Dual Wage Rigidities: Theory and Some Evidence

Kim, Insu

University of California, Riverside

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Dual Wage Stickiness: Theory and Some Evidence

Insu Kim*
University of California, Riverside

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Abstract

This paper investigates wage dynamics assuming the potential presence of dual wage stickiness: with respect to both the frequency as well as the size of wage adjustments. In particular, this paper proposes a structural model of wage inflation dynamics assuming that although workers adjust wage contracts at discrete time intervals, they are limited in their abilities to adjust wages as much as they might desire. The dual wage stickiness model nests the baseline model, based on Calvo-type wage stickiness, as a particular case. Empirical results favor the dual sticky wage model over the baseline model that assumes only one type of wage stickiness in several dimensions. In particular, it outperforms the baseline model in terms of goodness of fitness as well as in the ability to explain the observed reverse dynamic cross-correlation between wage inflation and real output - which the baseline model fails to capture.

JEL Classification: E31, E32, J30

Key words: Wage inflation, sticky wages, sticky prices, new Keynesian, hybrid.

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* Kim, address: Economics Department, University of California, Riverside, Sproul Hall 4128, 900 University Avenue, Riverside, CA 92521 (email:insu.kim@email.ucr.edu). The author is grateful to Marcelle Chauvet for helpful comments and suggestions.

1. Introduction

Wage dynamics have important implications for households, firms, and for monetary and fiscal policies. The goal of this paper is to construct a sticky wage model that is able to provide not only an improved characterization of wage dynamics for policy analysis, but also to replicate the reverse dynamic correlation between wage inflation and real output. [1] In particular, this paper proposes a novel framework that successfully combines two types of wage stickiness.

Staggered wage contract models based on Calvo (1983) have been widely employed in the literature (e.g., Kollmann 1996; Erceg, Henderson and Levin 2000; Christiano, Eichenbaum and Evans 2005; Smets and Wouters 2007; Justiniano and Primiceri 2008; among several others). These models assume that a fraction of workers completely adjust their wages at discrete time intervals in response to changes in the economic environment. However, the assumption that workers are able to adjust their wages as much as they would like to when they periodically negotiate their wage contracts is not realistic. Since wages are determined through the interaction between workers and firms, the workers' ability to fully adjust their wages is likely to be limited. As a consequence, although workers may re-optimize their wages at certain time intervals, wages can be partially adjusted in response to changes in economic conditions.

In this respect, this paper investigates the existence of dual types of wage stickiness: one with respect to the frequency of wage adjustments and another with

[1] The dynamic correlation that has been observed between wage inflation and real output indicates that current output is negatively related to past wage inflation, while also being positively correlated to future wage inflation. Taylor (1999) stresses that the ability to explain the reverse dynamic correlation between price inflation and real output is an important "measure of success" of monetary models. Similarly, the ability to explain the reverse dynamic correlation between wage inflation and real output could be considered to be a success of a sticky wage model.

respect to the magnitude of those adjustments. More specifically, the proposed model introduces, in addition to Calvo-type wage stickiness, the quadratic costs of wage adjustment that make it costly for current wages to deviate from previous period wages. In this way, workers' limited abilities to fully adjust wages are formally taken into consideration. Although both the Calvo-type wage setting and the quadratic costs of wage adjustment play a similar role in generating wage stickiness, their implications are different with respect to the frequency and size of wage adjustments. That is, while Calvo-type wage stickiness is related to the timing/frequency of wage adjustment, the quadratic costs of wage adjustment are associated with the magnitude of wage changes when workers reset their wage contracts. In the proposed dual wage stickiness model, current wage inflation depends on past and expected future wage inflation, current and expected future price inflation, and wage markup.[2] The lagged wage inflation term is introduced into the model due to these two sources of wage stickiness. The proposed model extends the baseline sticky wage model by Erceg, Henderson and Levin (EHL baseline, 2000) to include our proposed feature, dual wage stickiness.[3]

In order to investigate the presence of dual wage stickiness and wage inflation dynamics, this paper builds a dynamic stochastic general equilibrium (DSGE) model that allows workers and firms to optimally set their wage contracts and prices, respectively, in monopolistically competitive labor and goods markets. The central bank conducts monetary policy using the Taylor rule.

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[2] Wage markup is defined as the difference between the real wage rate and the marginal rate of substitution between consumption and leisure.

[3] While the Calvo-cum-wage-indexation model by Christiano, Eichenbaum and Evans (2005) assumes that wages change continuously, the proposed model assumes that wages are adjusted infrequently. The Calvo-cum-wage-indexation model allows each worker to adjust their wages optimally or by automatic indexation in any given period.

The DSGE model is estimated using Bayesian techniques. The findings favor the dual wage stickiness model over the baseline model based on only Calvo-type wage stickiness. First, although households reset their wages at certain intervals of time, estimates of the parameter associated with the quadratic costs of wage adjustment are significantly different from zero, rejecting the null hypothesis of no quadratic wage adjustment costs. Second, the marginal likelihood clearly supports the dual wage stickiness model over the baseline model, which relies only on Calvo-type wage stickiness (Calvo 1983). The inclusion of quadratic wage adjustment costs yields a substantial improvement of the model in fitting the data. Third, the observed dynamic correlation between wage inflation and real output can be better replicated under dual wage stickiness. While the baseline model fails to generate the expected lead-lag relationship between wage inflation and output, the introduction of quadratic costs of wage adjustment in the proposed model yields the observed negative (positive) relationship between past (future) wage inflation and real output. The dual wage stickiness model is able to explain the fact that a rise in current output is associated with a subsequent increase in wage inflation. Overall, the presence of dual sticky wage stickiness helps provide an improved explanation of wage inflation dynamics.

In order to check the stability of the structural parameters, the DSGE model is estimated using two subsamples. The full sample, from 1960:1 to 2007:4, is divided before and after 1980. The findings demonstrate that while most of the structural parameters are stable over subsamples, there are substantial changes in monetary policy along the lines of the ones found in Clarida, Gali and Gertler (2000). In particular, the response of the Federal Reserve to inflation is different across subsamples.

The rest of this paper is organized as follows. The sticky wage model is derived in the next section assuming the two types of wage stickiness. Section 3 presents the empirical results from estimation of the proposed DSGE model using Bayesian techniques. Evidence on dual wage stickiness is provided in terms of the marginal likelihood and the dynamic cross-correlation between wage inflation and output. In addition, this section investigates robustness of the estimation results to sub-samples. The last section concludes this paper.

