{\overline{W}}{}_t^e + \frac{\gamma-\beta(\gamma-1)}{\eta}\hat{\overline{P}}_t - \frac{\beta(\gamma-1)}{\eta}\hat{z}_t,
\end{aligned} \tag{10}
$$

where $\eta = \gamma - (\gamma-1)[\phi + \beta - \phi e^{-1} e_u s_L]$.

It will be assumed that the overall effect of a rise in employment is to increase output (i.e., the direct effect of employment on output outweighs the fact that a rise in employment reduces unemployment, which decreases workers' efficiency), which implies that $1 - e^{-1} e_u s_L > 0$. Given this assumption, η>0.

Differentiating the production function (3) and dividing by the original equation yields

$$
\hat{Y}_t = \frac{\phi}{1-\beta}\hat{A}_t + \frac{\phi}{1-\beta}\hat{L}_t + \frac{1-\phi-\beta}{1-\beta}\hat{K}_t + \frac{\phi}{1-\beta}e^{-1}[e_W\hat{W}_t - e_W\hat{\overline{W}}{}_t^e + e_u du_t] - \frac{\beta}{1-\beta}\hat{z}_t. \tag{11}
$$

This equation expresses deviations in output from its steady-state value as a function of deviations in other variables. Appendix A demonstrates that substituting equation (10) and the relationships $\theta_t = Y_t$, $du_t = -s_L\hat{L}_t$, and $e^{-1}e_W = 1$ into (11) yields the following equation for the short-run AS curve:

$$
\begin{aligned}
\hat{Y}_t &= \frac{\phi}{1-\beta-\phi(1-e^{-1}e_u s_L)}\hat{A}_t + \frac{1-\phi-\beta}{1-\beta-\phi(1-e^{-1}e_u s_L)}\hat{K}_t + \frac{\phi e^{-1}e_u s_L}{1-\beta-\phi(1-e^{-1}e_u s_L)}\hat{W}_t \\
&\quad - \frac{\phi}{1-\beta-\phi(1-e^{-1}e_u s_L)}\hat{\overline{W}}{}_t^e - \frac{\beta}{1-\beta-\phi(1-e^{-1}e_u s_L)}\hat{z}_t + \frac{\phi(1-e^{-1}e_u s_L)}{1-\beta-\phi(1-e^{-1}e_u s_L)}\hat{\overline{P}}_t.
\end{aligned} \tag{12}
$$

Given the assumption that $1-e^{-1}e_u s_L > 0$, the AS curve is upward sloping since an increase in the price level is associated with a rise in output. In this equation, the coefficient on $\hat{\overline{P}}_t$ is the slope of the AS curve (holding current wages constant), and the coefficients on $\hat{A}_t$ and $\hat{z}_t$ show how the AS curve shifts in response to supply shocks.

An equivalent specification for the AS curve is

$$
\begin{aligned}
\hat{Y}_t = {} & \frac{\phi}{1-\beta-\phi(1-e^{-1}e_u s_L)}\hat{A}_t + \frac{1-\phi-\beta}{1-\beta-\phi(1-e^{-1}e_u s_L)}\hat{K}_t - \frac{\beta}{1-\beta-\phi(1-e^{-1}e_u s_L)}\hat{z}_t \\
& + \frac{\phi}{1-\beta-\phi(1-e^{-1}e_u s_L)}(\hat{W}_t - \hat{\overline{W}}_t^{e}) - \frac{\phi(1-e^{-1}e_u s_L)}{1-\beta-\phi(1-e^{-1}e_u s_L)}(\hat{W}_t - \hat{\overline{P}}_t).
\end{aligned} \tag{13}
$$

In (13), output depends positively on the difference between the actual and expected nominal wage and depends negatively on the real wage, implying that the aggregate supply relationship can be explained both by theories emphasizing misperceptions and by theories emphasizing the role of real wages on employment.[12]

IV. The Dynamics of Price and Output Adjustment

The previous section derives an equation for the AS curve from microeconomic principles, but it does not predict the paths followed by output and prices in response to shocks. However, expressions for these paths can be derived if functional forms are specified for wage expectations ($\overline{W}_t^{e}$) and for demand (θ). In this section specific assumptions are made about these variables, enabling the dynamics of the economy's adjustment to demand and supply shocks to be analyzed. In modeling wage expectations, it is assumed that expectations are a weighted average of rational and adaptive expectations, as in Campbell (2008). In particular, it is assumed that

(14) $\hat{\bar{W}}_t^e = \omega \hat{W}_t + (1-\omega)\hat{W}_{t-1}$,

where ω represents the degree to which expectations are rational. Campbell (2008) discusses previous studies that find that expectations are neither completely rational nor complete adaptive. Because the AD-AS framework is generally expressed in terms of levels, the adaptive component of workers' expectations is lagged average wages. The end of this section discusses the implications of assuming that the adaptive expectations component is a function of lagged wage changes.

Demand is assumed to be described by an IS-LM specification. If the IS and LM curves are linearized around their steady-states, they can be expressed as

IS: $\hat{Y}_t = a_1 \hat{E}_t - a_2 \hat{i}_t$, and

LM: $\hat{Y}_t = b_1(\hat{M}_t - \hat{\bar{P}}_t) + b_2 \hat{i}_t$,

where M is nominal demand, E represents autonomous real expenditures, and i represents the interest rate. Eliminating the interest rate yields

$$\hat{Y}_t = \frac{b_1 a_2}{a_2 + b_2}\hat{M}_t - \frac{b_1 a_2}{a_2 + b_2}\hat{\bar{P}}_t + \frac{b_2 a_1}{a_2 + b_2}\hat{E}_t .$$

Accordingly, the price level can be expressed as

(15) $\hat{\bar{P}}_t = \hat{M}_t - \kappa \hat{Y}_t + \psi E_t$,

where

$$\kappa = \frac{a_2 + b_2}{b_1 a_2}, \qquad \psi = \frac{b_2 a_1}{b_1 a_2}.$$

It will be assumed that $\kappa \geq 1$, implying that a 1% rise in the money supply raises nominal GDP by no more than 1% in the short run. In the special case in which demand is determined from a constant velocity specification, (15) can be expressed as $\hat{\hat{P}}_t = \hat{M}_t - \hat{Y}_t$, implying that κ=1 and ψ=0.

