Supply and Demand in the Aggregate Labor Market: A Structural VAR Analysis

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This paper examines the puzzling correlation between real wages and hours worked in a sticky wage model with two shocks, one aggregate demand and one supply. I estimate the response of real wages to the shocks with a VAR under a long-run restriction on real wages. It is shown that the response of real wages to the aggregate demand shock is countercyclical and to the aggregate supply shocks is procyclical. The variance decomposition shows that aggregate demand shocks are important. The results are consistent with the implications of the sticky wage model, and the model can explain with the near zero correlation between wages and hours worked. (*JEL* Classifications: E32, E60, J20)

I. Introduction

The baseline real business cycle (RBC) model poorly replicates the near zero correlation between real wages and hours worked. This paper attempts to find a way to overcome this shortcoming of the RBC model by using a two shock model.

The near zero correlation has for a long time been a puzzle to the Classical and Keynesian models. Both models predict a negative correlation, because both models share the common assumption that real wages and hours worked lie on a downward sloped labor demand curve. This predictions is inconsistent with the data.

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Dunlop (1938) and Tarshis (1939) found a positive correlation between real and money wages. They interpreted this positive correlation as evidence of positive correlation between hours worked and real wages given the procyclical movement of money wages. Bodkin (1969) and Modigliani (1977) noted that the contemporaneous correlation between real wages and employment is usually statistically insignificant, even though the correlation is positive.

Sargent (1978) and Neftci (1978) criticized earlier studies for using simple contemporaneous regressions between real wages and the business cycle. They each added distributed lags to their regression and concluded that real wages and employment are negatively related. However, Geary and Kennan (1982) found that the evidence of Sargent and Neftci disappears when the nominal wage is deflated by the Wholesale Price Index instead of the Consumer Price Index and a longer time period is considered. Thus, they argue that it is difficult to reject the independence of real wages and employment for the 12 OECD countries.

Several panel data studies have found a negative relationship between real wages and unemployment. Bils (1985) and Keane, Moffitt and Runkle (1989) used panel data collected by the National Longitudinal Survey to estimate the relationship between real wages and unemployment. Both studies found a negative relationship. Barsky and Solon (1989) concluded that aggregated real wages show no relation to business cycles. However, they found that the data from the Panel Study of Income Dynamics revealed a substantial negative relationship between real wages and unemployment.

Most aggregate data studies consistently show the near zero correlation between real wages and hours worked. Thus, the predictions implied by the various theories need to be reexamined. In the real world, there are many types of shocks: technological shocks, money shocks, government expenditure shocks, foreign trade shocks, and so forth. Different shocks may affect the correlation differently. The realized contemporaneous correlation is the mixture of responses to different shocks. Thus, a real wage-hours worked regression cannot be a limits test for a macroeconomic model, unless the model assumes only one shock. Each model needs to be empirically evaluated for each correlation to each shock.

This paper overcomes this shortcoming of previous studies by allowing for two shocks in an economy: an aggregate demand shock and an aggregate supply shock.[1] To find the theoretical prediction regarding the correlation to shocks, the responses of real wages to shocks are calculated in a simple aggregate supply and demand model.

The responses of real wages to the two shocks are estimated using a structural vector autoregression (VAR) method and are compared to the response predicted by the theory. The results of the VAR are as follows: 1) the impulse response functions show that real wages are countercyclical to demand shocks and procyclicl to supply shocks; and 2) the variance decomposition shows that the aggregate demand shock is important to both real wages and hours worked.

The results give several implications for competing macro-economic models. First, the countercyclical movement of real wages to demand shocks is evidence of rigidity in wage contracts. Second, the mildly positive or zero correlation between hours worked and real wages is not evidence for rejecting Keynesian rigid wage theory. Also, the rigid wage assumption has the potential to solve the correlation puzzle in the RBC models.

The remainder of this paper is organized as follows. Section II calculates the prediction of the correlation to the aggregate demand shocks and aggregate supply shocks in a simple aggregate model. Section III describes the VAR model and introduces a long run restriction to real wages to identify the impulse response functions. Section IV interprets the results of the impulse response functions and a variance decomposition and explains how the shortcomings of the RBC models are solved. Section V concludes this paper.