2 A Model Economy

2.1 Households

There is a continuum of households indexed by $i \in [0,\ 1]$. Following EHL (2000), this paper assumes that each household is a monopolistic supplier of a differentiated labor service. A representative labor aggregator combines households' differentiated labor services into units of labor for use in the production sector. While each household has monopoly power over a differentiated labor service, the labor aggregator faces perfect competition, making zero profits.[4] Each household chooses the amount of consumption, the amount of contingent claims and set his/her wage. The intertemporal utility function of household i is given by

$$E_t \sum_{k=0}^{\infty} (\beta)^k \left[\frac{1}{1-1/\sigma} C_{i,t+k}^{1-1/\sigma} - H_{i,t+k} \right]. \tag{1}$$

Household i maximizes the expected utility function subject to the budget constraint,

[4] As in Erceg, Henderson and Levin (2000), this paper does not assume capital. See EHL for details.

$$C_{i,t}+\frac{J_{t,t+1}B_{i,t+1}}{P_t}+\frac{\overline{C}}{2}\left(\frac{W_{i,t}/P_t}{W_{i,t-1}/P_{t-1}}-1\right)^2 I_{i,t}=\frac{W_{i,t}}{P_{t-1}}H_{i,t}+\frac{B_{i,t}}{P_t}+\frac{\Pi_{i,t}}{P_t} \tag{2}$$

where $C_{i,t}$, $H_{i,t}$, $B_{i,t}$, P_t, $W_{i,t}$ and $\Pi_{i,t}$ denotes real consumption, hours worked, state-contingent claims, the price index, wages, and a share of profits, respectively. $J_{t,t+1}$ is the price of state contingent claims that pays one dollar if a particular state of nature is realized in period $t+1$. Each household owns an equal share of all firms and receives equal profit ($\Pi_{i,t}$) from firms. The indicator function $I_{i,t}$ is equal to 1 when household i resets its wage contract and otherwise is equal to zero. The indicator function is introduced because of the assumption that each household keeps its wage contract unchanged with a constant probability α_w in any given period. It is worth emphasizing that households face the quadratic costs of adjusting wages only when they reset their wage contracts. In the Calvo economy, a constant fraction ($1-\alpha_w$) of households that receive a random wage-change signal are allowed to reoptimize their wage contracts every period, whereas the remaining households keep their wages unchanged in any given period.[5] The quadratic costs of wage adjustment appear in the budget constraint to restrict each household's ability to fully adjust its wages in response to changes in economic environment. The costs of wage adjustment increase with the magnitude of the adjustment, resulting in sticky wages.

In the literature, wage rigidities are typically introduced through either a Calvo-type staggered wage setting (e.g., EHL 2000) or the quadratic wage adjustment costs (e.g., Kim 2000). Since these modeling approaches play the same role in making wages sticky,

[5] The timing/frequency of wage changes is exogenously determined in the Calvo economy. The time interval between wage changes is given by $1/(1-\alpha_w)$ on average.

within the literature either one or the other is considered to be a potential source of wage stickiness. However, despite the similarity between the two approaches in terms of wage stickiness, they reflect different dimensions of the decision problems that households face. Households are likely to face two problems regarding wage setting in the micro level: (1) when to change wages, (2) how much to change wages. The second problem is especially critical when households' abilities to fully adjust their wages are limited. Analogous to the idea the firms have limited abilities to fully adjust prices due to the interaction between consumers and firms in the goods market, which is formally introduced through the use of quadratic adjustment costs (e.g., Rotemberg 1982), households' limited abilities that arise as a result of the interaction between firms and households in the labor market could be modeled using the quadratic costs of adjusting wages. While the first problem of households is related to Calvo-type staggered wage setting, the second problem is associated with the quadratic wage adjustment costs.

Following EHL (2000), this paper assumes that a set of complete state-contingent claims are available to households, which ensures that these agents are homogeneous with respect to holdings of contingent claims and consumption. Since such claims are able to provide complete insurance from the idiosyncratic income risk that arises from staggered wage contracts and the wage adjustment cost, households make identical decisions with respect to consumption and holdings of contingent claims.

The maximization of the objective function with respect to consumption and holdings of contingent claims subject to the budget constraint leads to the Euler equation. Log-linearizing the Euler equation gives rise to the familiar IS curve that can be written as

$$y_t = E_t y_{t+1} - \sigma(r_t - E_t \pi_{t+1}) \tag{3}$$

where y_t denotes output. The nominal interest rate r_t is defined as the log-deviation of $[J_{t,t+1}]^{-1}$ from the steady state. The parameter σ measures the intertemporal elasticity of substitution.

2.2 Households and Wage Setting

Household i supplies a differentiated labor service $H_{i,t}$ to the labor aggregator, which combines a continuum of individual types of labor supplied into an aggregate labor service, H_t, using a CES aggregator function described by

$$H_t = \left[\int_0^1 H_{i,t}^{(\theta_w - 1)/\theta_w} di \right]^{\theta_w/(\theta_w - 1)} \tag{4}$$

where the parameter $\theta_w \geq 1$ is the elasticity of substitution across differentiated labor services. The labor aggregator purchases individual types of labor at a given wage $W_{i,t}$ for labor type i and sells each unit of labor to the production sector at the aggregate wage rate W_t. The perfectly competitive labor aggregator chooses $H_{i,t}$ to maximize its profit, taking each household's wage as given. The aggregator's objective function is described by

$$W_t \left[\int_0^1 H_{i,t}^{(\theta_w - 1)/\theta_w} di \right]^{\theta_w/(\theta_w - 1)} - \int_0^1 W_{i,t} H_{i,t} di. \tag{5}$$

The first order condition associated with this problem leads to the demand for labor supplied by household i

$$H_{i,t} = \left(\frac{W_{i,t}}{W_t} \right)^{-\theta_w} H_t. \tag{6}$$

Integrating (6) results in the following equation

$$W_t = \left(\int_0^1 W_{i,t}^{1-\theta_w} di \right)^{1/(1-\theta_w)} \tag{7}$$

which shows the relationship between W_t and $W_{i,t}$. The wage rate W_t could be interpreted as the aggregate wage index.

Household i chooses its nominal wage by maximizing the objective function (1) subject to both the budget constraint and the labor demand function (6), assuming that the newly optimized wage remains in effect with the probability α_w in any given period. Solving household i's problem with respect to $W_{i,t}$ is equivalent to maximizing the objective function:

$$E_t \sum_{k=0}^{\infty} (\alpha_w \beta)^k \left[\Gamma_{t+k} \frac{W_{i,t}}{P_{t+k}} H_{i,t+k} - H_{i,t+k} \right] - \frac{\overline{C}}{2} \left(\frac{W_{i,t}/P_t}{W_{i,t-1}/P_{t-1}} - 1 \right)^2 \tag{8}$$

subject to the labor demand curve (6), delivering the same first order condition. Γ_{t+k} represents the marginal utility of income at time $t+k$. The objective function (8) clearly shows each household's problem with respect to a wage $W_{i,t}$ for labor type i.