Given these assumptions about wage expectations and demand, Appendix B derives the following equation for wages:

(16)
$$\hat{W}_t = \frac{\phi(\kappa - 1)}{\lambda + \beta - 1} \sum_{j=0}^{t-1} \mu^j \hat{A}_{t-j} + \frac{\kappa - 1}{\lambda + \beta - 1} \sum_{j=0}^{t-1} \mu^j \hat{K}_{t-j} - \frac{1 - \beta}{\lambda + \beta - 1} \sum_{j=0}^{t-1} \mu^j \hat{M}_{t-j}$$
$$- \frac{\psi(1 - \beta)}{\lambda + \beta - 1} \sum_{j=0}^{t-1} \mu^j \hat{E}_{t-j} - \frac{\beta(\kappa - 1)}{\lambda + \beta - 1} \sum_{j=0}^{t-1} \mu^j \hat{z}_{t-j},$$

where

$$\lambda = [1 - \beta + (\kappa - 1)\phi(1 - e^{-1} e_u s_L)] \frac{e_{WW}}{e_u - e_{Wu}} s_L^{-1} - \phi(\kappa - 1) < 0,$$

and

$$\mu = \frac{(1 - \omega)\lambda}{(1 - \omega)\lambda + \beta - 1} < 1.$$

We first consider shocks to demand. Suppose that there is a one-time permanent shock to nominal demand such that $\hat{M}_t = 0$ for $t \leq 0$ and $\hat{M}_t = \Delta\hat{M}$ for $t \geq 1$. The path of wages over time is

(17)
$$\hat{W}_t = (1 - \mu^t)\Delta\hat{M}.$$

In addition, substituting $\hat{W}_t^e = \omega \hat{W}_t + (1-\omega)\hat{W}_{t-1} = \omega(1-\mu^t)\Delta\hat{M} + (1-\omega)(1-\mu^{t-1})\Delta\hat{M}$ $= [1-(1+\omega\mu-\omega)\mu^{t-1}]\Delta\hat{M}$ into (B1) yields the following expression for output:

$$(18) \qquad \hat{Y}_t = \frac{\phi e^{-1} e_u s_L (1-\mu^t)\Delta\hat{M} - \phi[1-(1+\omega\mu-\omega)\mu^{t-1}]\Delta\hat{M} + \phi(1-e^{-1}e_u s_L)\Delta\hat{M}}{1-\beta+(\kappa-1)\phi(1-e^{-1}e_u s_L)}$$

$$= \frac{\phi[(1-\omega)(1-\mu)+\mu(1-e^{-1}e_u s_L)]}{1-\beta+(\kappa-1)\phi(1-e^{-1}e_u s_L)}\mu^{t-1}\Delta\hat{M}\ .$$

If (18) is substituted into (15), the price level can be expressed as,

$$(19) \qquad \hat{\hat{P}}_t = \Delta M - \kappa\frac{\phi[(1-\omega)(1-\mu)+\mu(1-e^{-1}e_u s_L)]}{1-\beta+(\kappa-1)\phi(1-e^{-1}e_u s_L)}\mu^{t-1}\Delta\hat{M}$$

$$= \left[1-\kappa\frac{\phi[(1-\omega)(1-\mu)+\mu(1-e^{-1}e_u s_L)]}{1-\beta+(\kappa-1)\phi(1-e^{-1}e_u s_L)}\mu^{t-1}\right]\Delta\hat{M}\ .$$

Given the assumption that $e^{-1}e_u s_L$ <1, this demand shock raises both output and prices in the short run. However, $\hat{Y}_t \to 0$ and $\hat{\hat{P}}_t \to \Delta\hat{M}$ as $t\to\infty$. Thus, in the long run, prices rise by the same percentage amount as the shock, and output eventually returns to its initial level.

The real wage is described by the equation,

$$(20) \qquad \hat{W}_t - \hat{\hat{P}}_t = (1-\mu^t)\Delta\hat{M} - \left[1-\kappa\frac{\phi[(1-\omega)(1-\mu)+\mu(1-e^{-1}e_u s_L)]}{1-\beta+(\kappa-1)\phi(1-e^{-1}e_u s_L)}\mu^{t-1}\right]\Delta\hat{M}$$

$$= \left[\kappa\frac{\phi[(1-\omega)(1-\mu)+\mu(1-e^{-1}e_u s_L)]}{1-\beta+(\kappa-1)\phi(1-e^{-1}e_u s_L)} - \mu\right]\mu^{t-1}\Delta\hat{M}$$

$$= \left[\frac{\kappa\phi(1-\omega)(1-\mu)-(1-\beta)\mu+\mu\phi(1-e^{-1}e_u s_L)}{1-\beta+(\kappa-1)\phi(1-e^{-1}e_u s_L)}\right]\mu^{t-1}\Delta\hat{M}$$

$$= (1-\omega)\left[\frac{-\kappa\phi(1-\beta)-(1-\beta)\lambda+\lambda\phi(1-e^{-1}e_u s_L)}{[(1-\omega)\lambda-(1-\beta)][1-\beta+(\kappa-1)\phi(1-e^{-1}e_u s_L)]}\right]\mu^{t-1}\Delta\hat{M} \ .$$

Depending on the model's parameters, the term in the large square brackets can be positive, zero, or negative, which means that real wages can be procyclical, acyclical, or countercyclical.[13] The prediction that real wages can be either procyclical or countercyclical is consistent with evidence that real wages appear to be procyclical in some periods and countercyclical in other periods. For example, Huang, Liu, and Phaneuf (2004) review previous studies that find that real wages were countercyclical in the interwar period but have been procyclical since the end of World War II.

As previously discussed, a criticism of models in which wages are rigid but prices are flexible is that these models predict countercyclical real wages, while most empirical evidence suggest that they have been procyclical in recent decades. In the present study the source of nominal stickiness is the slow adjustment of nominal wages. Nominal wages adjust slowly because of the assumptions of efficiency wages and partly adaptive expectations. On the other hand, there is no impediment to price adjustment, other than the slow adjustment of nominal wages. Given nominal wages, firms set prices at their optimal level in each period. Thus, it is demonstrated that real wages can be procyclical in a model in which prices are flexible but nominal wages are sticky.

Shocks to real demand (E) can be analyzed in a similar manner as shocks to nominal demand. From equations (14), (B1), and (15), shocks to real demand raise wages, output, and prices by ψ times the amount that nominal demand shocks raise these variables.

We now consider shocks to technology (A) and shocks to input prices (z). These shocks are likely to also affect autonomous expenditures (E). Technological improvements are likely to increase investment and permanent income, leading to an increase in *E*. On the other hand, increases in oil prices may reduce the consumption of domestic goods by reducing permanent income and by raising consumption of foreign imports at the expense of domestic goods. Input price increases may also reduce investment if investment and the input are complements.

