Cyclical Movements in Hours and Effort under Sticky Wages [*]

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Abstract: We examine the response of a sticky-wage economy to various real and nominal shocks. In addition to variations in hours, we allow for an endogenous response in worker effort per hour. Despite wages being predetermined, the labor market clears through the effort margin. We find that the ability of a sticky-wage model to mimic U.S. business cycles is much improved by allowing for reasonable effort movements. The model also provides a ready explanation for the finding that *TFP* is negatively affected by nominal shocks.

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1. Introduction

There is an immense literature on the impact of nominal wage rigidities. This literature is partly motivated by the large numbers of workers whose wage rates are updated to reflect economic news, including inflation, only at intervals of a year or longer. It is also partly motivated as a way to explain why purely monetary shocks can create important fluctuations in hours and output.

In Bils and Chang (2000) we point out, however, that the predictions of sticky-wage models rely critically, not only on wages being predetermined, but also on an implicit assumption that neither firms nor workers can adjust the intensity of workers' effort. Figure 1 illustrates this. In the standard treatment of sticky wages, an unexpectedly low price, given a sticky nominal wage, causes the market to move from point *E* to *E¢*, with labor supply exceeding labor demand. This causes firms to cut back on hours until this reduction is sufficient to drive the marginal product of labor up to the level of the "too high" real wage. But note that at point *E¢* it is clearly profitable for firms to ask more of workers in terms of effort or exertion. If firms ask more of workers this shifts the demand for hours of labor upward. It also shifts the labor supply curve upward reflecting the greater cost to workers of each hour at the higher effort. Firms can ask more of workers up to the point that work intensity justifies the "too high" real wage at a point like *E²*. Given the upward shift in labor demand, hours are reduced by less than at *E¢*. Note that the labor market still clears, despite the sticky wage, thanks to the effort margin. We find that this response greatly reduces the welfare costs of specifying wages in advance in the face of monetary shocks. We argue that perhaps this helps to justify why firms and workers appear willing to trade under a sticky wage.

Here we ask a more ambitious question: Does a model with sticky wages and an effort response help for understanding business cycle fluctuations? To answer this question, we compare the model quantitatively to models both with flexible and sticky wages, but no effort margin.

The next section presents a general equilibrium model that incorporates the endogenous effort response just described. Under sticky wages workers must produce enough to merit the specified wage to maintain employment. Section 3 quantifies the model for empirical purposes. The model economy is calibrated and stochastic disturbances to the economy in technology, preference, and money growth, are considered. We estimate the disturbance process three ways to be consistent three types of labor market arrangement––flexible wages, sticky wages, and finally sticky wages with an endogenous effort. Section 4 examines the model responses for hours, output, and productivity to the business cycle shocks.

We find that allowing for a response in effort dramatically improves the ability of a sticky-wage model to mimic U.S. business cycles. Fluctuations in hours are much more persistent and the correlation between fluctuations in hours and labor productivity is much closer to that observed in the data. Compared with flexible wages, the model with sticky wages and an effort response is more successful in generating increases in productivity in advance of increases in hours worked. For U.S. data, fluctuations in real wages, labor productivity, and TFP all dramatically lead those in hours. Furthermore, the model with sticky-wages and varying effort is the only one that generates a decline in TFP in response to a positive nominal shock, as we estimate for U.S. data.

2. Model

Consumers:

There are a large number of identical infinitely lived consumers in the economy. At time *t*, the representative consumer maximizes expected discounted utility defined over a stream of effective consumption, x_t.

$$U(t) = E_t \sum_{t=t}^{\infty} b^{t-t} u(x_t), \;\; b < 1,$$

E_t is the expectations operator; the discount factor is b. Following Becker (1965), consumption activity requires an input of time as well as goods. More exactly, effective consumption reflects commodities c_t, real balances m_t/P_t and effective labor spent on consumption activities $\tilde{l}_t$. We assume the utility function reflects the following relations.

$$u(x_t) = \log x_t$$

$$x_t = z_t^{q_t} \tilde{l}_t^{1-q_t}$$

$$z_t = [c c_t^{1-\frac{1}{u}} + (1-c)(\frac{m_t}{P_t})^{1-\frac{1}{u}}]^{\frac{u}{u-1}}.$$

Shifts in preferences occur through variations in q_t. An increase in q_t represents increased importance of purchased inputs relative to time in producing effective consumption.

Goods and real money balances combine through a CES function with substitution elasticity υ. This yields a demand for real balances with elasticity of 1 with respect to consumption and –υ with respect to the nominal interest rate. We can conveniently draw upon a large empirical literature in calibrating a value for υ.

The distinctive feature of our model is that the effective amount of labor supplied to the market and to home consumption depends not only on how hours are split between market and home, but also on levels of exertion or effort.[1] Suppose the consumer spends an amount of time n_t in the market and 1- n_t at home for consuming. Let f_t and $\tilde{f}_t$ represent the effort levels he exerts at work and in the activity of consuming. Then we treat effective labor in the market l_t and effective time in consumption $\tilde{l}_t$ as

$$l_t = n_t f_t^{g}$$

$$\tilde{l}_t = (1-n_t)\tilde{f}_t^{\,l},$$

where both g and l are $\geq$ 0 and < 1.

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[1] Other papers that examine labor-market issues by exploiting the hours/effort tradeoff include Becker (1985), Oi (1990), Hartley (1992), and Leamer (1996).

We impose a constraint on the available energy that a consumer can exert in market and non-market activity. The "energy constraint" is

$$(1) \qquad f_t n_t + (1 - n_t)\tilde{f}_t = 1 .$$

If the consumer works more intensely in the market, he is left with less energy for non-market activities. (Becker, 1985, introduces this constraint.) More generally, we can envision a number of ways in which consumers can potentially show themselves to be more desirable employees. For instance workers could reduce absenteeism at the cost of less flexibility to stay at home on days they deem that as attractive.

The consumer spends his money income for purchases of consumption goods c_t, investment i_t, and money holdings m_t. Income includes labor income, rental income and a cash transfer from the government. Given the nominal wage rate W_t, rental rate R_t, price of goods P_t, and money transfer from government T_t, the budget constraints are

$$(2) \qquad c_t + \frac{m_t}{P_t} + i_t \leq \frac{W_t}{P_t} n_t + \frac{R_t}{P_t} k_t + \frac{m_{t-1}}{P_t} + \frac{T_t}{P_t}$$

$$(3) \qquad k_{t+1} = i_t + (1-d)k_t$$

The money transfer from the government reflects the income from money creation. $T_t = M_t - M_{t-1} = (m_t - 1)M_{t-1}$, where $m_t = \frac{M_t}{M_{t-1}}$. Capital depreciates at rate d.

The effective labor of a worker is $n_t f_t^g$. Therefore, to be employed, the worker has to provide an effort dictated by

$$(4) \qquad f_t = (\frac{W_t}{P_t} / W_t)^{1/g} .$$

W_t is the market's valuation of labor, the marginal product of efficiency unit of labor, determined in general equilibrium as described below. Under sticky wages the worker takes not only W_t but also the real wage as given. So the choice of effort is constrained, much as hours are constrained in a standard sticky wage model. Here, by working hard enough, workers maintain the choice of hours.[2] In fact, even though the wage is sticky the labor market continues to clear. (Recall Figure 1.)