II. Real Wage and Hours Worked in an Aggregate Economy

For illustrative purposes, a simple aggregate supply and demand

[1]Sumner and Silver (1989) included two shocks in their estimation by resampling their data: an aggregate demand shock dominant period occurs when inflation and unemployment changes are in different directions, while aggregate supply shock dominant periods occur when inflation and unemployment changes are in the same direction. This resampling is very sensitive to the data. Many periods that are included in the demand shock dominant period in their study, are included in the supply shock dominant period if alternative data (real compensation per hour instead of average hourly earnings) are used.

model is introduced and the equilibrium real wage and hours worked are derived under the nominal wage contracts assumption. The model is similar to Fischer (1977), Taylor (1980) and Blinder and Mankiw (1984). I assume that an aggregate economy is characterized by the following four equations:

$$y_t^d = m_t - p_t + v_t\,, \tag{1}$$

$$y_t^s = al_t + \theta_t\,, \tag{2}$$

$$l_t^d = -bw_t + c\theta_t\,, \tag{3}$$

$$l_t^s = \frac{1}{1+d}, \tag{4}$$

where m_t, p_t, v_t, y_t, l_t, w_t, and θ_t are log of the money stock, log of the price level, log of velocity, log of real output, log of hours worked, log of the real wage, and log of technology shock, respectively. All parameters — a, b, c, and d — are assumed to be positive.

Equation (1) is the aggregate demand function from the quantity theory of aggregate demand. The velocity of money, v_t, is assumed to be constant through time for simplicity. Equation (2) is an aggregate supply function or a production function which uses only labor in production. Equation (3) is a labor demand function which assumes that wages decrease labor demand and a productivity shock increases labor demand.[2] Equation (4) is a labor supply function in which some fixed portion of total hours is assumed to be provided as the supply of labor.[3]

To close the model, the behaviors of exogenous variables are specified. Shocks in this economy come from two exogenous variables: technology and monetary policy.

Each exogenous variable is assumed as follows:

[2] This can be derived from an intertemporal profit maximization. The production function, in equation (2), implies $b=c=1/(1-a)$ when the market is perfectly competitive and there are no friction. However, the market is imperfectly competitive or there are adjustment costs for changes in the labor input, the parameter restrictions do not hold. For generality, the paper leaves the parameters as b and c. See Rotemberg and Woodford (1991) for the labor supply curve in imperfectly competitive market or the presence of adjustment costs.

[3] The labor supply can be derived by following utility maximization;

$$\max\ [\log w_t l_t + d \log(1 - l_t)],$$

where the endowment of time is normalized to be one.

$$\theta_t = \theta_{t-1} + \eta_t, \tag{5}$$

$$m_t = a\, m_{t-1} + \gamma_t, \tag{6}$$

where η_t and γ_t are mutually and serially uncorrelated. Technology is assumed to have a unit root. Technological change affects the aggregate supply sector, so a shock to the technology, η_t, is regarded as an aggregate supply shock. Monetary policy initially affects aggregate demand, so the money shock, γ_t, is regarded as an aggregate demand shock.

To solve for the equilibrium wage and hours worked, the contract rule in the labor market is specified. Wages are not perfectly flexible in the real world. Some wages are formally determined by one to three year union contracts and others are informally determined by an annual salary review, so a nominal wage contract model might be more realistic. Thus, a one period ahead nominal wage contract model is adopted.

Keynes' nominal wage contract model implies that the money wage is set in advance and firms, on the labor demand curve, choose employment optimally taking predetermined wages as given. Hence, it is possible for the quantities of labor supplied and demanded not to be equal in the nominal wage contracts economy.