Suppose there is a one-time permanent shock to technology of the amount $\Delta\hat{A}$. Suppose also that this shock to technology affects autonomous expenditures by the amount ν, so that $\Delta\hat{E} = \nu\Delta\hat{A}$. Then from (14) the path of wages is

$$(21) \qquad \hat{W}_t = \frac{\phi(1-\kappa)}{1-\beta}(1-\mu^t)\Delta\hat{A} + \psi\nu(1-\mu^t)\Delta\hat{A} = \left[\frac{\phi(1-\kappa)}{1-\beta} + \psi\nu\right](1-\mu^t)\Delta\hat{A}\,.$$

Substituting this expression for $\hat{W}_t$ and the relationship $\hat{W}_t^e = \omega\hat{W}_t + (1-\omega)\hat{W}_{t-1}$ into (B1) yields the following equation for output:

$$(22) \qquad \hat{Y}_t = \frac{\begin{array}{l}\phi\Delta\hat{A} + \phi e^{-1}e_u s_L\left(\frac{\phi(1-\kappa)}{1-\beta} + \psi\nu\right)(1-\mu^t)\Delta\hat{A} - \phi\left[\omega\left(\frac{\phi(1-\kappa)}{1-\beta} + \psi\nu\right)(1-\mu^t)\Delta\hat{A}\right. \\ \left. + (1-\omega)\left(\frac{\phi(1-\kappa)}{1-\beta} + \psi\nu\right)(1-\mu^{t-1})\Delta\hat{A}\right] + \nu\psi\phi(1-e^{-1}e_u s_L)\Delta\hat{A}\end{array}}{1-\beta+(\kappa-1)\phi(1-e^{-1}e_u s_L)}$$

$$= \left[\frac{\phi}{1-\beta} + \frac{\phi[(1-\omega)(1-\mu) + \mu(1-e^{-1}e_u s_L)]}{1-\beta-(1-\kappa)\phi(1-e^{-1}e_u s_L)}\left(\frac{\phi(1-\kappa)}{1-\beta} + \psi\nu\right)\mu^{t-1}\right]\Delta\hat{A}\,.$$

The price level and real wage can be expressed as

$$(23) \qquad \hat{\hat{P}}_t = \hat{M}_t - \kappa\hat{Y}_t + \psi\hat{E}_t$$

$$= \left[\nu\psi - \frac{\kappa\phi}{1-\beta} - \frac{\kappa\phi[(1-\omega)(1-\mu)+\mu(1-e^{-1}e_u s_L)]}{1-\beta-(1-\kappa)\phi(1-e^{-1}e_u s_L)} \left(\frac{\phi(1-\kappa)}{1-\beta} + \psi\nu \right) \mu^{t-1} \right] \Delta\hat{A} \,,$$

and

$$\hat{W}_t - \hat{\hat{P}}_t = \left[\frac{\phi(1-\kappa)}{1-\beta} + \psi\nu \right] (1-\mu^t)\Delta\hat{A}$$

$$(24) \qquad - \left[\nu\psi - \frac{\kappa\phi}{1-\beta} - \frac{\kappa\phi[(1-\omega)(1-\mu)+\mu(1-e^{-1}e_u s_L)]}{1-\beta-(1-\kappa)\phi(1-e^{-1}e_u s_L)} \left(\frac{\phi(1-\kappa)}{1-\beta} + \psi\nu \right) \mu^{t-1} \right] \Delta\hat{A}$$

$$= \left[\frac{\phi}{1-\beta} + \left(\frac{\phi(1-\kappa)}{1-\beta} + \psi\nu \right) \left(\frac{\kappa\phi[(1-\omega)(1-\mu)+\mu(1-e^{-1}e_u s_L)]}{1-\beta-(1-\kappa)\phi(1-e^{-1}e_u s_L)} - \mu \right) \mu^{t-1} \right] \Delta\hat{A} \,.$$

The long-run effect of this technology shock is to raise output by $\phi/(1-\beta)$. Whether output rises by more or less than this amount in the short run depends on the value of $[\phi(1-\kappa)/(1-\beta)] + \psi\nu$. With reasonable parameter values, the overall effect will be to cause output to temporarily rise above potential output. Cover, Enders, and Hueng (2006) estimate that a 1% supply shock shifts the AD curve 0.64% to the right, implying that ν=0.64. Mankiw and Summers (1986) estimate that the quantity elasticity of money demand and the interest elasticity of money demand approximately equal 1.0 and -0.1, respectively. These values imply that b_1=1 and b_2=0.1. They also report estimates from Friedman (1978) that the interest elasticity of spending is 0.17. In addition, Ramey (2008) estimates that the multiplier is 1.4. Friedman's and Ramey's estimates imply that a_1=1.4 and a_2=0.24. Taken together, these estimates yield κ=1.42 and ψ=0.59. If it is assumed that ϕ=0.7 and β=0.02 (implying that a doubling of input prices reduces output by 2%), then $[\phi(1-\kappa)/(1-\beta)] + \psi\nu$ =0.078, which means that a positive technology shock raises short-run output more than it raises long-run output and that unemployment initially falls below the natural rate.

The long-run response of prices to this technology shock depends on the value of $\nu\psi-(\kappa\phi)/(1-\beta)$. With the above parameter values, this expression equals -0.64, which means that positive technology shocks reduce the price level. In addition, the coefficient on μ^{t-1} is negative, implying that the price level falls more in the short run than in the long run.

In the long run, this technology shock raises real wages by $[\phi/(1-\beta)]\Delta\hat{A}$. Substituting this value for $\hat{W}_t-\hat{\bar{P}}_t$ into (13) shows that a technology shock of $\Delta\hat{A}$ results in an eventual rise in output of $[\phi/(1-\beta)]\Delta\hat{A}$.

In the special case in which demand is described by a constant velocity specification (i.e., $\hat{M}_t=\hat{Y}_t-\hat{\bar{P}}_t$), κ=1 and ψ=0. Under these conditions, technology shocks do not affect wages, since nominal demand is the only exogenous variable that affects wages in equation (14) if κ=1 and ψ=0. Also, the assumption that $\hat{\bar{W}}_t^e=\omega\hat{W}_t+(1-\omega)\hat{W}_{t-1}$ means that supply shocks do not affect expected wages either. Equation (B3) shows that employment (and thus unemployment) is not affected by technology shocks in this case. Under these conditions, technology shocks shift the short-run and long-run AS curves by the same amount and do not affect the AD curve. Accordingly, output rises to its new potential value following a technology shock and remains there.

The effects of input price shocks are proportional to the effects to productivity shocks, but in the opposite direction. Under reasonable parameter values, adverse input price shocks cause output to initially fall below the new (and lower) value of potential GDP and unemployment to initially rise above the natural rate, before returning to the natural rate. In addition, these shocks cause the price level to rise, with the price level rising more in the short run than in the long run. These predictions appear to be consistent with empirical evidence. Following large increases in oil prices in 1973-74 and 1979-80, both unemployment and inflation initially rose and then decreased.

In this section it is assumed that workers' expectations of average wages are a weighted average of rational and adaptive expectations. The preceding analysis considers a specification in which the adaptive component of workers' expectations is the lagged average wage. However, in an economy that has historically experienced wage growth, it may be more reasonable to assume that the adaptive expectations component equals last period's wage adjusted by past wage inflation. In this case, workers' expectations of average wages can be expressed as

$$\overline{W}_t^{\,e} = \overline{W}_t^{\,\omega}\left(\overline{W}_{t-1}\frac{\overline{W}_{t-1}}{\overline{W}_{t-2}}\right)^{1-\omega}.$$

With this specification for workers' expectations, the wage equation is a second-order difference equation. In this case it can be demonstrated that disinflationary aggregate demand shocks temporarily reduce output and that wage and price inflation exhibit inertia.[14]

V. Inflation Variability and the Slope of the AS Curve

Lucas (1973) finds that nominal demand shocks have smaller effects on real output (i.e., the AS curve is steeper) in countries with higher inflation variability. His explanation for the negative relationship between the slope of the AS curve and the variability of inflation is that firms in countries with highly variable inflation tend to view changes in their own price as more reflective of overall price changes and less reflective of relative price changes, resulting in smaller adjustments in output.