The first order condition associated with the object function (8) leads to the same optimal wage choice for all households that adjust their wages at time t.[6] Following Calvo's scheme, the aggregate wage level evolves according to

$$W_t = \left[(1-\alpha_w) \widetilde{W}_t^{1-\theta_w} + \alpha_w W_{t-1}^{1-\theta_w} \right]^{1/(1-\theta_w)} \tag{9}$$

where $\widetilde{W}_t$ is the optimal wage chosen by households at time t. Log-linearizing the first order condition from (8) yields the following equation given by

[6] see Woodford (2003) for details.

$$E_t \sum_{k=0}^{\infty} (\alpha_w \beta)^k [\tilde{w}_t - p_{t+k} - mrs_{t+k}] = \frac{\bar{c}}{1-\theta_w} [\tilde{w}_t - \tilde{w}_{t-1} - \pi_t^p] \tag{10}$$

where $\bar{c} = \overline{C} / \left[c_{ss}^{-1/\sigma} h_{ss} \frac{w_{ss}}{p_{ss}} \right]$. x_{ss} is the steady state value of x for $x = c, h, w$ and p.

The lower-case variables represent the log-deviations of variables of interest from steady state values. mrs_t denotes the marginal rate of substitution between consumption and hours worked. π_t^p is defined as $p_t - p_{t-1}$.

The log-linearization of equation (9) yields $\tilde{w}_t = (w_t - \alpha_w w_{t-1})/(1-\alpha_w)$, therefore $\tilde{w}_t - \tilde{w}_{t-1} = (\pi_t^w - \alpha_w \pi_{t-1}^w)/(1-\alpha_w)$ where π_t^w is defined as $w_t - w_{t-1}$. When plugging $\tilde{w}_t - \tilde{w}_{t-1}$ into equation (10), a lagged wage inflation term π_{t-1}^w is endogenously introduced into the model. Since dual wage stickiness makes wages sticky twice, current wages can be expressed as a function of w_{t-2}, which is necessary to generate a lagged wage inflation term. The wage Phillips curve can be written as follows:

$$\pi_t^w = \Lambda_1 E_t \pi_{t+1}^w + \Lambda_2 \pi_{t-1}^w - \Psi_1 E_t \pi_{t+1}^p + \Psi_2 E_t \pi_t^p + \lambda^w [mrs_t - (w_t - p_t)] \tag{11}$$

where $\Lambda_1 \equiv \kappa_1 / \xi, \Lambda_2 \equiv \kappa_2 / \xi, \psi_1 \equiv \tau_1 / \xi, \psi_2 \equiv \tau_2 / \xi, \xi \equiv [\alpha_w(\theta_w - 1) + \bar{c}(1-\alpha_w\beta)(1+\alpha_w^2\beta)]$, $\kappa_1 \equiv (\alpha_w \beta)[(\theta_w - 1) + \bar{c}(1-\alpha_w\beta)]$, $\kappa_2 \equiv \bar{c}(1-\alpha_w\beta)\alpha_w$, $\tau_1 \equiv \alpha_w \beta\, \bar{c}(1-\alpha_w\beta)(1-\alpha_w)$, $\tau_2 \equiv \bar{c}(1-\alpha_w\beta)(1-\alpha_w)$, and $\lambda_{\mathrm{w}} \equiv (\theta_w - 1)(1-\alpha_w)(1-\alpha_w\beta)/\xi$. The wage mark-up ($\mu_t^w$) as a driving force of wage inflation is defined as the difference between the real wage and the marginal rate of substitution, that is, $\mu_t^w \equiv (w_t - p_t) - mrs_t$. When the quadratic adjustment cost does not exist, the proposed model collapses into the baseline model reported in the literature,

$$\pi_t^w = \beta E_t \pi_{t+1}^w + \frac{(1-\alpha_w\beta)(1-\alpha_w)}{\alpha_w} [mrs_t - (w_t - p_t)]. \tag{12}$$

Since the proposed dual wage stickiness model nests equation (12) as a special case, the significant estimate of $\bar{c}$ can be interpreted as a test for the presence of the quadratic costs of adjustment.

The following identity relationship between real wages and wage inflation is considered:

$$w_t - p_t \equiv w_{t-1} - p_{t-1} + \Delta w_t - \Delta p_t. \tag{13}$$

In the next subsection, the new Keynesian Phillips curve is derived for DSGE model analysis.

2.3 Firms and Price Setting

This paper assumes that the economy consists of two types of firms, the representative final-goods-producing firm and a continuum of intermediate-goods-producing firms. The final-goods-producing firm purchases intermediate goods and transforms a continuum of intermediate goods, indexed by $j \in [0,1]$, into the final good using a constant returns to scale production function of the Dixit-Stiglitz form:

$$Y_t = \left[\int_0^1 Y_{j,t}^{(\theta_p - 1)/\theta_p} dj \right]^{\theta_p/(\theta_p - 1)} \tag{14}$$

where $\theta_p \geq 1$ is the constant elasticity of substitution across intermediate goods. The final good, Y_t, is produced by combining intermediate goods from the perfectly competitive, representative firm, which maximizes its profit taking the prices of intermediate goods ($P_{j,t}$, $j \in [0,1]$) as given. Maximizing profit with respect to $Y_{j,t}$ yields the demand curve that an intermediate-goods-producing firm j faces

$$Y_{j,t} = \left(\frac{P_{j,t}}{P_t} \right)^{-\theta_p} Y_t. \tag{15}$$

Integrating (15) reveals the relationship between the price of the final good and the prices of intermediate goods, which can be written as

$$P_t = \left(\int_0^1 P_{j,t}^{1-\theta_p} dj \right)^{1/(1-\theta_p)}. \tag{16}$$

The price of the final good is viewed as the aggregate price index. It is assumed that a constant fraction $(1-\alpha_p)$ of firms can reset their prices with all other firms keeping their prices unchanged in any given period. Since the intermediate-goods-producing firms choose the same price, $\tilde{P}_t = P_{j,t}$ for all j in equilibrium, the aggregate price level evolves according to

$$P_t = \left[(1-\alpha_p) \tilde{P}_t^{1-\theta_p} + \alpha_p P_{t-1}^{1-\theta_p} \right]^{1/(1-\theta_p)}. \tag{17}$$

The Calvo pricing equation implies that the aggregate price level is a function of its own lag, which can potentially cause aggregate prices to change in a sluggish manner.