Equating expected labor supply and demand, expected real wages are determined. Hours worked are determined along the labor demand curve taking predetermined wages as given. As shown in the appendix, equilibrium real wages and hours worked are as follows:

$$\begin{aligned} w_t^* &= -\frac{1}{b(1+d)} - \frac{1}{1+ab}(m_t - m_t^e) + \frac{1+ac}{1+ab}(\theta_t - \theta_t^e) + \frac{c}{b}\theta_t^e \\ &= -\frac{1}{b(1+d)} - \frac{1}{1+ab}\gamma_t + \frac{1+ac}{1+ab}\eta_t + \frac{c}{b}\sum_{i=1}^{\infty}\eta_{t-i} \end{aligned} \tag{7}$$

$$\begin{aligned} l_t^* &= -\frac{1}{1+d} + \frac{b}{1+ab}(m_t - m_t^e) + \frac{c-b}{1+ab}(\theta_t - \theta_t^e) \\ &= \frac{1}{1+d} + \frac{b}{1+ab}\gamma_t + \frac{c-b}{1+ab}\eta_t. \end{aligned} \tag{8}$$

From equations (7) and (8), the responses of real wages and hours worked to aggregate shocks are summarized in Table 1. These responses are expected impulse response functions of the VAR.

Table 1 shows that the aggregate demand shocks have only short-run effects. The aggregate demand shocks, such as price surprises, cause firms to move along their labor demand curve, generating a

TABLE 1

ANTICIPATED IMPULSE RESPONSE FUNCTIONS TO SHOCKS

	Demand shocks		Supply shocks	
	$i=0$	$i=1, 2, 3\cdots$	$i=0$	$i=1, 2, 3\cdots$
Real wages	$-\frac{1}{1+ab}<0$	0	$\frac{1+ac}{1+ab}>0$	$\frac{c}{b}>0$
Hours worked	$\frac{b}{1+ab}>0$	0	$\frac{c-b}{1+ab}$?	0

countercyclical movement of wage rates, since contracts force nominal wages to be rigid. Real wages are decreased by the aggregate demand shock in the short run. Aggregate demand shocks cannot affect real wages or hours worked in the long run.

The aggregate supply shocks increase real wages in the short run. The response of hours worked to the aggregate supply shock is unclear and depends on the magnitude of b and c. The only long run effect is that of aggregate supply shocks on real wages. Aggregate supply shocks increase future real wages, with the effect persisting due to the unit root in the technology shock. The persistent effect to the aggregate supply shocks implies nonstationarity of real wages, and the unit root test of the next section confirms this implication.

In summary, the nominal wage contract model predicts that real wages would fall in response to demand shocks and rise with supply shocks in the short run. Hours worked are predicted to rise with both shocks in the short run and to rise with aggregate supply shocks in the long run.

The prediction of the correlation between real wages and hours worked can be examined from Table 1. The prediction of the nominal wage contract model is unclear since the correlation to the demand shock is negative and to the supply shock is positive. Thus, the prediction by the Keynesian model of the correlation is no longer necessarily negative if two shocks are introduced.

III. The Structural VAR Model

A. Data and Unit Root Tests

This paper uses CITIBASE data from the first quarter of 1947 to

TABLE 2
AUGMENTED DICKEY-FULLER UNIT ROOT TEST

$$\Delta Y_t = \alpha_0 + \alpha_1 t + \beta_0 Y_{t-1} + \sum_{j=1}^{m} \beta_j \Delta Y_{t-j} + e_t$$

$$H_0 : \beta_0 = 0,\ H_1 : \beta_0 < 0$$

Y_t	β_0	Std Error of β_0	t-stat
Real wage	0.0045	0.0105	0.4276
Hours worked	-0.0563	0.0335	-1.6823
ΔReal wage	-1.5320	0.3349	-4.5743
ΔHours worked	-1.2863	0.2898	-4.4389

Note 1: $m = \text{integer}[(T/100)^{1/4} \times 12]$, $T = 176 \Rightarrow m = 13$.
2: The critical values are -3.17 (3.14) at the 5% significance level and -2.89 (2.99) at the 10% significance level when sample size is 100 (250).