Consumer maximization yields a static first-order condition for choosing hours worked and two dynamic first-order conditions for choosing investment in capital and investment in real money balances.[3]

$$(5) \qquad n_t; \quad \frac{1-l}{1-n_t} + \frac{l f_t}{1-n_t f_t} = \frac{q_t}{1-q_t}\frac{W_t}{P_t \tilde{c}_t}$$

$$(6) \qquad k_{t+1}; \quad b\,\frac{\tilde{c}_t}{q_t} E_t\left[\frac{R_{t+1}/P_{t+1} + 1 - d}{\tilde{c}_{t+1}/q_{t+1}}\right] = 1$$

$$(7) \qquad m_t; \quad \frac{1-c}{c}\left(\frac{m_t}{P_t \tilde{c}_t}\right)^{-\frac{1}{u}} = 1 - bE_t\left[\frac{q_{t+1} P_t \tilde{c}_t}{q_t P_{t+1} \tilde{c}_{t+1}}\right]$$

where $\tilde{c}_t = c_t[1 + \frac{1-c}{c}(\frac{m_t}{P_t c_t})^{1-\frac{1}{u}}]$ is consumption magnified by a factor equal to one plus the foregone interest cost of real balances held per unit of consumption.

Firms:

There are a large number of identical firms. Each firm hires capital and labor to maximize profits $(P_t Y_t - W_t N_t - R_t K_t)$ subject to the production function

$$(8) \qquad Y_t \equiv F(K_t, N_t, F_t; A_t, Q_t) \equiv A_t K_t^{1-a} (Q_t N_t F_t^{g})^{a} \; .$$

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[2] This might appear to require that firms have very accurate measures of effort or performance. But even if firms have only very imperfect measures, the essence of the argument applies. If the wage is predetermined at a level that is too high, ex post, the firm can raise threshold levels of measured performance required for retention or promotion.

[3] If wages were flexible there would be an additional static first-order condition for effort choice $(f_t; \quad \frac{l f_t}{1-n_t f_t} = \frac{g q_t}{1-q_t}\frac{W_t}{P_t \tilde{c}_t}$), replacing the constraint in (4).

This technology exhibits constant returns to scale in capital and effective labor. F_t represents the aggregate effort level; A_t reflects temporary productivity shifts, whereas Q_t reflects a deterministic trend of technology that grows at rate g .

The first order conditions for capital and labor are

$$(9) \qquad \frac{R_t}{P_t} = MPK_t = (1-a)A_t K_t^{-a}(Q_t N_t F_t^{g})^{a}$$

$$(10) \qquad \frac{W_t}{P_t} = MPN_t = aA_t K_t^{1-a} Q_t^{a} N_t^{a-1} F_t^{ga} \ .$$

(10) yields a wage rate per efficiency unit of labor equal to $W_t = aA_t Q_t^{a}(\frac{K_t}{N_t F_t^{g}})^{1-a}$.

The wage rates for workers must be specified a period in advance—this is the source of wage stickiness. The wage is chosen to minimize the expected cost of labor in efficiency units, recognizing that the wage dictates the level of effort that firms can require. The first-order condition for this choice can be written as:

$$(11) \qquad W_{t+1};\ W_{t+1}E_t[\frac{q_{t+1}n_{t+1}}{P_{t+1}\tilde{c}_{t+1}}] = \frac{1-l}{1-g}E_t[\frac{(1-q_{t+1})n_{t+1}}{1-n_{t+1}}] \ .$$

To illustrate the logic of this choice, consider the case of no uncertainty. In this case (11), together with equations (1) and (5), results in a wage, W_{t+1}, that delivers effort at work relative to home, $\frac{f_{t+1}}{\tilde{f}_{t+1}}$, equal to $\frac{g(1-l)}{l(1-g)}$. This effort ratio, in turn, corresponds to the optimal effort choices under flexible wages. (See Bils and Chang, 2000, for more detail.)

Rational Expectations Equilibrium:

The markets for goods, labor, and money clear each period. A rational expectations equilibrium is a set of stochastic processes for the endogenous variables $\{Y_t, K_t, N_t, f_t, c_t, m_t, P_t, W_t, R_t\}$ that satisfies (3)-(7), (9)-(11), and market clearing given the exogenous stochastic processes $\{A_t, q_t, m_t\}$. The model is solved numerically using a log-linear approximation of the system of first order conditions and constraints of the stationary economy around the steady state as in King, Plosser and Rebelo (1988.)[4]

3. Calibration of Model Parameters and Shocks

Calibration of Model Parameters:

In our model the labor market clears, despite short-run wage stickiness, thanks to fluctuations in market effort. Consequently, the model's predictions for fluctuations in hours and output depend not only on the conventional elasticity of labor supply, but also on how desired hours are affected by these fluctuations in effort. Key parameters are g and l, which dictate the willingness of workers to trade off exertion and hours in production and consumption. As an example, in the limit as g and l approach one hours and effort are perfect substitutes. Consider a nominal shock that drives up the real wage and effort by one percent. Workers' hours simply decrease by one percent, holding output (and welfare) constant. More generally, however, the increase in real wage and effort leads to a lesser decrease in hours, an increase in output, and a fall in effective leisure $\tilde{l}_t$.

We use the values g = 1/3 and l = 1/4. Detailed explanations for these choices are provided in Bils and Chang (2000). We calibrate the value for g based primarily on World War II evidence on how piece-rate workers responded in work efficiency to large swings in their weekly hours of work. We set the ratio of exertion at work to exertion at home on the steady-state growth path, $\frac{f}{\tilde{f}}$, equal to 3/2. Given a value for g this dictates l's value, as $\frac{f}{\tilde{f}}$ is equal to the parameter combination $\frac{g(1-l)}{l(1-g)}$. (We also explore robustness to a range of values for parameters g and l.)

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[4] Given the existence of trends in technology and the money supply, we need to transform the economy so that it admits a stationary solution. We can do so by dividing real variables by the technology index and nominal variables by the previous period's money stock. (To save on notation, we use the same variables for the transformed stationary variables.)

Let x denote the elasticity response of hours to the real wage holding current consumption expenditures constant. The model implies an elasticity of one for $(1-n)$ with respect to the wage. Therefore it implies a value of approximately $\frac{1-n}{n}$ for x. We set the compensated elasticity of labor supply, x, equal to one by choosing parameters that yield steady-state n equal to one half. This value for x is considerably lower than what is typically employed in simulations of real business cycles, but is quite large relative to most estimates from cross-sectional and panel data (Ghez and Becker, 1975, MaCurdy, 1981, and Altonji, 1986).[5]

First-order conditions (6) and (7) imply that money demand is proportional to consumption and has an interest rate elasticity of $-\upsilon$. There is a very large empirical literature estimating υ. We take $\upsilon = 0.1$ as a reasonable value given the range of estimates (e.g., Laidler, 1985). We set the parameter χ equal to .9999. For a value of 0.1 for υ and a nominal interest rate of 8 percent this implies a real balance-consumption ratio, $\frac{m_t}{P_t c_t}$, of 0.51. For the United States for 1954 to 1996 the observed ratio for $\frac{m_t}{P_t c_t}$, measuring money by M2, is 0.24. The small value of $\frac{m_t}{P_t c_t}$ renders the effect of real balances on consumption demand nearly zero.

We use standard values for other parameters such as the depreciation rate d, labor's share a, the discount factor b, and the growth rate of technological progress g. A steady-state value for the preference parameter q is dictated by the other parameters. Table 1 summarizes our parameter choices.

Estimating the Stochastic Processes for Shocks:

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[5] Several studies have examined how time is divided between market and non-market pursuits based on time use diaries. (Examples include Hill, 1983, Juster and Stafford, 1985, 1991.) From Juster and Stafford (1991), a sample of men in the United States in 1981 report spending 48 hours per week in market work, including commuting, and 42 hours in social entertainment and various sorts of passive and active leisure. For women the comparable number of hours are respectively 26 and 42. These numbers suggest a value for $\frac{1-n}{n}$ of one or perhaps somewhat larger.