The efficiency wage – imperfect information model provides an alternative interpretation of this finding. Campbell (2009b) derives a model of workers' expectations of average wages from utility-maximizing behavior. It is demonstrated that their expectations of average wages can be expressed as a weighted average of rational and adaptive expectations, with the weights depending on the cost of obtaining information about current average wages and on the historical accuracy of adaptive expectations. In particular, the degree to which expectations are rational (represented by a higher value of ω in the present study) depends positively on the forecast error of adaptive expectations. It is likely that adaptive expectations will predict wages less accurately in countries with higher inflation variability, resulting in a higher value of ω in these countries. As demonstrated below, the degree to which nominal demand shocks affect real output depends negatively on ω.

The coefficient on ΔM in the equation for $\hat{Y}_t$ (equation 16) can be expressed as $C\mu^{t-1}$, where

$$C = \frac{\phi[(1-\omega)(1-\mu) + \mu(1-e^{-1}e_u s_L)]}{1-\beta+(\kappa-1)\phi(1-e^{-1}e_u s_L)}.$$

The effect of ω on μ is

$$\frac{d\mu}{d\omega} = \frac{(1-\beta)\lambda}{[(1-\omega)\lambda-(1-\beta)]^2} < 0,$$

and the effect of ω on C is

$$\frac{dC}{d\omega} = \frac{\phi\left[-(1-\mu)+\omega\frac{d\mu}{d\omega} - e^{-1}e_u s_L \frac{d\mu}{d\omega}\right]}{1-\beta+(\kappa-1)\phi(1-e^{-1}e_u s_L)}$$

$$= \frac{\phi\left[\dfrac{1-\beta}{(1-\omega)\lambda-(1-\beta)} + \dfrac{(\omega-e^{-1}e_u s_L)(1-\beta)\lambda}{[(1-\omega)\lambda-(1-\beta)]^2}\right]}{1-\beta+(\kappa-1)\phi(1-e^{-1}e_u s_L)}$$

$$= \frac{\phi(1-\beta)[(1-e^{-1}e_u s_L)\lambda-(1-\beta)]}{[1-\beta+(\kappa-1)\phi(1-e^{-1}e_u s_L)][(1-\omega)\lambda-(1-\beta)]^2} < 0\,.$$

Since μ and C depend negatively on ω, a rise in ω lowers the degree to which nominal demand shocks affect real output at any value of t. As nominal demand shocks have a smaller effect on output, they have a greater effect on prices (from (15)), which means that a rise in ω is associated with a steeper aggregate supply curve.

VI. A Generalized Version of the Model

In Section III it is assumed that workers' efficiency depends on the ratio between their wages and their expectations of average wages. More generally it could be assumed that their efficiency depends on the ratio between their wage and their reference wage (W_t^R), so that

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

The reference wage can be viewed as any variable with which workers compare their current wage 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.) 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.[15] Determinants of a worker's perceived fair wage may include the worker's past wage or past wage increases. For example, if a worker has received 4% wage increases for the past several years, he or she may view the fair wage as last period's wage plus a 4% increase. Suppose that a worker's reference wage is the maximum of last period's wage, last period's wage adjusted by recent wage increases, and the worker's expectations of average wages. Then the reference wage can be expressed as

$$W_t^R = \text{Max}[W_{t-1}, W_{t-1}(1+\%\Delta W_{t-1}), \overline{W}_t^{\,e}].$$

Such a model can explain why wages generally increase in recessions, even if workers have rational expectations about average wages. Since efficiency may depend on a worker's wage relative to what he or she would earn if given the same wage increase as in recent years, firms may have an incentive to continue to grant wage increases when unemployment is high. In addition, 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. Thus, this model can explain why nominal wages may exhibit downward rigidity, and hence why negative aggregate demand shocks may cause economic downturns.

VII. Conclusion

This study develops an efficiency wage – imperfect information model of the aggregate supply curve from a model in which firms maximize profits and output is determined from a production function with labor as an input. The profit-maximization problem of firms yields a reduced-form equation for aggregate supply as a function of technology, input prices, capital, wages, expected wages, and the price level. Under reasonable assumptions, the coefficient on the price level is positive, so that the aggregate supply curve is upward sloping.

If specific assumptions are made about workers' expectations of average wages and about aggregate demand, the model predicts how the aggregate demand and supply curves shift and how output and prices adjust in response to demand shocks and supply shocks. In response to aggregate demand shocks, wages and prices adjust slowly to their new equilibrium values, and output initially rises. However, output approaches potential GDP as wages and prices adjust to their new steady-state values. When the economy experiences a technology shock or input price shock, the short-run and long-run AS curves both shift. In addition, supply shocks may shift the AD curve through their effect on real expenditures. With reasonable parameters, positive supply shocks cause output to initially rise above the new (and higher) value of potential GDP, so that unemployment initially falls below the natural rate. In addition, positive supply shocks cause the price level to decrease, with the short-run decrease exceeding the long-run decrease. Adverse supply shocks have the opposite effect on output and prices.

The model also provides another explanation for Lucas' (1973) finding that the aggregate supply curve is steeper in countries with greater inflation variability. In counties with greater inflation variability, workers have a greater incentive to acquire information about average wages, so that their expectations of average wages are likely to be more rational and less adaptive. The model predicts that the aggregate supply curve steepens as wage expectations become more rational.

The model can be generalized to make efficiency a function of the ratio between a worker's wage and his or her reference wage, where the reference wage may depend on workers' perception of their fair wage, as well as on their expectations of average wages. This generalized model may explain why wages often continue to rise in recessionary periods and why nominal wages may exhibit downwards rigidity.