The model assumes an economy with firms producing intermediate goods according to constant returns to scale, $Y_{j,t} = A_t H_{j,t}$. A_t represents the neutral technology shock, which is identical across firms. The integration of the production function with respect to j leads to $Y_t = A_t H_t$. The log-linearization of $Y_t = A_t H_t$ yields

$$y_t = a_t + h_t \tag{18}$$

where a_t and h_t are the log-deviations of A_t and H_t from steady state values, respectively. a_t follows an AR(1) process, $a_t = \delta_a a_{t-1} + v_t^a$, where v_t^a is distributed $N(0, \sigma_a)$.

The monopolistically competitive intermediate-goods-producing firm j chooses $\tilde{P}_t$ to maximize the following objective function,

$$E_t \sum_{k=0}^{\infty} (\alpha_p \beta)^k \left[\frac{(\tilde{P}_t - MC_{t+k}) Y_{j,t+k}}{P_{t+k}} \right], \tag{19}$$

subject to the demand curve for the intermediate good j, equation (15).[7] MC_t denotes the marginal cost at time t. Combining equation (17) and the first order condition of equation (19) yields the new Keynesian Phillips curve:

$$\pi_t^p = \beta E_t \pi_{t+1}^p + \frac{(1-\alpha_p \beta)(1-\alpha_p)}{\alpha_p} mc_t. \tag{20}$$

where mc_t is defined as the distance between the real wage and the marginal product of labor, $(w_t - p_t) - mpl_t$.

2.4 Monetary Policy and the Taylor Rule

The central bank conducts monetary policy using the Taylor rule to set short-term interest rates in response to inflation and output.

$$r_t = \rho r_{t-1} + (1-\rho)(\alpha_\pi E_t \pi_{t+1}^p + \alpha_y y_t) \tag{21}$$

The parameter ρ measures the degree of interest rate smoothing in monetary policy. To stabilize the economy, the central bank adjusts nominal interest rates gradually in response to changes in the expected inflation and output. The central bank's response to inflation and output is determined by the magnitude of α_π and α_y, respectively.

[7] Firms can face costs of adjusting wages. However, those costs of adjusting wages are not related to the newly optimized price. So, we ignore it in the above objective function.

3 Empirical Results: Bayesian Estimation

3.1 The Data

The data used are quarterly U.S. series for interest rate, price inflation, real wages, hours worked, and real GDP. The sample period ranges from 1960:1 to 2007:04. Aggregate price is measured by the GDP deflator. Hours worked and nominal wages (nominal compensation per hour) are from the non-farm business sector. Real wages are obtained by dividing nominal compensation per hour by the GDP deflator. The effective federal fund rate is used to represent interest rates. The real wage and hours worked are detrended using the HP-filter. Output is detrended by the use of the Congressional Budget Office's potential output. Price inflation is defined as the quarterly log difference in the GDP deflator. Wage inflation is similarly defined as the log difference in nominal wages.

3.2 Empirical Model

Following Ireland (2004), in order to consider the potential misspecification in the IS and Phillips curves related to the presence of lags of price inflation and output, I replace equation (3) and (20), respectively, with:

$$y_t = \varphi E_t y_{t+1} + (1-\varphi) y_{t-1} - \sigma(r_t - E_t \pi_{t+1}) \tag{22}$$

$$\pi_t^p = \beta(\gamma E_t \pi_{t+1}^p + (1-\gamma)\pi_{t-1}^p + \frac{(1-\alpha_p \beta)(1-\alpha_p)}{\alpha_p} mc_t. \tag{23}$$

These equations nest equation (3) and (20) as a special case when φ and γ, respectively.[8] The estimates of φ and γ determine the relative importance of the lagged terms in explaining output and inflation dynamics.[9]

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[8] This paper also estimates the DSGE model with φ (or γ) fixed to be 1. See Table 3.

For empirical analysis, we add exogenous shocks to (11), (21), (22) and (23). Each exogenous shock can be written as follows:

$$\varepsilon_t^k = \delta_k \varepsilon_{t-1}^k + \nu_t^k \tag{24}$$

where each innovation ν_t^k is normally distributed $N(0, \sigma_k)$ for $k = w, r, y, p$. We assume that $\delta_r = \delta_w = 0$.[10] The shocks are interpreted as the wage-push, interest rate, demand, and cost-push shocks, respectively. All of these shocks, including the technology shock, are assumed to be uncorrelated with each other.

3.3 Estimation Results

The DSGE model parameters are collected in the parameter vector, $\Phi = \{\alpha_p, \beta, \sigma, \bar{c}, \varphi, \gamma, \rho, \alpha_\pi, \alpha_y, \delta_\pi, \delta_y, \delta_a, \sigma_\pi, \sigma_y, \sigma_i, \sigma_w, \sigma_a\}$. The parameter θ_w is set equal to 6. Due to an identification problem, the parameter α_w is set at 0.75, which is equivalent to assuming that households negotiate their wages every 4 quarters. After surveying both direct and indirect evidence in the literature, Taylor (1999) reports that the average frequency of wage changes is about one year. It is worth emphasizing that in the literature, in contrast to price rigidities, wages rigidities -- with respect to the frequency of wage changes -- are not controversial. In this respect, we focus on the empirical relevance of quadratic costs of wage adjustment in this section.[11] A Bayesian approach is

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[9] A rationale for the lagged output term in the IS curve can be found, for example, in habit in consumption (Furher 2000), which significantly improves the model's fit to the data (e.g., Smets and Wouters 2007). A lagged price inflation term can be introduced into the Phillips curve by assuming that a fraction of firms index their prices to past inflation, as in Gali and Gertler (1999) and Christiano et al (2005). Rabanal and Rubio-Ramirez (2005) use Bayesian techniques to show that the introduction of price indexation significantly improves the model's fit to the data.

[10] Although not reported here, the estimation results indicate that the estimates of δ_r and δ_w are not significantly different from zero.

[11] The contribution of Calvo-type wage stickiness to the marginal likelihood is investigated in section 3.4.

adopted to estimate the model parameters. The posterior distribution for the estimated coefficients is obtained using the Metropolis-Hastings algorithm.