Three disturbances to the economy are considered: disturbances to technology A_t, to preferences q_t, and to the rate of money growth m_t. We denote a variable's percentage deviation from its steady-state value by adding a circumflex [e.g. $\hat{A}_t = \log(A_t / A)$].[6] We assume that $S_t = [\hat{A}_t\ \hat{q}_t\ \hat{m}_t]$ reflects a stationary stochastic process,

(12) $$S_t' = rS_{t-1}' + e_t', \quad r = \begin{bmatrix} r_A & 0 & 0 \\ 0 & r_q & 0 \\ 0 & 0 & r_m \end{bmatrix}, \; r_A, r_q, r_m < 1, \; e_t = [e_{At}\ e_{qt}\ e_{mt}]$$

(13) $$Q = Ee_t'e_t .$$

We estimate this process three ways to be consistent first with a model with flexible wages and constant effort, then with a model with sticky wages and constant effort, and finally with a model with sticky wages and an effort response.

With constant effort we can measure shifts in productivity $\hat{A}_t$ in a conventional manner using the Solow residual. But more generally the Solow residual reflects variations in effort

$$\hat{Y}_t - (1-a)\hat{K}_t - a\hat{N}_t = \hat{A}_t + ag\hat{f}_t \ .$$

To adjust for effort variations, we exploit the fact that $E_{t-1}\hat{f}_t$ can be directly related to $E_{t-1}\hat{n}_t$ given the wage setting in equation (11), constraint (1), and first-order condition (5). After subtracting $agE_{t-1}[\hat{f}_t]$ from the Solow residual for *t*, we project what remains on lagged and predetermined variables to construct the variable $E_{t-1}\hat{A}_t$. (This is described in greater detail in the Appendix.) Then, given that $E_{t-1}\hat{A}_t$ has the same autocorrelation as $\hat{A}_t$, we use the series for $E_{t-1}\hat{A}_t$ to estimate r_A.

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[6] For the rate of money growth $\hat{m}_t$ denotes an absolute, rather than percentage, deviation.

Under flexible wages preference shifts can be related to observed variables as $\frac{q_t}{1-q_t} = \frac{1-l}{1-g} \frac{P_t \tilde{c}_t}{W_t} \frac{1}{1-n_t}$. This parallels Hall (1986), Parkin (1988), and Baxter and King's (1991) use of the static first-order condition to measure preference shocks. If wages are sticky this relationship holds only in expectation as of *t*-1. As in the treatment of $\hat{A}_t$, we first use this relationship to construct $E_{t-1}\hat{q}_t$, then estimate r_q from its autocorrelation.

Lastly, we need to calibrate the stochastic process of monetary shocks. Our reading of the literature provides no consensus on an appropriate measure of monetary shocks. Short of such a measure, we proceed as follows to construct a measure of money growth that is consistent with our model. The money demand equation requires that nominal money holdings be proportional to nominal expenditures on consumption and exhibit an elasticity with respect to the nominal interest rate (R_t) of $-\upsilon$.

$$\hat{m}_t = (\hat{P}_t + \hat{c}_t) - u(\frac{\hat{R}_t}{1+R_t}) \quad .$$

Taking first differences and employing a value for υ of .1, this yields a measure of disturbances to the rate of growth in money. A potential problem with this measure is that, if we are incorrect in assuming elasticities of money demand of 1 and –.1 with respect to nominal consumption and nominal interest rates, then our measure of nominal shocks will be correlated spuriously with spending and interest rates. To mitigate this problem, we first instrument for this measure of monetary disturbances by projecting on arguably exogenous components of monetary policy. Specifically, we use innovations to monetary policy, suggested by Strongin (1995), and their lagged variables, which are identified from a VAR of total reserves, the ratio of non-borrowed reserves to total reserves, and the federal funds rate as instruments. We will refer to the resulting series as our instrumented monetary shocks. Estimation of the three shocks, with results, is described in greater detail in an appendix.

4. Results for Cyclical Fluctuations

The cyclical behavior of hours and productivity

We contrast three models with respect to their predictions for how output, consumption, investment, productivity, and prices respond to shocks. The models being: a standard flexible wage model, a model with sticky nominal wages and rationing in the labor market, and the model we have introduced with sticky nominal wages where the labor market clears through endogenous effort. First, however, we examine the behavior of these variables for the U.S. economy with a particular emphasis on the cyclical behavior of productivity.

Table 2 presents the standard deviations, first-order autocorrelations, and contemporaneous correlations with real GDP for the eight series real GDP, consumption, investment, hours, prices, real wage, labor productivity, and the Solow residual (TFP) for the U.S. economy. The series are annual Hodrick-Prescott filtered data for 1954-1996. Prices and the real wage reflect the GDP deflator. The hours series are from the Bureau of Labor Statistics and reflect a correction for changes in the composition of the workforce by age and education.[7] The series for the real wage, labor productivity, and TFP are corrected in a consistent manner. As has been often documented, variability of hours is nearly as large as that in output, with the standard deviation in the real wage and labor productivity less than half that of hours. Note that fluctuations in hours are actually more persistent than fluctuations in labor productivity or TFP, in contrast to typical results for models that have been calibrated. Prices are very countercyclical for the period 1954 to 1996, with a correlation of -.57 with output.

Table 3 presents correlations of the real wage, labor productivity, and the Solow residual with hours contemporaneously as well as for leads and lags of up to 3 years. Real wages and TFP exhibit contemporaneously correlations of .43 and .45 with hours, but labor productivity and hours are largely uncorrelated. Fluctuations in all three variables

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[7] The adjustments for labor force composition are described in detail in BLS (1993). Without correcting the standard deviation of hours is 2.19 percent instead of 2.01 percent. Without correcting the correlations of labor productivity with output and hours equal .30 and -.21, rather than the corresponding values in Table 3 of .48 and .06.

dramatically lead fluctuations in hours. For both labor productivity and TFP the correlation at a lead of 2 years is over .5.

With sticky wages, but endogenous effort, an unexpected increase in prices reduces the real wage, causing a decrease in effort and TFP. It is well known that price and TFP are strongly negatively correlated in the data. For instance, Figure 2a shows the impulse responses from a bivariate VAR of inflation and TFP growth rate for the period 1960-1996. The number of lags included equals 2 (representing 2 years). The VAR is structured with inflation entering first in the ordering. TFP responds to a 1 percent increase in inflation by decreasing initially by about .25 percent and by even more in the following year. However, the response of TFP to inflation does not clearly capture the relation between nominal shocks and effort if there are important cyclical shocks to technology. The negative impact of productivity shocks on prices might create a negative association between inflation and TFP even if effort does not vary.

Ideally, we would like to isolate the response of TFP to innovations in inflation due solely to exogenous monetary shocks. Figure 2b repeats the VAR presented in Figure 2a, but replacing the rate of inflation with our instrumented monetary shocks. (See Section 3.) TFP responds to a 1 percent increase in (instrumented) money growth by decreasing quite dramatically by about .6 and .4 percent in the first two years.[8] Thus *TFP* declines even more dramatically in response to a monetary innovation than to the rate of inflation. This result is clearly anticipated by our model with endogenous effort, but not by the flexible wage or standard sticky-wage model.

Impulse responses for the models

We examine impulse responses to technology, preference and monetary shocks for each of the three models.[9] First consider a technology shock of one percent. As the responses of the models to technology shock are well known, we describe them briefly here. In the flexible wage model with constant effort, investment responds much more

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[8] The results in Figure 2a and 2b are qualitatively robust to reordering the variables.

[9] Recall that for each model, the persistence of shocks corresponds to the autocorrelation of the shocks estimated from that model. In practice, the differences in persistence of shocks across models is very similar; so this has little impact on the appearance of the impulse responses.

than consumption and output, with consumption's response being humped shape. In response to a one percent increase in A_t, investment and output increase by slightly more than 3 percent and one percent, respectively, in the first period. The real wage (and labor productivity) responds much more, and much more persistently, than hours.[10] The initial increase of real wage and hours are slightly less than one percent and 0.4 percent, respectively. Price falls by 0.5 percent from its steady state in the first period.