Appendix A

<u>Derivation of equation (2):</u>

$$
\begin{aligned}
\Pi_t =\ & \theta_t^{1/\gamma} A_t^{\frac{\phi(\gamma-1)}{\gamma}} L_t^{\frac{\phi(\gamma-1)}{\gamma}} \left(\frac{\gamma}{\beta(\gamma-1)} \right)^{\frac{\beta(\gamma-1)}{\beta(\gamma-1)-\gamma}} \theta_t^{-\frac{\beta(\gamma-1)}{\gamma[\beta(\gamma-1)-\gamma]}} A_t^{-\frac{\phi\beta(\gamma-1)^2}{\gamma[\beta(\gamma-1)-\gamma]}} L_t^{-\frac{\phi\beta(\gamma-1)^2}{\gamma[\beta(\gamma-1)-\gamma]}} K_t^{-\frac{\beta(1-\phi-\beta)(\gamma-1)^2}{\gamma[\beta(\gamma-1)-\gamma]}} \\
& \times e[\bullet]^{-\frac{\phi\beta(\gamma-1)^2}{\gamma[\beta(\gamma-1)-\gamma]}} z_t^{\frac{\beta(\gamma-1)}{\beta(\gamma-1)-\gamma}} K_t^{\frac{(1-\phi-\beta)(\gamma-1)}{\gamma}} e[W_t / \overline{W}_t^{e}, u_t]^{\frac{\phi(\gamma-1)}{\gamma}} \overline{P}_t \\
& - W_t L_t - (\delta + i) K_t \\
& - z_t \overline{P}_t \left(\frac{\gamma}{\beta(\gamma-1)} \right)^{\frac{\gamma}{\beta(\gamma-1)-\gamma}} \theta_t^{-\frac{1}{\beta(\gamma-1)-\gamma}} A_t^{-\frac{\phi(\gamma-1)}{\beta(\gamma-1)-\gamma}} L_t^{-\frac{\phi(\gamma-1)}{\beta(\gamma-1)-\gamma}} K_t^{-\frac{(1-\phi)(\gamma-1)}{\beta(\gamma-1)-\gamma}} e[\bullet]^{-\frac{\phi(\gamma-1)}{\beta(\gamma-1)-\gamma}} z_t^{\frac{\gamma}{\beta(\gamma-1)-\gamma}}
\end{aligned}
$$

$$
\begin{aligned}
\Pi_t =\ & \theta_t^{-\frac{1}{\beta(\gamma-1)-\gamma}} A_t^{-\frac{\phi(\gamma-1)}{\beta(\gamma-1)-\gamma}} L_t^{-\frac{\phi(\gamma-1)}{\beta(\gamma-1)-\gamma}} \left(\frac{\gamma}{\beta(\gamma-1)} \right)^{\frac{\beta(\gamma-1)}{\beta(\gamma-1)-\gamma}} K_t^{-\frac{(1-\phi-\beta)(\gamma-1)}{\beta(\gamma-1)-\gamma}} e[\bullet]^{-\frac{\phi(\gamma-1)}{\beta(\gamma-1)-\gamma}} \overline{P}_t z_t^{\frac{\beta(\gamma-1)}{\beta(\gamma-1)-\gamma}} \\
& - W_t L_t - (\delta + i) K_t \\
& - \left(\frac{\gamma}{\beta(\gamma-1)} \right)^{\frac{\gamma}{\beta(\gamma-1)-\gamma}} \theta_t^{-\frac{1}{\beta(\gamma-1)-\gamma}} A_t^{-\frac{\phi(\gamma-1)}{\beta(\gamma-1)-\gamma}} L_t^{-\frac{\phi(\gamma-1)}{\beta(\gamma-1)-\gamma}} K_t^{-\frac{(1-\phi-\beta)(\gamma-1)}{\beta(\gamma-1)-\gamma}} e[\bullet]^{-\frac{\phi(\gamma-1)}{\beta(\gamma-1)-\gamma}} \overline{P}_t z_t^{\frac{\beta(\gamma-1)}{\beta(\gamma-1)-\gamma}}
\end{aligned}
$$

$$
\begin{aligned}
\Pi_t =\ & \theta_t^{\frac{1}{\gamma-\beta(\gamma-1)}} A_t^{\frac{\phi(\gamma-1)}{\gamma-\beta(\gamma-1)}} L_t^{\frac{\phi(\gamma-1)}{\gamma-\beta(\gamma-1)}} K_t^{\frac{(1-\phi-\beta)(\gamma-1)}{\gamma-\beta(\gamma-1)}} e[\bullet]^{\frac{\phi(\gamma-1)}{\gamma-\beta(\gamma-1)}} \overline{P}_t z_t^{-\frac{\beta(\gamma-1)}{\gamma-\beta(\gamma-1)}} \\
& \times \left(\frac{\gamma}{\beta(\gamma-1)} \right)^{-\frac{\gamma}{\gamma-\beta(\gamma-1)}} \frac{\gamma-\beta(\gamma-1)}{\beta(\gamma-1)} \\
& - W_t L_t - (\delta + i) K_t
\end{aligned}
$$

<u>Derivation of equation (12):</u>

$$
\begin{aligned}
\hat{Y}_t =\ & \frac{\phi}{1-\beta}\hat{A}_t + \frac{1-\phi-\beta}{1-\beta}\hat{K}_t + \frac{\phi}{1-\beta}\hat{W}_t - \frac{\phi}{1-\beta}\hat{\overline{W}}_t^{e} - \frac{\beta}{1-\beta}\hat{Z}_t + \frac{\beta}{1-\beta}\hat{\overline{P}}_t \\
& + \frac{\phi}{1-\beta}[1 - e^{-1} e_u s_L] \left[\frac{(\phi+\beta)(\gamma-1)-\gamma}{\eta}\hat{W}_t + \frac{1}{\eta}\hat{\theta}_t + \frac{\phi(\gamma-1)}{\eta}\hat{A}_t \right. \\
& \left. + \frac{(1-\phi-\beta)(\gamma-1)}{\eta}\hat{K}_t - \frac{\phi(\gamma-1)}{\eta}\hat{\overline{W}}_t^{e} + \frac{\gamma-\beta(\gamma-1)}{\eta}\hat{\overline{P}}_t - \frac{\beta(\gamma-1)}{\eta}\hat{z}_t \right]
\end{aligned}
$$

Using the relationship $\theta_t = Y_t$ yields

$$\hat{Y}_t\left[1-\frac{\phi(1-e^{-1}e_u s_L)}{1-\beta}\frac{1}{\eta}\right]=\frac{\phi}{1-\beta}\left[1+\frac{\phi(\gamma-1)(1-e^{-1}e_u s_L)}{\eta}\right]\hat{A}_t$$
$$+\left[\frac{1-\phi-\beta}{1-\beta}+\frac{\phi(1-e^{-1}e_u s_L)}{1-\beta}\frac{(1-\phi-\beta)(\gamma-1)}{\eta}\right]\hat{K}_t$$
$$+\left[\frac{\phi}{1-\beta}+\frac{\phi(1-e^{-1}e_u s_L)}{1-\beta}\frac{(\phi+\beta)(\gamma-1)-\gamma}{\eta}\right]\hat{W}_t-\left[\frac{\phi}{1-\beta}+\frac{\phi(1-e^{-1}e_u s_L)}{1-\beta}\frac{\phi(\gamma-1)}{\eta}\right]\hat{\overline{W}}_t^{e}$$
$$-\left[\frac{\beta}{1-\beta}+\frac{\phi(1-e^{-1}e_u s_L)}{1-\beta}\frac{\beta(\gamma-1)}{\eta}\right]\hat{z}_t+\left[\frac{\beta}{1-\beta}+\frac{\phi(1-e^{-1}e_u s_L)}{1-\beta}\frac{\gamma-\beta(\gamma-1)}{\eta}\right]\hat{\overline{P}}_t$$