Table 1: Bayesian Estimation of DSGE Model

Parameters	Prior distribution	Prior mean	Prior St. dev.	Posterior mean	95% of confidence interval
α_p	beta	0.66	0.05	0.83	[0.80 , 0.86]
β	normal	0.99	0.01	0.99	[0.97 , 1.00]
σ	invg	0.10	2.00	0.06	[0.05 , 0.08]
$\bar{c}$	normal	0.00	25.0	117.2	[91.6, 142.5]
φ	beta	0.50	0.10	0.66	[0.60 , 0.72]
γ	beta	0.50	0.10	0.34	[0.26 , 0.42]
ρ	beta	0.70	0.05	0.77	[0.74 , 0.80]
α_π	normal	1.50	0.15	1.70	[1.57 , 1.83]
α_y	normal	0.50	0.10	0.52	[0.38 , 0.65]
δ_π	beta	0.50	0.10	0.05	[0.01 , 0.09]
δ_y	beta	0.50	0.10	0.87	[0.83 , 0.92]
δ_α	beta	0.50	0.10	0.88	[0.84 , 0.93]
σ_π	invg	0.10	2.00	0.21	[0.19 , 0.24]
σ_y	invg	0.10	2.00	0.04	[0.03 , 0.04]
σ_i	invg	0.10	2.00	0.31	[0.28 , 0.33]
σ_w	invg	0.10	2.00	0.44	[0.40 , 0.48]
σ_a	invg	0.10	2.00	0.58	[0.53 , 0.62]

Note: Table 1 shows Bayesian estimation results for DSGE model. The parameter, α_w, is assumed to be 0.75, which implies that the average duration of fixed wages is 4 quarters. The number of draws is 50,000. This paper keeps 25,000 draws. The Metropolis-hastings algorithm is used to obtain the posterior distribution. Estimates cover the sample period 1960Q1 to 2007Q4. Log-likelihood is -466.6.

Table 1 reports the prior and posterior distribution of each coefficient. The Calvo parameter for staggered price setting is estimated to be around 0.83, which implies that the average contract duration is about 5.9 quarters. The estimated mean of this parameter is in line with the one obtained in Gali and Gertler (1999). However, the estimated duration of fixed prices is much higher than the values reported in micro studies such as Bils and Klenow (2004) and Nakamura and Steinsson (2008). In particular, Nakamura and Steinsson (2008) reports that the average frequency of price changes is about 3 quarters. The posterior mean estimate of β is consistent with the conventional estimate from the literature. The elasticity of intertemporal substitution σ is 0.06, which is lower than assumed in the prior distribution. Since the Calvo wage stickiness parameter α_w is set to be 0.75, a main point is to test the null hypothesis of $\bar{c} = 0$, that is, to test the existence of any additional sources of wage stickiness associated with the size of wage adjustment. The prior for $\bar{c}$ is set to be zero, which is consistent with the literature. In contrast with the literature, the estimate of $\bar{c}$ is significantly different from its prior mean, supporting the proposed sticky wage model.[12]

The coefficient on output expectations (φ) is estimated to be 0.66, which implies that expectations play a relatively more important role than past output in determining current output. In contrast, the estimate of γ (0.34) suggests that past inflation in the Phillips curve plays a crucial role in explaining inflation dynamics.[13]

Turning next to the monetary policy parameters, the parameter measuring the degree of smoothing is estimated to be 0.77. There is a range of evidence regarding the substantial degree of interest rate smoothing in the literature (e.g., Clarida, Gali and Gertler 2000). The response of the Federal Reserve to inflation is estimated to be 1.70, ranging from 1.57 to 1.83. The parameter estimate associated with the Fed's response to output is 0.52.

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[12] These results are quite robust to a possible set of wage stickiness with respect to the frequency of wage changes. The estimate of $\bar{c}$ corresponding to an integer value of the average duration of wage changes $1/(1-\alpha_w)$, from 2 to 8 quarters is significantly different from its prior mean.

[13] In the next subsection, this paper further investigates the importance of these backward-looking components in terms of the value of marginal likelihood.

3.4 The Relative Importance of Each Friction of the Model

In the literature, the most common way of characterizing staggered wage setting is to employ a variant of Calvo's (1983) mechanism as a source of wage stickiness with respect to the frequency of wage adjustment. Deviating from the existing literature, this paper introduces an additional source of wage rigidities through the quadratic costs of adjusting wages. The introduction of wage rigidities with respect to the size of wage adjustment, in addition to Calvo-type wage stickiness, raises the question of whether the friction is empirically relevant in explaining wage inflation dynamics. In response to this question, the contribution of the quadratic costs of wage adjustment to explaining the data is evaluated in terms of the marginal likelihood. This section also examines the contribution of other frictions to the marginal likelihood.

Table 2 presents the estimates of the mode of the model parameters and the marginal likelihood to evaluate the relative importance of each friction of the DSGE model, such as the backward-looking components in the IS and Phillips curves, price and wage stickiness, by examining the relevance of each friction one at a time. The marginal likelihood is computed using the Laplace approximation.

For comparison, the second column of Table 2 reports the estimates of the mode of the parameters of the proposed DSGE model as a benchmark, which are quite similar to the posterior mean estimates from Table 1. The third column shows the estimates of the mode of the DSGE model parameters when the purely forward-looking IS curve is employed. These estimates are similar to those of the benchmark model. However, the marginal likelihood is lower than that of the benchmark model (which has a difference of about 11), indicating that the lagged output term improves the model fit.

Table 2: The Relative Importance of Each of the Frictions

Parameters	Benchmark	$\varphi=1$	$\gamma=1$	$\alpha_p=1$	$\bar{c}=1$	$\alpha_w=1/3$ $\&\bar{c}=0$
α_p	0.83	0.84	0.88	-	0.77	0.88
α_w	-	-	-	-	0.91	-
β	0.99	0.98	0.98	0.99	1.00	0.98
σ	0.06	0.07	0.08	0.66	0.14	0.73
$\bar{c}$	117.1	110.2	100.8	117.7	-	-
φ	0.66	-	0.72	0.65	0.51	0.07
γ	0.35	0.33	-	0.14	0.55	0.26
ρ	0.77	0.80	0.76	0.80	0.78	0.77
α_π	1.70	1.61	1.84	1.80	1.63	1.65
α_y	0.51	0.53	0.53	0.42	0.51	0.76
δ_π	0.03	0.03	0.93	0.87	0.31	0.01
δ_y	0.88	0.91	0.88	0.89	0.99	0.85
δ_α	0.88	0.87	0.90	0.91	0.88	0.90
σ_π	0.21	0.21	0.05	0.96	0.23	0.22
σ_y	0.03	0.04	0.04	0.03	0.03	0.35
σ_i	0.30	0.30	0.31	0.31	0.26	0.31
σ_w	0.43	0.43	0.43	0.44	0.80	2.55
σ_a	0.57	0.57	0.57	0.57	0.58	0.57
Marginal likelihood	-466.7	-477.8	-489.0	-585.7	-590.6	-688.5

Note: This Table shows the estimates of the mode of the model parameters using Bayesian techniques. Note that α_p=1/3 (α_w=1/3) implies that the average frequency of price (wage) changes is 1.5 quarters. The estimates cover the sample period 1960Q1 to 2007Q4. In the 6th column, the present paper adopts the same prior for α_p and α_w.