For a sticky-wage model with no response in effort (g = 0), for the first year, during which the nominal wage is predetermined, the impact on the real wage is simply the opposite of the response of the price level. The price level falls by about 2/3 of a percent. The induced increase in the real wage of 2/3 of a percent is somewhat smaller than the real wage increase under flexible wages of about 0.9 percent. Because employment is demand determined, this leads to a much larger increase in employment and output in the first year.

The response of the model with sticky wages but endogenous effort is intermediate to the flexible-wage and standard sticky-wage results. The path for the real wage looks much like the simple sticky wage model. The sticky nominal wage causes the real wage to increase by less than its flexible wage counterpart. This leads to a reduction in the productivity of effort (f_t^g) by 0.4 percent in the first year. Hours increase by about 0.8 percent, which is greater than the response of 0.4 percent under flexible wages and smaller than the response of 1.2 percent under the standard sticky model. However, the expansions in output, consumption, and investment look very much like that under completely flexible wages.

Next we examine the responses of these economies to a preference shock reflecting a one-percent increase in q_t. The responses of the flexible wage economy are given in Figure 3a. The preference shock causes both consumption and investment to expand, with the increase in investment modestly larger. Output expands by about 1 percent in the first year, declining gradually to be about 0.5 percent above trend in the fifth

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[10] We also examined a flexible-wage model with endogenous effort. Effort moves very little. Burnside, Eichenbaum, and Rebelo (1993) and Bils and Cho (1994) achieve greater movements in effort under flexible wages by adding adjustment costs for hours.

year. Prices and real wages are countercyclical. Prices fall by 0.7 percent in the first year. Real wages fall by about 0.5 percent initially, but only slightly by the fifth year.

The response of the standard sticky-wage model to the preference shock, an increase in consumption demand, is quite perverse. Looking at Figure 3b, the increase in consumption drives up the demand for real balances causing prices to drop. This, in turn, increases the real wage by about 0.2 percent in the first year. Because the level of technology and the capital stock are unaffected in the first year, this increase in the real wage necessarily generates a fall in employment and output. So an increase in demand for consumption actually results in a contraction in output in the first year, with the increase in consumption more than offset by a significant drop in investment. As nominal wages adjust investment and output subsequently increase.

Again the response of the sticky wage model with effort – Figure 3c – is intermediate to the other two models. The real wage rises initially, similarly to the simple sticky wage model. But this induces an increase in productive effort at work that increases the marginal product of labor. This increase in effort exceeds the increase in real wage and results in an expansion in hours. The increase in hours in the first year is substantially less than for the flexible wage model. But thanks to the increase in effort, output expands nearly as much as under flexible wages. Note that hours and output both peak in the second year of the shock, with hours in particular showing a very strong humped shape response. Furthermore, real wages (and labor productivity) and TFP clearly lead the expansion in hours and output. By the time hours peak, TFP is back to normal and the real wage and labor productivity are below trend. The response of the model with sticky wages and endogenous effort to a preference shock is the only example of an impulse response, among the three models and three shocks we consider, that generates productivity leading hours.[11] From Table 3, this is a striking feature of the data.

[11] The models in Burnside, Eichenbaum, and Rebelo (1993) and Bils and Cho (1994) generate productivity leading hours thanks to important short-run adjustment costs for employment, despite complete wage flexibility. In many respects, however, our predictions differ sharply from those models. We predict a short-run decrease in effort in response to a favorable technology shock, whereas those models predict an increase. Most obviously contrasting with our results, those models, given flexible wages, predict no (or essentially no) response in hours or effort to monetary shocks.

Lastly we examine responses to a shock of one percent to the monetary growth rate. The impact on the economy with flexible wages is extremely small (no real variable departs as much as .001 percent from its steady-state value), so we skip to the two sticky wage models.[12] Results for the sticky wage model without effort response appear in Figure 4a. The impact on hours and output is very dramatic. The decline in real wages induces a transitory increase in hours of 4 percent and in output of 2.5 percent. The expansion is almost entirely through investment, which increases by about 8 percent. The monetary shock creates a persistent expansion in consumption, but not in output.

With endogenous effort, Figure 4b, the impact of the monetary shock is almost neutralized by the decrease in effort brought about by the decrease in the real wage. Hours still expand significantly by about 2 percent, as opposed to 4 percent. But this increase in hours is largely offset by a decline in effort so that the increase of effective labor in the market is very small. The impact on consumption, investment, and output is also small relative to the case of sticky wages with no effort response. The fall in effort created by the 1 percent monetary shock translates into a one-period drop in TFP of a little more than 0.6 percent. This is in the direction, and of similar magnitude, that we find for a VAR estimated on U.S. data, as reported above.

Cyclical moments for the models

We now compare the moments for time series generated from each of the three models to those reported for U.S. data in Table 2 and 3. Both data and the generated series are H-P filtered. The shocks to the models consist of the technology, preference, and monetary shocks estimated under each model, as described in the appendix.

Results for the flexible wage model are contained in Tables 4a and 4b. The model generates fluctuations in output and hours that are respectively 0.82 and 0.77 times the size of those observed in the data. The model generates slightly less persistent movements in real variables than exhibited by the data. The model generates much less persistent movements in prices than we see in the data. This statement holds for the other models

[12] None of the models we consider in the paper generates the liquidity effect in nominal interest from money supply, as we do not impose any friction other than nominal-wage rigidity in the labor market.

we consider as well. From Table 4b we see that the model generates contemporaneous correlations of labor productivity and TFP with hours of respectively .01 and .47. These are quite close to those estimated for U.S. data (.06 and .45). For the model movements in labor productivity and TFP modestly lag movements in hours. However, in the data, as discussed in the text, they very strongly lead hours.

Results under sticky wages and constant effort appear in Tables 5a and 5b. Hours are more variable for the model than in the data. The sticky-wage model, even augmented with technology and preference shocks, fails to produce the observed persistence of economic time series. This is particularly true for hours, which display a first-order correlation of .53 in the data but only .08 for the sticky wage model. (This problem is well known in the literature. For a recent discussion see Chari, et. al., 2000.) From Table 5b, the correlation between TFP and hours is .28. Unlike the data, hours and labor productivity are quite negatively correlated, with a correlation of –.41 compared to .06 for the data. Fluctuations in TFP do lead fluctuations in hours as in the data.

Finally, we present results for the model with sticky wages but varying effort in Tables 6a and 6b. Broadly speaking, the time-series properties of key macro variables such as output, consumption, investment and hours from this model are similar to those of the flexible wage model. Output is a bit more volatile than for the flexible wage model, and therefore closer to the volatility depicted in Table 3 for the U.S. economy. Looking at Table 6b, the model generates a contemporaneous correlation between hours and labor productivity of –.13 and between hours and TFP of .21. Both correlations fall below those for the flexible wage model and below those for the data. However, this model does exhibit fluctuations in labor productivity and TFP that significantly lead those in hours worked.[13] This is a significant improvement over the flexible-wage results in Table 5b.

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[13] The finding that TFP leads hours under sticky wages partly reflects the positive covariance between preference and productivity shocks. In particular, if we set the covariance of the two real shocks equal to zero, then productivity does not lead hours under sticky wages with constant effort. Consumption increases in response to an increase in q, causing prices to decrease. With a sticky wage this initially increases the real wage and, under constant effort, decreases hours. But this is transitory; hours expand after nominal wages can respond—see Figure 3b. If the preference shock is positively correlated with the technology shock then TFP leads hours. TFP goes up due to the technology shock. The delayed response in hours reflects the preference shock. These effects are relevant, but less important, for our sticky-wage

In sum, allowing for an effort response substantially improves how well a sticky-wage model matches the major features of U.S. business cycles. In particular, fluctuations in hours become much more persistent (as in the data); and the correlation between fluctuations in hours and labor productivity also becomes much closer to that observed for the data. Contrasts with the flexible-wage model are less striking. The sticky-wage with effort model does, however, do much better in producing that productivity strongly leads the cycle.[14]

5. Conclusions

We examine the impact of wage stickiness allowing a response in effort as well as hours. Sticky wages do create inefficient fluctuations in exertion at work relative to at home. But, because the labor market still clears, the consumption–leisure margin is much less distorted than if no response in effort is allowed. The impact of the sticky wage on hours worked is largely offset by variations in effort at work.