TABLE 3
ENGLE-GRANGER COINTEGRATION TEST

$$X_{it} = a + bX_{2t} + u_t$$

$$\Delta u_t = \alpha_0 + \alpha_1 t + \beta_0 u_{t-1} + \sum_{j=1}^{m} \beta_j \Delta u_{t-j} + e_t$$

$$H_0 : \beta_0 = 0,\ H_1 : \beta_0 < 0$$

Dependent variable	β_0	Std Error of β_0	t-stat
Real wage	-0.1037	0.0415	-2.5013
Hours worked	-0.0563	0.0335	-1.6823

Note 1: $m = \text{integer}[(T/100)^{1/4} \times 12]$, $T = 176 \Rightarrow m = 13$.
2: The critical values are -3.17 (3.14) at the 5% significance level and -2.89 (2.99) at the 10% significance level when sample size is 100 (250).

the fourth quarter of 1991. Real wages are compensation per hour for manufacturing workers (LCPM7). Hours worked per capita is manhours of employed labor force per week (LHOURS) divided by civilian labor force (LHC). All data are seasonally adjusted data.

The unit roots of real wages and labor hours are tested with the augmented Dickey-Fuller test (ADF test). The results are in Table 2. The t-statistics of real wages and hours worked are 0.4276 and -1.6823, respectively and we cannot reject the null hypothesis that there are unit roots in real wages and hours worked at the five percent significance level. Thus I try the growth rates of both series. The t-statistics of the growth rates of real wages and hours worked are -4.5743 and -4.4389, respectively so I reject the null hypothesis that the growth rates have a unit root at the five percent significance level. Since both variables are nonstationary, the Engle-Granger cointegration test is executed with the results reported in Table 3. The t-statistics indicate that I cannot reject the null hypothesis that there is no cointegration factor at the five percent significance level.

The unit root of real wage is an established fact, and the growth rates of real wages are used in the VAR model. However, the unit root of hours worked is not a known fact, and all leading theories assume that hours worked are stationary. The result of the ADF test may come from the restricted sample period, so the level of hours worked is used in the VAR model. Even though the hours worked variable has a unit root, some studies show that the asymptotic properties of VAR still hold.[4]

B. Vector Autoregression

Let $X=[w, l]'$ be the matrix of real wage growth rates and hours worked. Let $Z=[\eta, \gamma]$ be the matrix of aggregate supply shocks and aggregate demand shocks. Then the model to be estimate is

$$X_t = \sum_{i=0}^{\infty} A_i \times Z_{t-i} \qquad Var(Z_t)=I. \tag{9}$$

However, equation (9) cannot be estimated directly. I use the calculated reduced form to transform the coefficients and innovations to A and Z matrices which satisfy equation (9). The method is as follows.

First, the vector autoregression form of X_t is estimated with p lags which make the errors, ε_t, white noise.

$$X_t = \sum_{i=1}^{p} C_i \times X_{t-i} + \varepsilon_t. \tag{10}$$

The data are quarterly, so the candidates for the number of lags are 4, 8, and 12. The reported VAR is executed with eight lags and a constant.[5] The estimated coefficients of equation (10) are C_i. Using the Wold theorem, this autoregression form is transformed to a moving average representation as the following equation.

[4]See West (1988) and Sims, Stock and Watson (1990).

[5]The impulse response functions with 4 lags and 12 lags are similar as those with 8 lags.

$$X_t = \sum_{i=0}^{\infty} B_i \times \varepsilon_{t-i}. \tag{11}$$

Second, the moving average representation is orthonormalized to get the A and Z matrices in equation (9). The orthonormalization requires finding a matrix G which makes $(G^{-1}\times \varepsilon)(G^{-1}\times \varepsilon)'$ a two by two identity matrix as follows

$$X_t = \sum_{i=0}^{\infty} (B_i \times G)(G^{-1}\times \varepsilon_{t-i}) \tag{12}$$

$$E[(G^{-1}\times \varepsilon)(G^{-1}\times \varepsilon)'] = I \tag{13}$$

$$E[\varepsilon \times \varepsilon'] = G\times G' \tag{14}$$

$$G\times G' = \Omega. \tag{15}$$

The A matrix is calculated by multiplying B and G. There are two reasons for the orthonormalization. One is to find the impulse response functions. The orthonormalized innovations, $G^{-1}\times \varepsilon$, are uncorrelated across time and equations and variances of both innovations are the equal to one. The coefficients of the innovations, A or $B\times G$, are the responses of a unit shock. Therefore, the coefficients represent an impulse response function. The second reason for the orthonormalization is to calculate the variance decomposition. The uncorrelatedness of orthonormalized innovations makes it easy to compute the variances of the innovations simply by taking summation of the squares of coefficients. Therefore, we can easily calculate the variance decomposition across time.