$$\hat{Y}_t[\eta(1-\beta)-\phi(1-e^{-1}e_u s_L)]=\phi\left[\eta+\phi(\gamma-1)(1-e^{-1}e_u s_L)\right]\hat{A}_t$$
$$+(1-\phi-\beta)\left[\eta+\phi(1-e^{-1}e_u s_L)(\gamma-1)\right]\hat{K}_t$$
$$+\phi\left[\eta+(1-e^{-1}e_u s_L)[(\phi+\beta)(\gamma-1)-\gamma]\right]\hat{W}_t-\phi\left[\eta+(1-e^{-1}e_u s_L)\phi(\gamma-1)\right]\hat{\overline{W}}_t^{e}$$
$$-\beta\left[\eta+\phi(1-e^{-1}e_u s_L)(\gamma-1)\right]\hat{Z}_t+\left[\beta\eta+\phi(1-e^{-1}e_u s_L)[\gamma-\beta(\gamma-1)]\right]\hat{\overline{P}}_t$$

$$\hat{Y}_t=\frac{\phi}{1-\beta-\phi(1-e^{-1}e_u s_L)}\hat{A}_t+\frac{1-\phi-\beta}{1-\beta-\phi(1-e^{-1}e_u s_L)}\hat{K}_t+\frac{\phi e^{-1}e_u s_L}{1-\beta-\phi(1-e^{-1}e_u s_L)}\hat{W}_t$$
$$-\frac{\phi}{1-\beta-\phi(1-e^{-1}e_u s_L)}\hat{\overline{W}}_t^{e}-\frac{\beta}{1-\beta-\phi(1-e^{-1}e_u s_L)}\hat{z}_t+\frac{\phi(1-e^{-1}e_u s_L)}{1-\beta-\phi(1-e^{-1}e_u s_L)}\hat{\overline{P}}_t$$

Appendix B

Equation (12) can be expressed as

$$\hat{Y}_t = \frac{\phi}{1-\beta-\phi(1-e^{-1}e_u s_L)}\hat{A}_t + \frac{1-\phi-\beta}{1-\beta-\phi(1-e^{-1}e_u s_L)}\hat{K}_t + \frac{\phi e^{-1}e_u s_L}{1-\beta-\phi(1-e^{-1}e_u s_L)}\hat{W}_t$$
$$-\frac{\phi}{1-\beta-\phi(1-e^{-1}e_u s_L)}\hat{W}_t^e - \frac{\beta}{1-\beta-\phi(1-e^{-1}e_u s_L)}\hat{z}_t + \frac{\phi(1-e^{-1}e_u s_L)}{1-\beta-\phi(1-e^{-1}e_u s_L)}\hat{M}_t$$
$$-\frac{\kappa\phi(1-e^{-1}e_u s_L)}{1-\beta-\phi(1-e^{-1}e_u s_L)}\hat{Y}_t + \frac{\psi\phi(1-e^{-1}e_u s_L)}{1-\beta-\phi(1-e^{-1}e_u s_L)}\hat{E}_t.$$

The solution for $\hat{Y}_t$ is now

(B1)
$$\hat{Y}_t = \frac{\phi}{1-\beta+(\kappa-1)\phi(1-e^{-1}e_u s_L)}\hat{A}_t + \frac{1-\phi-\beta}{1-\beta+(\kappa-1)\phi(1-e^{-1}e_u s_L)}\hat{K}_t$$
$$+\frac{\phi e^{-1}e_u s_L}{1-\beta+(\kappa-1)\phi(1-e^{-1}e_u s_L)}\hat{W}_t - \frac{\phi}{1-\beta+(\kappa-1)\phi(1-e^{-1}e_u s_L)}\hat{W}_t^e$$
$$-\frac{\beta}{1-\beta+(\kappa-1)\phi(1-e^{-1}e_u s_L)}\hat{z}_t + \frac{\phi(1-e^{-1}e_u s_L)}{1-\beta+(\kappa-1)\phi(1-e^{-1}e_u s_L)}\hat{M}_t$$
$$+\frac{\psi\phi(1-e^{-1}e_u s_L)}{1-\beta+(\kappa-1)\phi(1-e^{-1}e_u s_L)}\hat{E}_t.$$

In addition, the labor demand curve (equation 10) can now be expressed as

(B2)
$$\hat{L}_t = \frac{(\phi+\beta)(\gamma-1)-\gamma}{\eta}\hat{W}_t + \frac{1-\kappa\gamma+\kappa\beta(\gamma-1)}{\eta}\hat{Y}_t + \frac{\phi(\gamma-1)}{\eta}\hat{A}_t$$
$$+\frac{(1-\phi-\beta)(\gamma-1)}{\eta}\hat{K}_t - \frac{\phi(\gamma-1)}{\eta}\hat{W}_t^e + \frac{\gamma-\beta(\gamma-1)}{\eta}\hat{M}_t$$
$$+\frac{\psi[\gamma-\beta(\gamma-1)]}{\eta}\hat{E}_t - \frac{\beta(\gamma-1)}{\eta}\hat{z}_t.$$

Substituting (B1) into (B2) yields

$$\hat{L}_t = \frac{1}{\eta}\Bigg[[(\phi+\beta)(\gamma-1)-\gamma]\hat{W}_t + \phi(\gamma-1)\hat{A}_t + (1-\phi-\beta)(\gamma-1)\hat{K}_t$$

$$-\phi(\gamma-1)\hat{\overline{W}}_t^e + [\gamma-\beta(\gamma-1)]\hat{M}_t - [\gamma-\beta(\gamma-1)]\kappa\hat{Y}_t$$

$$+\psi[\gamma-\beta(\gamma-1)]\hat{E}_t - \beta(\gamma-1)\hat{z}_t$$

$$+\frac{\phi[1-\kappa\gamma+\kappa\beta(\gamma-1)]}{1-\beta+(\kappa-1)\phi(1-e^{-1}e_u s_L)}\hat{A}_t + \frac{(1-\phi-\beta)[1-\kappa\gamma+\kappa\beta(\gamma-1)]}{1-\beta+(\kappa-1)\phi(1-e^{-1}e_u s_L)}\hat{K}_t$$

$$+\frac{\phi e^{-1}e_u s_L[1-\kappa\gamma+\kappa\beta(\gamma-1)]}{1-\beta+(\kappa-1)\phi(1-e^{-1}e_u s_L)}\hat{W}_t - \frac{\phi[1-\kappa\gamma+\kappa\beta(\gamma-1)]}{1-\beta+(\kappa-1)\phi(1-e^{-1}e_u s_L)}\hat{W}_t^e$$

$$-\frac{\beta[1-\kappa\gamma+\kappa\beta(\gamma-1)]}{1-\beta+(\kappa-1)\phi(1-e^{-1}e_u s_L)}\hat{z}_t + \frac{\phi(1-e^{-1}e_u s_L)[1-\kappa\gamma+\kappa\beta(\gamma-1)]}{1-\beta+(\kappa-1)\phi(1-e^{-1}e_u s_L)}\hat{M}_t$$

$$+\frac{\psi\phi(1-e^{-1}e_u s_L)[1-\kappa\gamma+\kappa\beta(\gamma-1)]}{1-\beta+(\kappa-1)\phi(1-e^{-1}e_u s_L)}\hat{E}_t\Bigg]$$