As a result, when we compare our model quantitatively to two models without an effort margin, one with flexible wages and one with sticky wages, we find output and consumption behave much like in the flexible-wage economy. Unlike the flexible wage

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model with an effort response. With responses in effort, productivity leads hours even if the covariance between the two real shocks is zero, though this effect is less striking.

[14] We also explore different specifications by varying γ and the steady-state ratio of effort between the market and at home, $\frac{f}{\tilde{f}}$, around their benchmark values. We consider the two added cases $\gamma = 1/6$ and $\gamma = ½$, while holding $\frac{f}{\tilde{f}}$ at its benchmark value of 1.5. A lower γ implies less substitutability between hours and effort in the market production, resulting in a slightly higher volatility and less persistence in hours and output. We also consider two added cases setting $\frac{f}{\tilde{f}} = 1$ and $\frac{f}{\tilde{f}} = 2$, holding $\gamma = 1/3$. A higher value of $\frac{f}{\tilde{f}}$ creates a further asymmetry between market and non-market activity in terms of substitutability between effort and hours, moving the economy closer to a standard to sticky wage model. As $\frac{f}{\tilde{f}}$ approaches 1, the volatility and persistence of the sticky-wage with endogenous economy become very similar to those of flexible wage economy. In fact, one can show that *to a first order approximation*, movements in effort offset those of hours when $\frac{f}{\tilde{f}}=1$. Yet, labor productivity and TFP continue to strongly lead hours of work under the sticky wage model with endogenous effort in all cases we consider.

model, however, our model can produce productivity that strongly leads hours over the cycle, as observed in the data. Allowing for an effort response significantly improves the ability of a sticky-wage model to match features of actual business cycles. Movements in hours and output become more persistent, as in the data. It eliminates the counterfactual prediction of the sticky-wage model that productivity and hours are negatively correlated. It also eliminates the sticky-wage model's odd result that a shock that increases consumption demand causes output to contract. Finally, the model with sticky-wages and varying effort is the only one considered that generates a decline in TFP in response to a positive nominal shock, as we find for U.S. data.

Appendix: ***Estimating the Models' Shocks:***

The three disturbances to technology, preferences, and the rate of money growth are described by equations (12) and (13) of the text.

As discussed in the text, with variable effort the Solow residual reflects variations in effort as well as technology $\hat{A}_t$,

$$\hat{Y}_t - (1-a)\hat{K}_t - a\hat{N}_t = \hat{A}_t + ag\hat{f}_t \ .$$

Wage setting in equation (11) yields an implied value for $E_t\hat{f}_{t+1}$. Intuitively, W_{t+1} is set such that the expectation of $\frac{f_{t+1}}{\tilde{f}_{t+1}}$ reflects its flexible wage counterpart of $\frac{g(1-l)}{l(1-g)}$. For $g \neq l$ this implies small movements in $E_t\hat{f}_{t+1}$ to satisfy energy constraint (1). We subtract $agE_t\hat{f}_{t+1}$ from the Solow residual at time t+1 to yield a variable with expectation at time t equal to $E_t\hat{A}_{t+1} = r_A\hat{A}_t$. We construct the expectation of the corrected t+1 Solow residual based on a projection on variables $\{\hat{Y}_t, \hat{Y}_{t-1}, \hat{N}_t, \hat{N}_{t-1}, \ \hat{K}_{t+1}, \hat{K}_t, \hat{K}_{t-1}, (\frac{\hat{W}_{t+1}}{W_t}), (\frac{\hat{W}_t}{W_{t-1}})\}$ to obtain $E_t\hat{A}_{t+1}$. We then estimate $\hat{r}_A$ from the first-order autocorrelation of $E_t\hat{A}_{t+1}$, which equals the autocorrelation of $\hat{A}_t$. Finally, we divide $E_t\hat{A}_{t+1}(= r_A\hat{A}_t)$ by $\hat{r}_A$ to obtain our time series for $\hat{A}_t$.

Under flexible wages preference shifts, q_t, can be related to hours worked and other observable variables, evaluating exertion at work and home at their first-best values, as $\frac{q_t}{1-q_t} = \frac{1-l}{1-g}\frac{P_t\tilde{c}_t}{W_t}\frac{1}{1-n_t}$. With the sticky wage choice for W_{t+1} in equation (11), this same relationship holds as of t+1 up to an expectation error as $\frac{q_{t+1}}{1-q_{t+1}} = \frac{1-l}{1-g}\frac{P_{t+1}\tilde{c}_{t+1}}{W_{t+1}}\frac{1}{1-n_{t+1}}e^{V_{t+1}}$, where $E_t[e^{V_{t+1}}] = 1$. Taking expectations of a log-linear approximation yields

$$E_t\hat{q}_{t+1} = (1-q)E_t[\frac{n}{1-n}\hat{n}_{t+1} + \hat{\tilde{c}}_{t+1} - (\tfrac{\hat{W}}{P})_{t+1}] .$$

Note $E_t[\hat{q}_{t+1}]$ has the same autocorrelation as $\hat{q}_t = r_q^{-1}E_t[\hat{q}_{t+1}]$. We use predicted values from regressing $\hat{q}_{t+1}$ on $\{\hat{n}_t, \hat{n}_{t-1}, \hat{\tilde{c}}_t, \hat{\tilde{c}}_{t-1}, (\frac{\hat{W}}{P})_t, (\frac{\hat{W}}{P})_{t-1}, \ \hat{K}_{t+1}, \hat{K}_t, \hat{K}_{t-1}, \ (\frac{\hat{W}_{t+1}}{W_t}), (\frac{\hat{W}_t}{W_{t-1}})\}$ to obtain $E_t[\hat{q}_{t+1}]$. Similarly to the treatment of $\hat{A}_t$, we use the first-order autocorrelation of $E_t[\hat{q}_{t+1}]$ to estimate r_q, then divide $E_t[\hat{q}_{t+1}]$ by r_q to obtain a series for $\hat{q}_t$. (We proceed in a similar manner for the model with sticky wages but no effort choice.)

Our monetary measure is based on calibrating nominal money demand and imposing, as is standard, that money supply equals demand. We then instrument for this variable with innovations to monetary policy. This is discussed in Section 3 of the text. It is well known that given the estimated growth rate of any monetary aggregate, stochastic general equilibrium models generate nominal variables that are far more volatile than the data. We find that, for all three models considered, our measure of money also leads to far more volatility in prices than we see in the data. For this reason, we scale down the monetary disturbances to half their estimated size to make the volatility of price closer to that in the data.