Regarding the model with the purely forward-looking Phillips curve reported in the fourth column, the marginal likelihood significantly falls from -466.7 to -489.0. The Bayes ratio is computed to be greater than 0.47×10^{10}, which, according to Jeffreys' rule (1961), implies that the lagged inflation term leads to a significant improvement in explaining inflation dynamics. This evidence is consistent with Rabanal and Rubio-Ramirez (2005). It is worth noting that the estimate of the AR(1) coefficient (δ_π)

significantly increases from 0.03 to 0.93 when the lagged inflation term is not included. This result suggests that when the purely forward-looking Phillips curve is adopted, the AR(1) process probably replaces the role of the lagged inflation term in describing the data.

Reducing the average duration between price changes to 1.5 quarters (that is, $\alpha_p = 1/3$) gives rise to a drastic fall in the marginal likelihood. The findings indicate that price stickiness plays a crucial role in accounting for inflation dynamics. The substantial decline in the marginal likelihood can be explained by the fact that the slope of the Phillips curve turns out to be greater than one when the parameter α_p is set to be 1/3.[14] When compared with the estimate (about 0.037) of the slope, in line with the findings of Gali and Gertler (1999), lowering the degree of price stickiness causes the slope of the Phillips curve to be unrealistic, creating a situation in which the model fails to fit the data. As a consequence, the marginal likelihood drops considerably from -466.7 to -585.7 in the 5th column when compared with the benchmark model. In this case, the estimates of both δ_π and the standard deviation of the cost-push shock turn out to be much higher than the ones from the benchmark model.

Turning to the 6th two column, the absence of the quadratic costs of wage adjustment (that is, $\bar{c} = 0$) gives rise to a significant fall in the marginal likelihood. While the Calvo-cum-wage-indexation model developed by Christiano, Eichenbaum and Evans (2005) does not significantly improve the fit of the baseline model (e.g., Rabanal and Rubio-Ramirez 2005), the dual wage stickiness model is able to provide a better fit to

[14] Note that the slope of the new Keynesian Phillips curve, $(1-\alpha_p\beta)(1-\alpha_p)/\alpha_p$, increases as the degree of price stickiness (α_p) decreases.

the data. Smets and Wouters (2007) evaluate a partial indexation model as a variant of the Calvo-cum-wage-indexation model in terms of the marginal likelihood, and find that assuming partial indexation of wages to past inflation does not lead to a significant improvement of the marginal likelihood. The estimate of the Calvo wage stickiness parameter (α_w) indicates that the average frequency of wage changes is 11 quarters. This estimate seems to be unrealistic when compared to what is found in the literature.[15] When the quadratic costs in wage setting are ignored, its contribution to the degree of wage stickiness may be absorbed by the Calvo-type wage stickiness. Overall, the findings favor the dual wage stickiness model over the baseline model based only on Calvo-type wage stickiness.

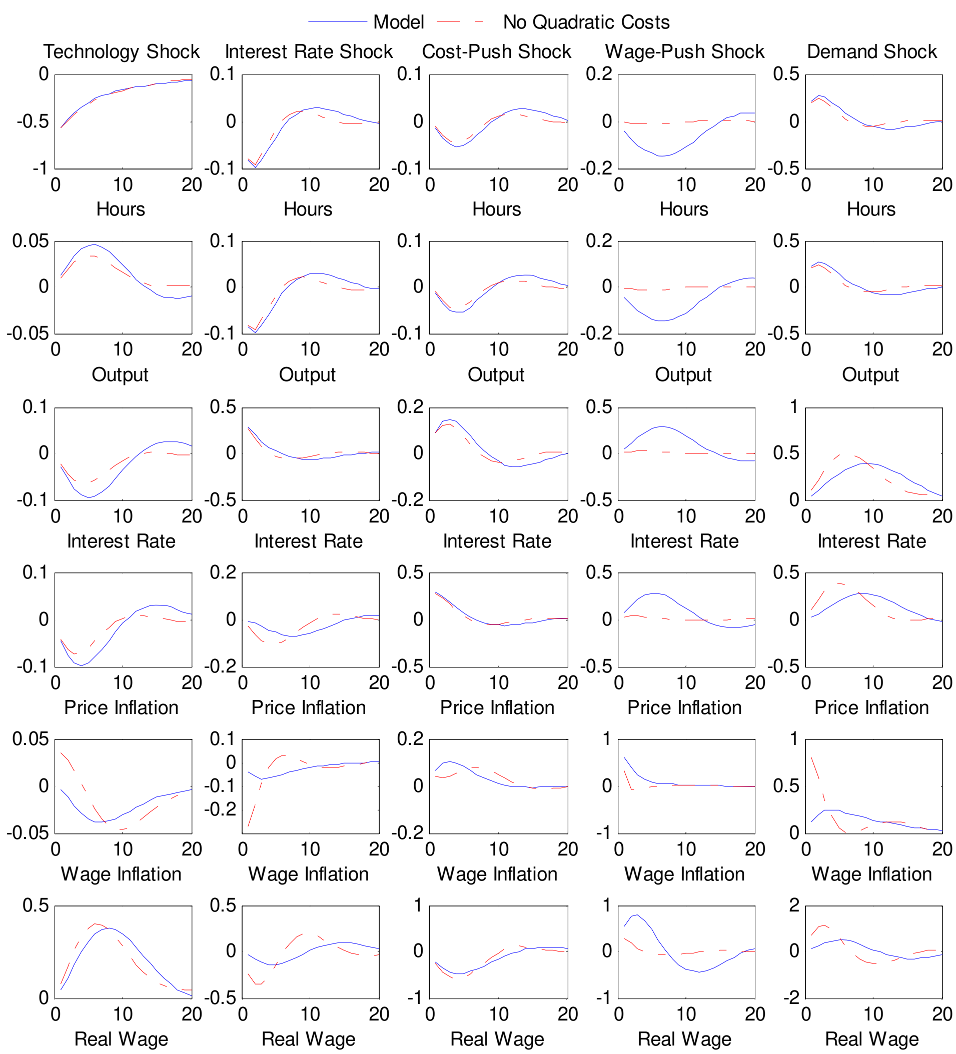
Next, in order to investigate the need of dual wage stickiness to the model dynamics, the Calvo wage stickiness parameter is reduced to 1/3, assuming that wages are adjusted every 1.5 quarters, and the parameter $\bar{c}$ related to the quadratic costs is controlled to be zero. In this way, the empirical relevance of dual wage stickiness is explored. The marginal likelihood for this case turns out to be -688.5, which is considerably lower than the one computed in the benchmark model. The findings indicate that two types of wage stickiness play an important role in fitting the model to the data. The contribution of the Calvo-type wage stickiness to the marginal likelihood can be measured by the difference between the last two columns. The difference of the marginal likelihood is about 100, providing evidence on Calvo-type wage stickiness.