C. *Identification of Impulse Response Functions*

Even though the orthonormalization has convenient properties, the orthonormal matrix is not unique. There are an infinite number of matrices G which satisfy equation (15) because the estimated variance covariance matrix Ω is a symmetric matrix. To identify the G matrix in this two equations system a restriction identify the G matrix in this two equations system a restriction is needed. The identification restriction is that one innovation does not have a long run effect on the level of real wages.[6]

Economic theory suggests that some shocks, such as innovations in productivity or increases in the labor force, have permanent

[6] Shapiro and Watson (1988), Blanchard and Quah (1989), Blanchard (1989), and Gali (1992) also use this long-run restriction.

effects on real variables. Some shocks, such as increases in government spending or changes in the money supply, have transitory effects on real variables. The temporary shocks can be regarded as the aggregate demand shocks and the permanent shocks can be regarded as the aggregate supply shocks. Real wages, a real variable, is assumed to be unaffected in the long run by temporary shocks such as aggregate demand shocks. Table 1 supports this assumption.

With this restriction, a unique G matrix is calculated and the shocks are decomposed into aggregate demand shocks and supply shocks.

$$X_t = \sum_{i=0}^{\infty} \begin{bmatrix} b_{11}^i & b_{12}^i \\ b_{21}^i & b_{22}^i \end{bmatrix} \begin{bmatrix} g_{11} & g_{12} \\ g_{21} & g_{22} \end{bmatrix} V_{t-i}, \tag{16}$$

$$V_{t-i} = (G^{-1}\varepsilon_{t-i}),$$

$$X_t = \sum_{i=0}^{\infty} \begin{bmatrix} b_{11}^i g_{11} + b_{12}^i g_{21} & b_{11}^i g_{11} + b_{12}^i g_{21} \\ b_{21}^i g_{12} + b_{22}^i g_{22} & b_{21}^i g_{12} + b_{22}^i g_{22} \end{bmatrix} V_{t-i}, \tag{17}$$

$$\sum_{i=0}^{\infty} \left(b_{11}^i g_{11} + b_{12}^i g_{21} \right) = 0. \tag{18}$$

In the VAR model, this restriction implies equation (18), since the upper factors of vector V_{t-i} are the demand shocks.

IV. The Results and Interpretation

Estimated impulse response functions of real wages to an aggregate demand and supply shocks are shown in Figure 1.[7] The response to an aggregate demand shock shows that real wages fall then return to their original level.[8] The fall for the first three years

[7]Both Figure 1 and Figure 2 give point estimates of responses to demand and supply shocks, as well as and 95% confidence intervals obtained by the Monte Carlo simulations. The impulse response functions in Figure 1 are levels of real wages that are calculated from the growth rates of real wages in the VAR.

[8]Gamber and Joutz (1993), Spencer (1993) and Fleischman (1993) examined the response of real wages to aggregate demand shocks in the VAR with the long run restrictions. The specifications and data are different. The results of Gamber and Joutz show the positive response of real wages to aggregate demand shocks and the results of other two's show the negative response.

is statistically significant at the 95% confidence level, so I can conclude that real wages fall in the short run. The fall is consistent with the prediction of the nominal wage contract model and may be evidence of wage rigidity. Real wages show a persistent statistically significant increase in response to the aggregate supply shock. The persistent increase is consistent with the nominal wage contract model and with nonstationarity of real wages. The unit root of productivity shocks increases wage rates not only in the short run but also in the long run.

Impulse response functions showing the reaction of hours worked to aggregate demand and supply shocks are displayed in Figure 2. Both graphs show positive responses to both shocks in the short run and no responses in the long run. These responses are consistent with the prediction of the nominal wage contract model.