Given the series for $\{\hat{A}_t, \hat{q}_t, \hat{m}_t\}$, the stochastic process (12)-(13) is estimated by OLS using annual data for the United States for 1962-1996. Linear time trends are included. Estimates for r and Q are as follows (with the monetary innovation scaled to half). Under flexible wages,

$$\hat{r} = \begin{bmatrix} \underset{(.08)}{.82} & 0 & 0 \\ 0 & \underset{(.09)}{.88} & 0 \\ 0 & 0 & \underset{(.18)}{.13} \end{bmatrix}, \quad \hat{Q}^{1/2} = 10^{-2} \begin{bmatrix} 1.24 & .14 & -.15 \\ .14 & 1.06 & .00 \\ -.15 & .00 & .31 \end{bmatrix},$$

under sticky wages,

$$\hat{r} = \begin{bmatrix} \underset{(.08)}{.82} & 0 & 0 \\ 0 & \underset{(.09)}{.87} & 0 \\ 0 & 0 & \underset{(.18)}{.13} \end{bmatrix}, \quad \hat{Q}^{1/2} = 10^{-2} \begin{bmatrix} 1.19 & .37 & -.12 \\ .37 & 1.14 & -.12 \\ -.12 & -.12 & .30 \end{bmatrix},$$

and under sticky wages with endogenous efforts,

$$\hat{r} = \begin{bmatrix} \underset{(.09)}{.77} & 0 & 0 \\ 0 & \underset{(.09)}{.86} & 0 \\ 0 & 0 & \underset{(.18)}{.13} \end{bmatrix}, \quad \hat{Q}^{1/2} = 10^{-2} \begin{bmatrix} 1.18 & .24 & -.12 \\ .24 & 1.19 & -.13 \\ -.12 & -.13 & .29 \end{bmatrix}.$$

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Table 1 – Parameter Values for the Benchmark Case

Parameters	Description
$\alpha = 2/3$	Labor share in output
$\beta = 0.98$	Discount factor
$\delta = 0.1$	Depreciation rate
$g = 0.02$	Growth rate of technological progress
$\xi = 1$	Labor supply elasticity
$n = 0.5$	Steady-state hours of work
$\gamma = 1/3$	Ability to substitute hours and effort in the market
$\lambda = 1/4$	Ability to substitute hours and effort at home
$\upsilon = .1$	Interest rate elasticity of money demand
$\chi = .9999$	Relative share of consumption in utility
$\theta = 0.6332$	Steady-state value in preference

Table 2 – Volatility, persistence, and cyclicality: U.S. time series 1954-1996 [#]

Variable (x)	σ_x	$\sigma_x / \sigma_{output}$	cor(x_t, x_{t-1})	cor(x, output)
Output	2.29	1.00	.57	1.00
Consumption	1.32	.58	.67	.88
Investment	6.39	2.79	.41	.83
Hours	2.01	.88	.53	.91
Price	.97	.42	.81	-.57
Real wage	.94	.44	.48	.49
Labor productivity	.97	.42	.46	.48
Solow residual	1.29	.57	.45	.82

Table 3 – Lead and Lag correlations with hours at *t*

Variable (x)	x(t-3)	x(t-2)	x(t-1)	x(t)	x(t+1)	x(t+2)	X(t+3)
Real wage	-.28	-.01	.38	.43	-.09	-.36	-.28
Labor productivity	.14	.54	.65	.06	-.38	-.23	-.14
Solow residual	.16	.51	.76	.45	-.28	-.46	-.39

[#] Output: real GDP. Consumption: expenditure on non-durables and services. Investment: fixed investment. Hours: employed man-hours. Real wage: average hourly earning. Labor productivity: output divided by hours. Quantities are divided by population of age over 20. All variables are annual and H-P filtered with the weight parameter 100.

Table 4a – Volatility, persistence, and cyclicality: Flexible wages

Variable (x)	σ_x	σ_x / σ_{output}	cor(x_t, x_{t-1})	cor(x, output)
Output	1.87	1.00	.41	1.00
Consumption	1.15	.61	.51	.92
Investment	4.07	2.17	.37	.96
Hours	1.55	.83	.38	.83
Price	1.22	.65	.51	-.90
Labor productivity	1.03	.55	.45	.55
TFP	1.14	.61	.38	.86

Table 4b – Lead and lag correlations with hours at *t*: Flexible wages

Variable (x)	x(t-3)	x(t-2)	x(t-1)	x(t)	x(t+1)	x(t+2)	x(t+3)
Labor productivity	-.12	-.12	-.09	.01	.12	.13	.11
TFP	-.11	-.02	.16	.47	.19	.02	-.07

Table 5a – Volatility, persistence, and cyclicality: Sticky wages & constant effort

Variable (x)	σ_x	$\sigma_x / \sigma_{output}$	cor(x_t, x_{t-1})	cor(x, output)
Output	2.07	1.00	.35	1.00
Consumption	1.10	.53	.53	.71
Investment	5.60	2.70	.11	.94
Hours	2.26	1.09	.08	.84
Price	1.21	.58	.51	-.69
Labor productivity	1.22	.59	.10	.13
TFP	1.41	.55	.37	.73

Table 5b – Lead and lag correlations with hours at *t*: Sticky wages & constant effort

Variable (x)	x(t-3)	x(t-2)	x(t-1)	x(t)	x(t+1)	x(t+2)	x(t+3)
Labor productivity	-.02	.09	.25	-.41	.12	.11	.06
TFP	-.06	.13	.41	.28	.07	-.05	-.12

Table 6a – Volatility, persistence, and cyclicality: Sticky wages & effort response

Variable (x)	σ_x	σ_x / σ_{output}	cor(x_t, x_{t-1})	cor(x, output)
Output	1.90	1.00	.40	1.00
Consumption	1.20	.63	.48	.91
Investment	4.07	2.14	.35	.95
Hours	1.51	.79	.38	.68
Price	1.32	.69	.48	-.89
Labor productivity	1.36	.72	.04	.61
TFP	1.41	.74	.14	.83

Table 6b – Lead and lag correlations with hours at *t*: Sticky wages & effort response

Variable (x)	x(t-3)	x(t-2)	x(t-1)	x(t)	x(t+1)	x(t+2)	x(t+3)
Labor productivity	-.00	.12	.34	-.13	-.09	-.02	.02
TFP	-.01	.18	.52	.21	-.04	-.12	-.12