3.5 Impulse Response Analysis

[15] For example, Taylor (1999) provides (in)direct survey evidence of the average frequency being 4 quarters.

In this subsection, the impulse responses to the various shocks using the posterior mean estimates of the DSGE model are reported in Table 1. Figure 1 exhibits the impulse responses of hours worked, real output, the nominal interest rate, price inflation, wage inflation and the real wage to each shock. Lines are produced using the proposed model, and dashed lines are generated with the quadratic wage adjustment costs controlled to be zero.

Figure 1: Impulse Response Functions



The first column of Figure 1 presents the responses of the endogenous variables to a one-standard-deviation technology shock. The shock causes hours worked to fall immediately, which is in line with Gali's (1999) empirical findings. However, the fall in hours worked is in contrast to implications of the standard RBC model, as addressed by Gali (1999). Following the technology shock, output starts to increase slowly. The gradual increase in real output results in an immediate fall in hours worked because the economy is able to produce more output with fewer hours due to an increase in productivity. Price inflation declines because the technology shock reduces the marginal cost of production. Both an increase in output and a relatively large decrease in inflation yield a fall in the short-term interest rate. Technology shocks also lead to a fall in wage inflation. This paper finds that the response of wage inflation to technology shocks is very weak in the post-1983 period (these results are available upon request). This result is consistent with the findings of Liu and Phaneuf (2007) using VARs.[16] As shown in the figure, real wages increase in response to a technology shock.

The second column exhibits the effects of a negative one-standard-deviation interest rate shock on the variables over time. This contractionary monetary policy shock leads to a decline in hours worked and real output. The monetary policy shock causes price and wage inflation to decrease as well. While the dual wage stickiness model generates a hump-shaped response of wage inflation to the monetary shock, the baseline model shows that wage inflation decreases immediately. The same shock gives rise to a gradual decrease in real wages, as shown in VAR studies (e.g., Christiano et al 2005). It is worth emphasizing that the presence of dual wage stickiness makes the response of real

[16] Liu and Phaneuf (2007) argue that the weak response of wage inflation could be a result of a change in monetary policy during the Volcker-Greenspan era.

wages to a monetary shock less volatile when compared to the baseline sticky wage model. The sticky price model with flexible wages fails to generate a gradual adjustment of real wages in response to monetary policy shocks. In this respect, models featuring both price and wage stickiness might be more appropriate in accounting for a gradual response of real wages to monetary policy shocks.[17] Indeed, Rabanal and Rubio-Ramirez (2005) show that models featuring both staggered price and wage contracts dominate models based only on staggered price contracts to explain the data.

The responses of the variables to a one-standard-deviation cost-push shock are presented in the third column. While the cost-push shock drives wages and price inflation up, the same shock reduces hours worked and real output. The rise in price inflation leads to an increase in the interest rate, allowing the Fed to stabilize price inflation. Following a cost-push shock, real wages decline due to a weaker response of wage inflation compared to price inflation. The fourth column displays the effects of a one-standard-deviation wage-push shock. The movement of hours is very similar to output, similar to responses to other kinds of shocks, excluding that to a technology shock. The wage-push shock works to reduce output and the number of hours worked over time. While the impact of cost-push shocks on output almost dies off within about 10 quarters, wage-push shocks have a relatively long-lasting effect on output. In response to wage-push shocks, the interest rate rises due to the Fed's attempt to stabilize price inflation. The wage-push shock drives real wages up as well. The absence of quadratic costs of wage adjustment generates very little effect of wage-push shocks on the variables, as shown by the dashed lines. Finally, looking at the last column, all variables rise as a result of a one-standard-

[17] Note that the sticky wage model with flexible prices implies that real wages increase in response to contractionary monetary policy shocks. This model does not explain the observed cyclical behavior of real wages.

deviation demand shock. The rise in output and prices causes the interest rate to increase when facing upward pressures in both output and inflation. The interest rate stays above the steady state for more than 20 quarters following demand shocks.

3.6 The Dynamic Correlation Between Wage Inflation and Real Output.

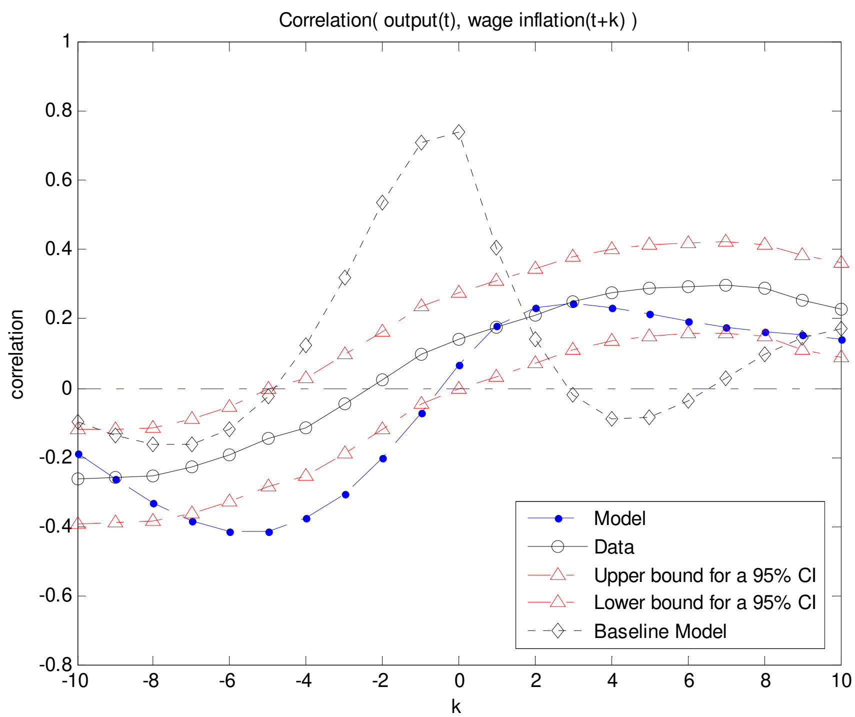
Taylor (1999) views the ability to generate the reverse dynamic cross-correlation between price inflation and output as a yardstick to evaluate the success of monetary models. Chauvet and Kim (2010) show that the output gap-based new Keynesian Phillips curve with a lagged inflation term is able to replicate the observed "reverse" dynamic correlation between the two variables by simulating a small scale DSGE model.[18] Their results indicate that the presence of the lagged inflation term plays a crucial role in explaining the fact that a rise in output signals a subsequent increase in future price inflation, and that an increase in past price inflation leads to a fall in current output. These properties of the data are in stark contrast to the implication of the purely new Keynesian Phillips curve, supporting the hybrid new Keynesian Phillips curve. Turning to the dynamics of wage inflation, it might be interesting to examine if the dual wage stickiness model is able to replicate the observed reverse dynamic cross-correlation between wage inflation and output.