The impulse response functions give some implication of the shortcomings of the baseline RBC model. The baseline RBC model, that relies only on technology shocks, works poorly in replicating the near zero correlation between real wages and hours worked. There are essentially three lines of research which aim to introduce aggregate demand shocks into the baseline RBC model. King (1991) introduced money into the RBC model with a sluggish price assumption, Christiano and Eichenbaum (1991) included money in the RBC model by using liquidity effects and Christiano and Eichenbaum (1992) introduced government expenditure into the RBC model. The first two models imply that real wages will increase in response to aggregate demand shocks, indicating strong positive correlation between real wages and hours worked. Thus, these two models still overstate the correlation. Only the last model, which generates a negative correlation between hours worked and real wages to the shocks of government spending, replicates the low correlation. This is evidence of a counter-cyclical wage movement in response to aggregate demand shock and is consistent with the impulse response functions in Figures 1 and 2. The remainder of this section explains how the shortcomings of the RBC model can be solved if nominal wage contracts are introduced into the model.

The puzzling correlation between real wages and hours worked can be explained by the impulse response functions. Figures 1 and

With different specification of VAR, Cogley (1993) found countercyclical movements in real wages in response to monetary shocks.

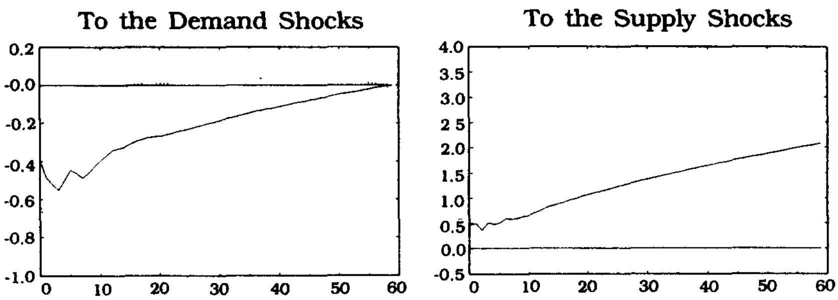

FIGURE 1
IMPULSE RESPONSE FUNCTIONS OF REAL WAGES

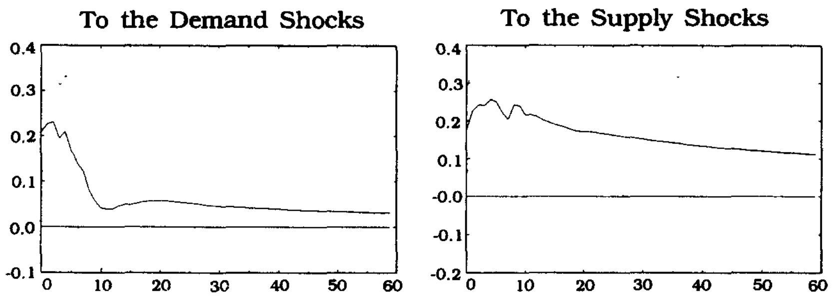

FIGURE 2
IMPULSE RESPONSE FUNCTIONS OF HOURS WORKED

2 show that real wages and hours worked move in opposite directions in response to an aggregate demand shock and in the same directions in response to and aggregate supply shock. Thus, the correlation is negative after a demand shock and positive after a supply shock. Which shock is more important to the correlation between the two variables? The variance decomposition shows the relative magnitude of the shocks to each variables. Table 4 indicates that roughly one third the variance of real wages and three fifths hours worked comes from the demand shock for the first eight quarters after the shock. The null hypothesis that the variances of

TABLE 4
THE VARIANCE DECOMPOSITION

Quarters	Real Wage Growth Rate		Hours Worked	
	By Demand	By Supply	By Demand	By Supply
1	27.71	72.29	68.96	31.04
	(13.55)	(13.55)	(14.73)	(14.73)
2	31.75	68.25	63.54	36.46
	(14.09)	(14.09)	(15.52)	(15.52)
3	35.53	64.47	57.75	42.25
	(14.62)	(14.62)	(16.36)	(16.36)
4	34.55	65.45	53.35	46.65
	(14.62)	(14.62)	(16.61)	(16.61)
8	34.01	65.99	42.33	57.67
	(15.02)	(15.02)	(16.17)	(16.17)
12	30.44	69.56	34.36	65.64
	(13.97)	(13.97)	(14.82)	(14.82)
20	20.06	79.94	29.27	70.73
	(10.57)	(10.57)	(13.82)	(13.82)
28	13.38	86.62	27.19	72.81
	(7.95)	(7.95)	(13.73)	(13.73)
36	9.26	90.74	25.87	74.13
	(5.99)	(5.99)	(13.71)	(13.71)
44	6.64	93.36	25.10	74.90
	(4.57)	(4.57)	(13.76)	(13.76)
52	4.95	95.05	24.59	75.41
	(3.56)	(3.56)	(13.82)	(13.82)
60	3.81	96.19	24.23	75.77
	(2.85)	(2.85)	(13.88)	(13.88)