Figure 1 Labor market equilibrium: sticky wage with effort

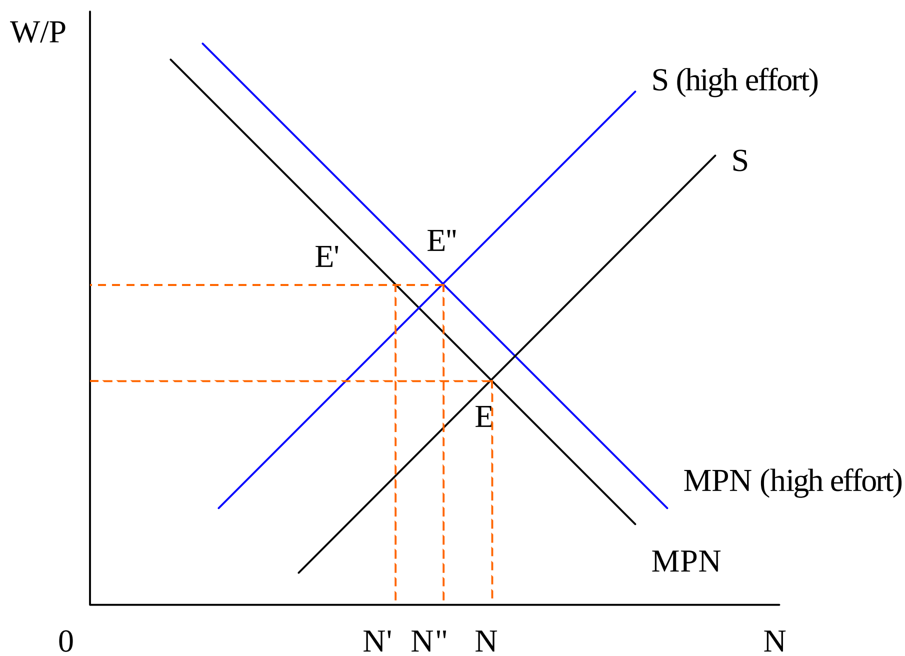

Figure 2a Impulse response of VAR: inflation rate and TFP

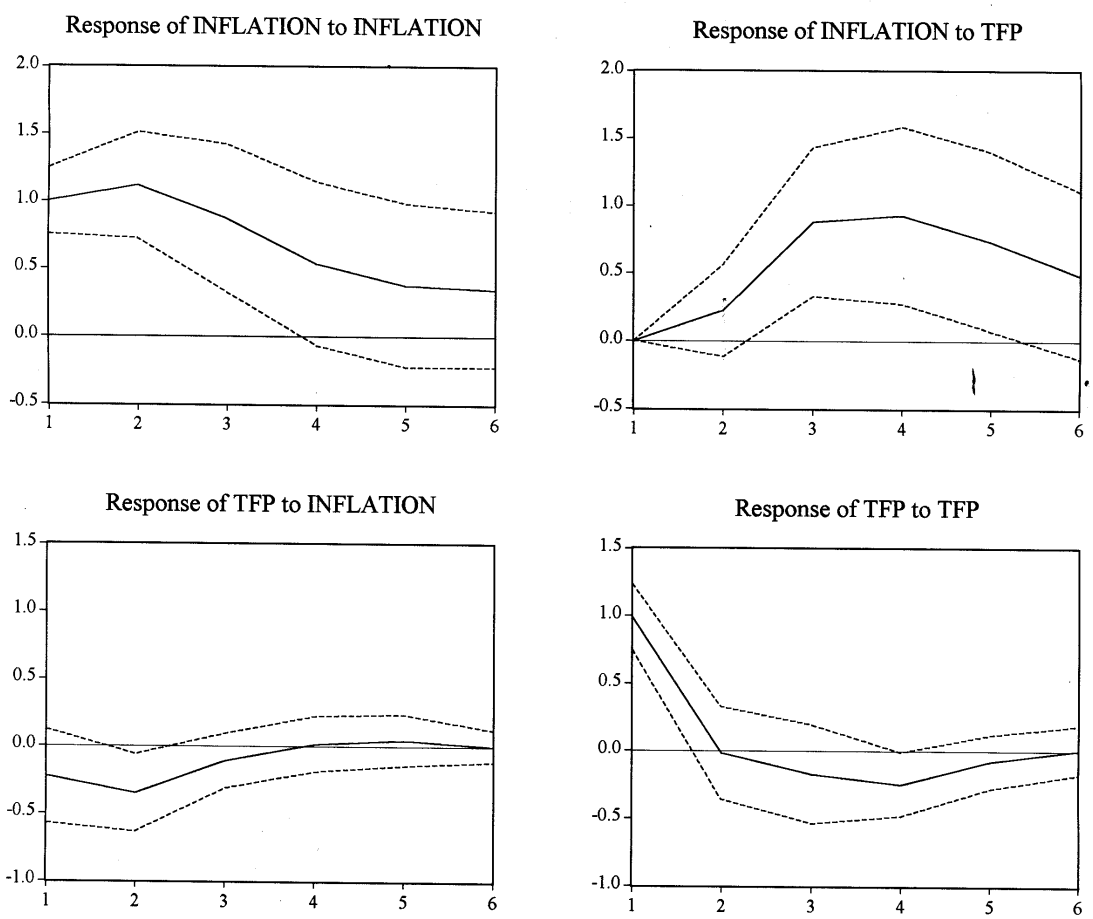

Figure 2b Impulse response of VAR: growth rate of money measure and TFP

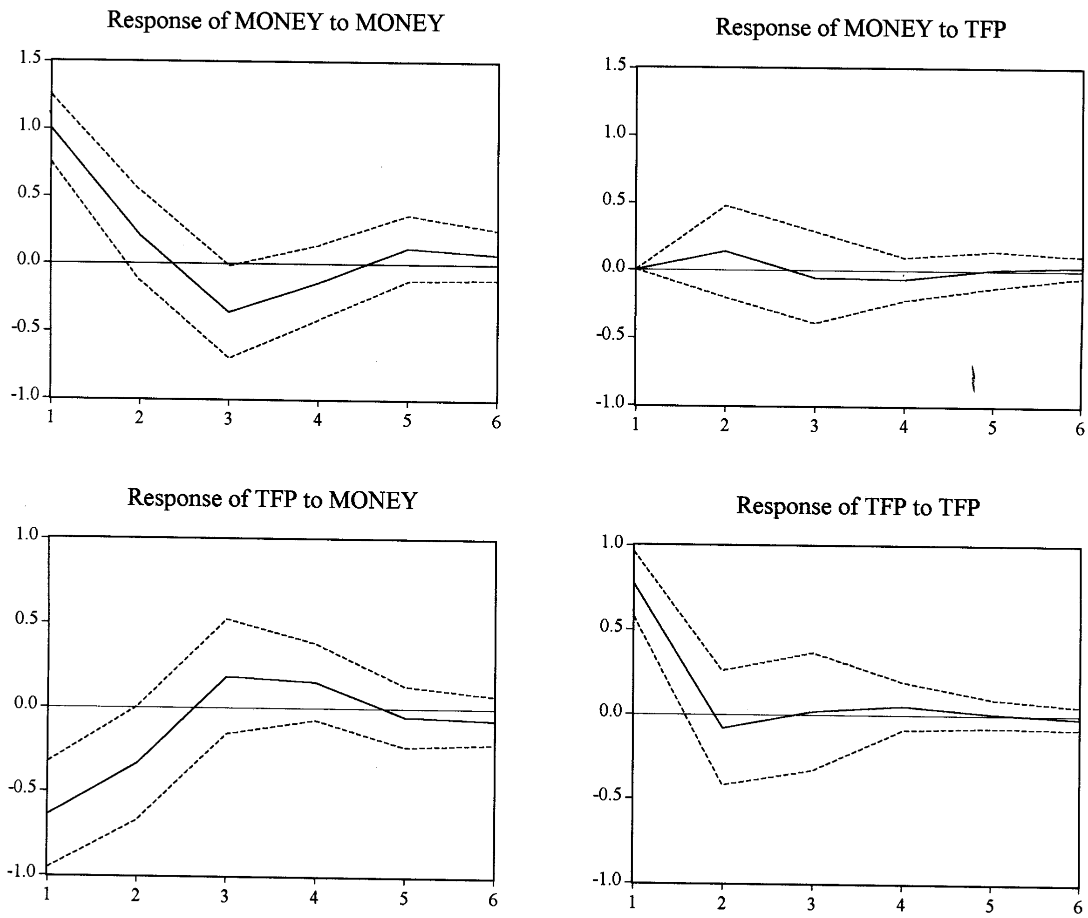

Figure 3a Impulse response to 1% increase in preference shock: flexible wage

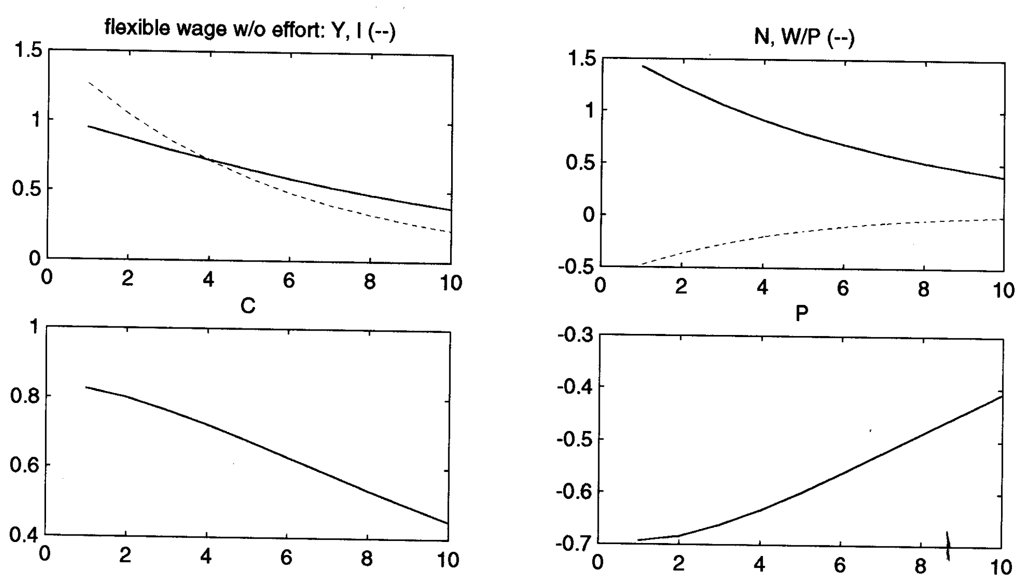