(B3)

$$\hat{L}_t = \frac{\beta+\phi-1-\phi\kappa}{1-\beta+(\kappa-1)\phi(1-e^{-1}e_u s_L)}\hat{W}_t + \frac{\phi(1-\kappa)}{1-\beta+(\kappa-1)\phi(1-e^{-1}e_u s_L)}\hat{A}_t$$

$$-\frac{\phi(1-\kappa)}{1-\beta+(\kappa-1)\phi(1-e^{-1}e_u s_L)}\hat{W}_t^e + \frac{1-\kappa}{1-\beta+(\kappa-1)\phi(1-e^{-1}e_u s_L)}\hat{K}_t$$

$$+\frac{1-\beta}{1-\beta+(\kappa-1)\phi(1-e^{-1}e_u s_L)}\hat{M}_t + \frac{\psi(1-\beta)}{1-\beta+(\kappa-1)\phi(1-e^{-1}e_u s_L)}\hat{E}_t$$

$$-\frac{\beta(1-\kappa)}{1-\beta+(\kappa-1)\phi(1-e^{-1}e_u s_L)}\hat{z}_t.$$

We then totally differentiate (6) and divide by the original equation, yielding

$$0 = \left[1 - e^{-1}e_W\frac{W_t}{\overline{W}_t^e} + \frac{e_{WW}}{e_W}\frac{W_t}{\overline{W}_t^e}\right]\hat{W}_t + \left[-1 + e^{-1}e_W\frac{W_t}{\overline{W}_t^e} - \frac{e_{WW}}{e_W}\frac{W_t}{\overline{W}_t^e}\right]\hat{\overline{W}}_t^e$$

$$+\left[\frac{e_{Wu}}{e_W} - e^{-1}e_u\right]du_t.$$

Since $\overline{W}_t^e = W_t$ in equilibrium and $(W_t / \overline{W}_t^e) = ee_W^{-1}$ (from equation 7), the above equation can be approximated by

(B4) $$\hat{W}_t = \hat{\overline{W}}_t^{\,e} + \frac{e_u - e_{Wu}}{e_{WW}} du_t .$$

If (B3) and the relationships $\hat{\overline{W}}_t^{\,e} = \omega \hat{W}_t + (1-\omega)\hat{W}_{t-1}$ and $du_t = -s_L \hat{L}_t$ are substituted into (B4), the following equation is obtained:

$$\begin{aligned}
\hat{W}_t = \overline{W}_t^{\,e} - s_L \frac{e_u - e_{Wu}}{e_{WW}} \Bigg[& \frac{\beta + \phi - 1 - \phi\kappa}{1-\beta+(\kappa-1)\phi(1-e^{-1}e_u s_L)} \hat{W}_t \\
& + \frac{\phi(1-\kappa)}{1-\beta+(\kappa-1)\phi(1-e^{-1}e_u s_L)} \hat{A}_t - \frac{\phi(1-\kappa)}{1-\beta+(\kappa-1)\phi(1-e^{-1}e_u s_L)} \hat{W}_t^{e} \\
& + \frac{1-\kappa}{1-\beta+(\kappa-1)\phi(1-e^{-1}e_u s_L)} \hat{K}_t + \frac{1-\beta}{1-\beta+(\kappa-1)\phi(1-e^{-1}e_u s_L)} \hat{M}_t \\
& + \frac{\psi(1-\beta)}{1-\beta+(\kappa-1)\phi(1-e^{-1}e_u s_L)} \hat{E}_t - \frac{\beta(1-\kappa)}{1-\beta+(\kappa-1)\phi(1-e^{-1}e_u s_L)} \hat{z}_t \Bigg].
\end{aligned}$$

$$\begin{aligned}
(1-\omega)\hat{W}_t = (1-\omega)\hat{W}_{t-1} - s_L \frac{e_u - e_{Wu}}{e_{WW}} \Bigg[& \frac{\beta - 1 + \phi(1-\kappa)(1-\omega)}{1-\beta+(\kappa-1)\phi(1-e^{-1}e_u s_L)} \hat{W}_t \\
& + \frac{\phi(1-\kappa)}{1-\beta+(\kappa-1)\phi(1-e^{-1}e_u s_L)} \hat{A}_t \\
& - \frac{\phi(1-\kappa)(1-\omega)}{1-\beta+(\kappa-1)\phi(1-e^{-1}e_u s_L)} \hat{W}_{t-1} + \frac{1-\kappa}{1-\beta+(\kappa-1)\phi(1-e^{-1}e_u s_L)} \hat{K}_t \\
& + \frac{1-\beta}{1-\beta+(\kappa-1)\phi(1-e^{-1}e_u s_L)} \hat{M}_t + \frac{\psi(1-\beta)}{1-\beta+(\kappa-1)\phi(1-e^{-1}e_u s_L)} \hat{E}_t \\
& - \frac{\beta(1-\kappa)}{1-\beta+(\kappa-1)\phi(1-e^{-1}e_u s_L)} \hat{z}_t \Bigg].
\end{aligned}$$

$$
\begin{aligned}
&\left[1-\omega+s_L\frac{e_u-e_{Wu}}{e_{WW}}\frac{\beta-1+\phi(1-\kappa)(1-\omega)}{1-\beta+(\kappa-1)\phi(1-e^{-1}e_u s_L)}\right]\hat{W}_t \\
&\qquad-\left[1-\omega+s_L\frac{e_u-e_{Wu}}{e_{WW}}\frac{\phi(1-\kappa)(1-\omega)}{1-\beta+(\kappa-1)\phi(1-e^{-1}e_u s_L)}\right]\hat{W}_{t-1} \\
&=-s_L\frac{e_u-e_{Wu}}{e_{WW}}\frac{\phi(1-\kappa)}{1-\beta+(\kappa-1)\phi(1-e^{-1}e_u s_L)}\hat{A}_t \\
&\qquad-s_L\frac{e_u-e_{Wu}}{e_{WW}}\frac{1-\kappa}{1-\beta+(\kappa-1)\phi(1-e^{-1}e_u s_L)}\hat{K}_t-s_L\frac{e_u-e_{Wu}}{e_{WW}}\frac{1-\beta}{1-\beta+(\kappa-1)\phi(1-e^{-1}e_u s_L)}\hat{M}_t \\
&\qquad-s_L\frac{e_u-e_{Wu}}{e_{WW}}\frac{\psi(1-\beta)}{1-\beta+(\kappa-1)\phi(1-e^{-1}e_u s_L)}\hat{E}_t+s_L\frac{e_u-e_{Wu}}{e_{WW}}\frac{\beta(1-\kappa)}{1-\beta+(\kappa-1)\phi(1-e^{-1}e_u s_L)}\hat{z}_t.
\end{aligned}
$$