Note: The standard error of each decomposed variances is in the parentheses.

real wages and hours worked to the demand shock for the first eight quarter are zero cannot be rejected statistically at the five percent significance level. Thus, the aggregate demand shocks are quite important to both variables at least in the short run, and the negative correlation due to the demand shocks can offset the positive correlation due to the supply shocks. The overall correlation between real wages and hours worked can be near zero due to the negative correlation to the aggregate demand shock. The opposite correlation to two shocks is predicted by the nominal wage contract model. Hence, the nominal wage contract model has the potential to solve the correlation puzzle in the RBC model.

This result implies that the traditional real wage-hours worked regression cannot be used as a litmus test for a macroeconomic model, unless the model assumes only one shock. In the real world, there are many types of shocks: technological, money, government expenditure, foreign, and so forth. Since different shocks have different effects on the correlation between real wages and hours worked, the realized contemporaneous correlation is a mixture of responses to different shocks. There is no reason for the Keynesian nominal wage contract model to predict a negative correlation between real wages and hours worked.

V. Conclusion

This paper models the response of real wages and hours worked to aggregate demand and supply shocks with the vector autoregression technique, under the assumption that the aggregate demand shocks have no long run effect on real wages. The impulse response functions show that real wages are countercyclical to the demand shocks and procyclical to the supply shocks. The variance decomposition shows that the aggregate demand shock is important to both real wages and hours worked. These results support the Keynesian rigid wage theory, which is consistent with the fact that the correlation between real wages and hours worked is near zero. Thus, the nominal wage contracts assumption has the potential to solve the shortcomings of the RBC model.

The lesson of this study is that a plausible theory must incorporate more than one shock. The explanatory power of this study comes from a two shocks model. This paper tries to identify the shocks with VAR under a long-run restriction. For a rigorous test of the theory, adequate identification of shocks is crucial.

Appendix

Nominal wage contract economy

Contracted nominal wage (W_t) is set to equate expected labor demand and supply,

$$W_t = w_t^e - p_t^e = -\frac{1}{b(1+d)} + \frac{c}{b}\theta_t^e + p_t^e, \tag{A1}$$

and firms choose equilibrium labor hours along the labor demand curve in equation (3),

$$\begin{aligned} l_t &= -b(W_t - p_t) + c\theta_t \\ &= \frac{1}{1+d} + b(p_t - p_t^e) - c\theta_t^e + c\theta_t. \end{aligned} \tag{A2}$$

Equating aggregate supply and demand, the price is

$$\begin{aligned} P_t &= m_t - al_t - \theta_t + v_t \\ &= m_t - \frac{a}{1+d} + ab(p_t^e - p_t) + ac(\theta_t^e - \theta_t) - \theta_t + v_t. \end{aligned}$$

Taking expectation, the expected price is

$$p_t^e = m_t^e - \frac{a}{1+d} - \theta_t^e + v_t^e$$

By plugging the expected price into the price equation,

$$p_t - p_t^e = \frac{1}{1+ab}(m_t - m_t^e) - \frac{1+ac}{1+ab}(q_t - q_t^e) \tag{A3}$$

The equilibrium real wage is

$$\begin{aligned} w_t &= W_t - p_t \\ &= -\frac{1}{b(1+d)} + p_t^e - p_t + \frac{c}{b}\theta_t^e \\ &= -\frac{1}{b(1+d)} - \frac{1}{1+ab}(m_t - m_t^e) + \frac{1+ac}{1+ab}(\theta_t - \theta_t^e) + \frac{c}{b}\theta_t^e \end{aligned}$$

and hours worked are obtained by plugging (A3) into (A2).

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