Figure 3b Impulse response to 1% increase in preference shock: sticky wage

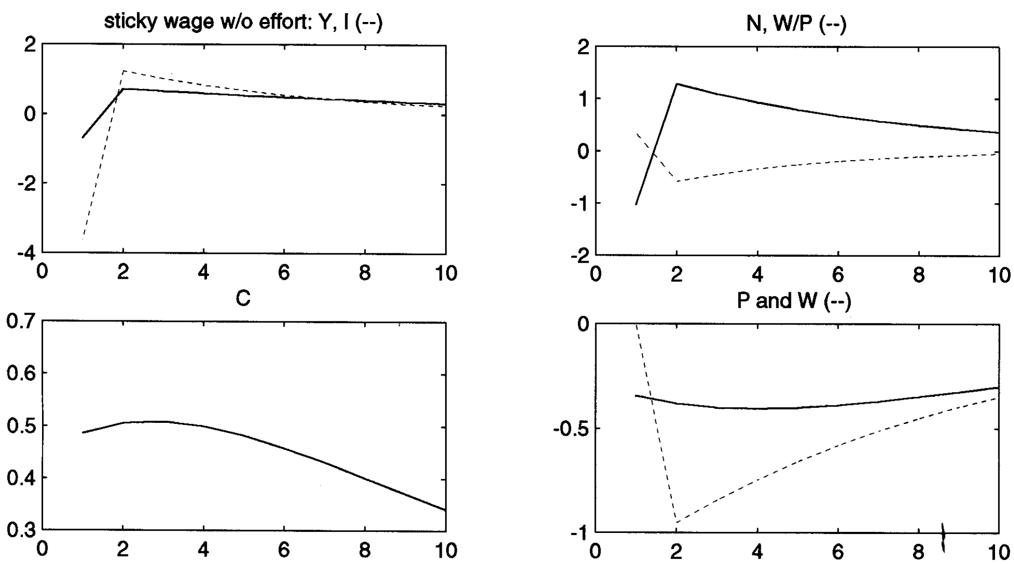

Figure 3c Impulse response to 1% increase in preference shock: sticky wage with effort

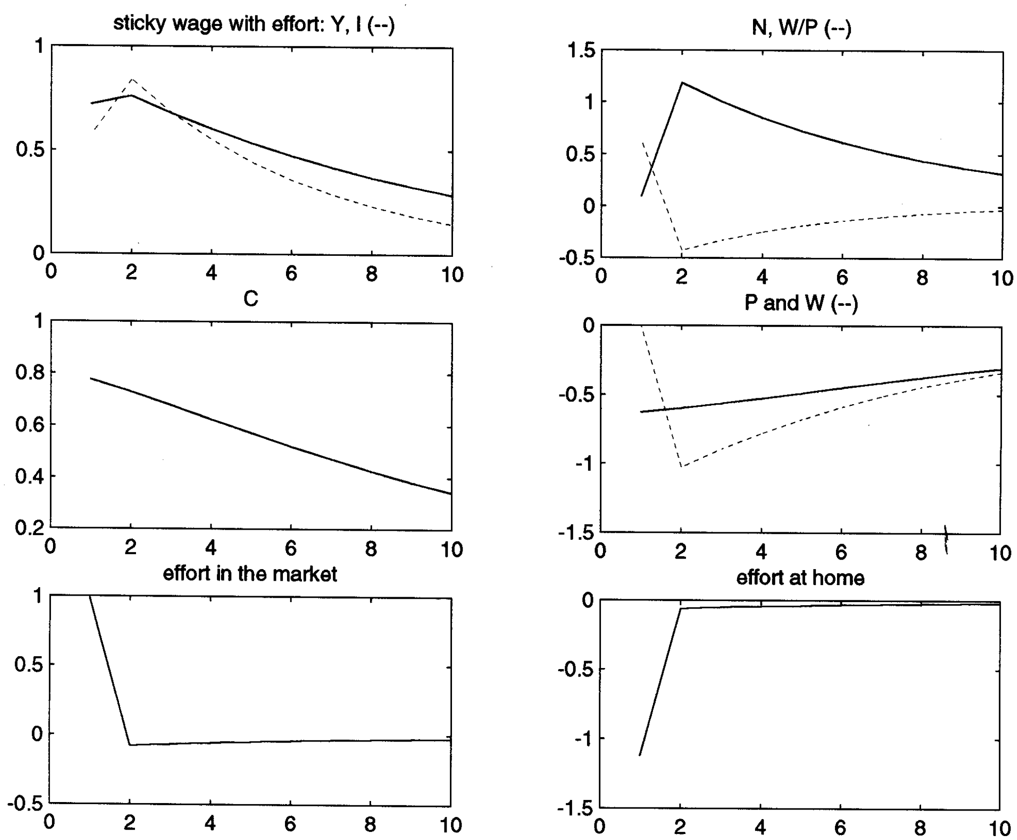

Figure 4a Impulse response to 1% increase in money growth: sticky wage

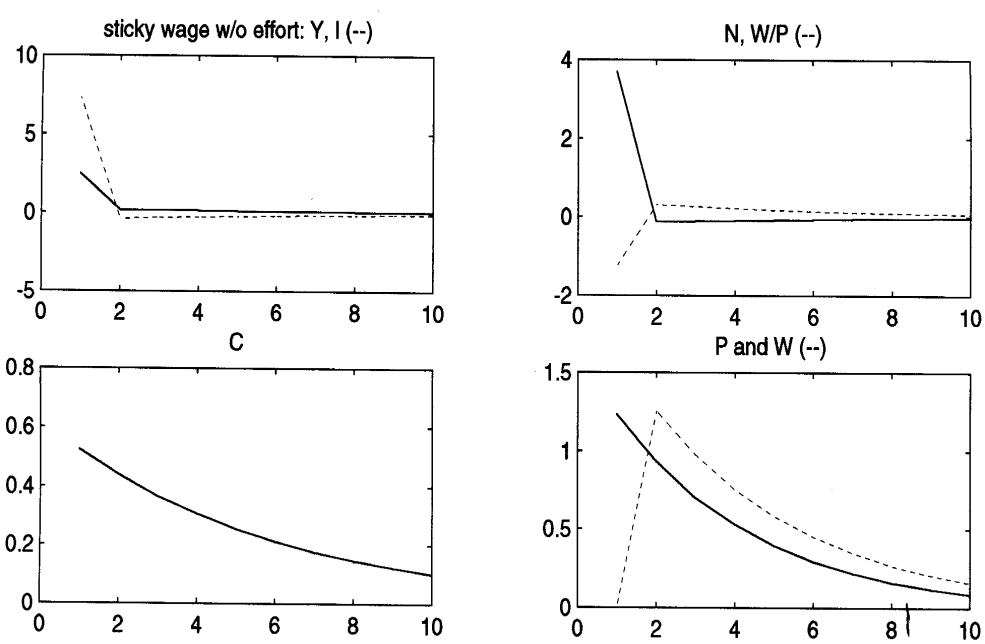

Figure 4b Impulse response to 1% increase in money growth: sticky wage with effort