$$
\begin{aligned}
&\left[(1-\omega)[1-\beta+(\kappa-1)\phi(1-e^{-1}e_u s_L)]\frac{e_{WW}}{e_u-e_{Wu}}s_L^{-1}+\beta-1+\phi(1-\kappa)(1-\omega)\right]\hat{W}_t \\
&\qquad-\left[(1-\omega)[1-\beta+(\kappa-1)\phi(1-e^{-1}e_u s_L)]\frac{e_{WW}}{e_u-e_{Wu}}s_L^{-1}+\phi(1-\kappa)(1-\omega)\right]\hat{W}_{t-1} \\
&=-\phi(1-\kappa)\hat{A}_t-(1-\kappa)\hat{K}_t-(1-\beta)\hat{M}_t-\psi(1-\beta)\hat{E}_t+\beta(1-\kappa)\hat{z}_t.
\end{aligned}
$$

Let

$$\lambda=[1-\beta+(\kappa-1)\phi(1-e^{-1}e_u s_L)]\frac{e_{WW}}{e_u-e_{Wu}}s_L^{-1}-\phi(\kappa-1)<0.$$

Then the above equation can be expressed as,

$$
\begin{aligned}
\hat{W}_t-\mu\hat{W}_{t-1}&=\frac{\phi(\kappa-1)}{\lambda+\beta-1}\hat{A}_t+\frac{\kappa-1}{\lambda+\beta-1}\hat{K}_t-\frac{1-\beta}{\lambda+\beta-1}\hat{M}_t \\
&\qquad-\frac{\psi(1-\beta)}{\lambda+\beta-1}\hat{E}_t-\frac{\beta(\kappa-1)}{\lambda+\beta-1}\hat{z}_t,
\end{aligned}
$$

where

$$\mu=\frac{(1-\omega)\lambda}{(1-\omega)\lambda+\beta-1}.$$

Since λ<0 and β<1, 0<μ<1. The solution to the difference equation yields

$$\hat{W}_t = \frac{\phi(\kappa-1)}{\lambda+\beta-1}\sum_{j=0}^{t-1}\mu^j \hat{A}_{t-j} + \frac{\kappa-1}{\lambda+\beta-1}\sum_{j=0}^{t-1}\mu^j \hat{K}_{t-j} - \frac{1-\beta}{\lambda+\beta-1}\sum_{j=0}^{t-1}\mu^j \hat{M}_{t-j}$$
$$- \frac{\psi(1-\beta)}{\lambda+\beta-1}\sum_{j=0}^{t-1}\mu^j \hat{E}_{t-j} - \frac{\beta(\kappa-1)}{\lambda+\beta-1}\sum_{j=0}^{t-1}\mu^j \hat{z}_{t-j}.$$

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Footnotes

[1] However, as discussed in Romer (2006), the short-run aggregate supply curve is horizontal in the Keynesian model with fixed prices.
[2] These issues are discussed in Mankiw and Reis (2002).
[3] In the other version of Rotemberg's model, other goods are the inputs in the production function.
[4] In terms of a worker's quit decision, imperfect information about average wages would not be likely to affect his or her decision about whether to accept a given outside job offer. However, it may affect the worker's motivation to search for another job. For example, a worker who believes he or she is paid less than the average wage (even if this belief is incorrect) will spend more time searching for another job, and *ceteris paribus*, will be more likely to receive a favorable job offer from another firm.
[5] While this study uses a representative worker and firm framework for simplicity, this assumption is obviously an abstraction. In reality, workers are heterogeneous, and the relevant comparison is the average wage for workers in similar occupations who have similar characteristics.
[6] The cost to firms of forming incorrect expectations about the overall price level is lower profits. The cost to workers of forming incorrect expectations about average wages is exerting a suboptimal amount of effort and/or engaging in a suboptimal amount of job search.
[7] Justification for the assumption that e_{Wu}<0 is discussed in Campbell (2008).
[8] If all firms paid the same wage, workers could infer the average wage from their own wage. Thus, for forming wage expectations to be a non-trivial exercise, it is necessary that wages vary across firms. For example, it could be assumed that firms make random errors in setting wages, but that the profit-maximizing wage is set on average. These errors may result from firms' lacking perfect information about the level of product demand or about the parameters in their profit functions.
[9] As discussed in Campbell (2008), assuming a positive relationship between efficiency and wages 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.
[10] The relationship $\theta_t = Y_t^D$ is obtained from the fact that $Y_t^D = \theta_t (P_t / \overline{P}_t)^{-\gamma}$ and that $P_t = \overline{P}_t$ in a representative firm model. The relationship $Y_t^D = Y_t$ is a consequence of market clearing.
[11] As previously discussed, wages must vary across firms if forming wage expectations is to be a non-trivial exercise. To incorporate wage variation into the model, it could be assumed that the condition for an individual firm is $W_{it} e[W_{it} / \overline{W}_t^e, u_t]^{-1} e_W [W_{it} / \overline{W}_t^e, u_t](1/\overline{W}_t^e) = 1 + \varepsilon_{\text{it}}$, where the ε_{it}'s sum to 0 for the aggregate economy in each time period. In this case, wages will vary across firms, but equation (6) will hold for the aggregate economy.
[12] If expansionary demand shocks initially raise real wages, the last term in (13) will be negative. However, under reasonable conditions the second-to-last term in (13) will rise more than the last term falls, so the overall effect will be to raise output.
[13] The fact that real wages can be either procyclical or countercyclical under reasonable conditions can be illustrated by calculating the relationship between unemployment and real wages with realistic parameter values. Values for for e, e_u, e_{WW}, e_{Wu}, and s_L are taken from Campbell (2008). Campbell (2008) considers two specifications for workers' efficiency: a micro-based efficiency function and a naïve efficiency function. These efficiency functions yield different values for e_{WW}, and e_{Wu}. A demand shock that lowers the unemployment rate by 1 percentage-point raises real wages by 0.44% with the naïve efficiency function and lowers real wages by 0.008% with the micro-based efficiency function. With a constant velocity specification (so that κ=1), a 1 percentage-point decrease in unemployment is still associated with a 0.44% rise in real wages with the naïve efficiency function and a 0.008 decrease in real wages with the micro-based efficiency function.
[14] See Campbell (2009a) for a model of the Phillips curve in which workers' wage expectations depend on the past growth rate of average wages. In response to a deceleration in the growth rate of demand, this model demonstrates that unemployment rises and that wage and price inflation exhibit persistence.
[15] See Akerlof and Yellen (1990) for a discussion of the fair wage-effort hypothesis.