For this purpose, Figure 2 compares the observed dynamic cross-correlation with the model-implied dynamic cross-correlation between output and wage inflation. In Figure 2, the data show that past wage inflation is negatively correlated to current output, and that current output is positively related to future wage inflation. As the figure shows,

[18] Chauvet and Kim (2009) employ the sticky price model with flexible wages. In addition to the new Keynesian Phillips curve with a lagged inflation term, they adopt the same IS curve and the Taylor rule as the ones employed in this paper.

the model is able to deliver a reasonable description of the observed dynamic cross-correlation between the two variables. In particular, the delayed, gradual impact of output on wage inflation is generated due to the presence of the lagged wage inflation term in the wage Phillips curve. The lagged wage inflation term generated by dual wage stickiness forces wage inflation to adjust slowly in response to changes in output. Note

Figure 2: The Dynamic Correlation Between Output and Wage Inflation

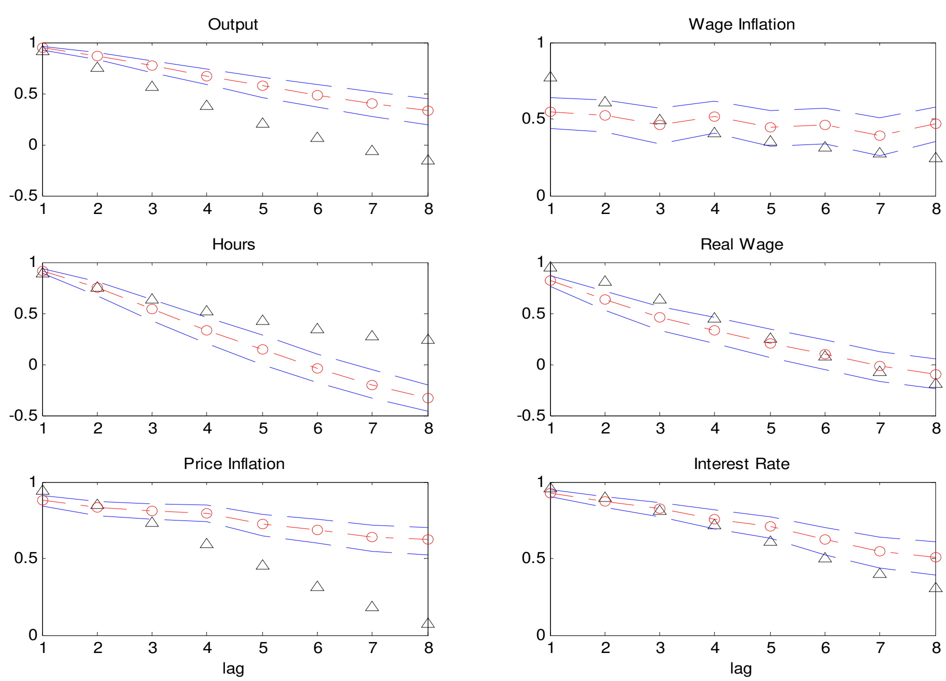


that the newly re-optimized wages are only partially adjusted in response to changes in economic conditions due to the convex costs of wage adjustment. As a result, a rise in output leads to a subsequent increase in wage inflation. As the figure shows, the absence of the quadratic wage adjustment costs causes the model to fail to explain the fact that output affects wage inflation with lags. When the quadratic wage adjustment costs do not exist, households are able to adjust their wages optimally without any restrictions in response to changes in output. As a result, the correlation between wage inflation and output could be high, as shown in Figure 3. However, the data show that the correlation coefficient is very low. While the data shows that output leads to wage inflation, the baseline model allows wage inflation to lead to output. In this respect, the dual wage stickiness model is favored over the baseline wage stickiness model.

3.7 The Observed and Theoretical Persistence of the Model Variables

To investigate whether the DSGE model is able to match the observed persistence in output, in price and wage inflation, in hours worked, and in real wages, Figure 3 compares the autocorrelation functions of the variables of interest observed from the data and generated from the model. In Figure 3, the model-implied autocorrelation functions (triangles) are generated using the posterior mean estimates of the model parameters reported in Table 1. Dashed blue lines display the 95% confidence intervals of the observed persistence (presented as circles) of the data.

Figure 3: Autocorrelation Functions of Variables



The autocorrelation function of output does well in accounting for the observed persistence, but there is still room for improvement in fitting the observed autocorrelations of output. The DSGE model under-predicts the observed persistence of output. In contrast to output, the model-implied persistence of hours worked over-predicts the observed persistence of hours. For price inflation, it is generally accepted that the introduction of lagged inflation to the Phillips curve significantly improves the fit of inflation persistence (e.g., Rabanal and Rubio-Ramirez 2005). However, the autocorrelation function of price inflation still does not closely match the observed persistence. It could be the case, as discussed in the recent literature, that there might be additional sources of inflation persistence, such as learning or more lags of price inflation (e.g., Milani 2005, Roberts 2005). In terms of wage inflation, the model-implied autocorrelation function of wage inflation is able to explain the observed persistence reasonably well. Interestingly, although wage inflation is less persistent when compared to other variables, the observed autocorrelation function is relatively high for many periods. For the real wage, the new Keynesian model with both staggered price and wage contracts closely replicates the observed persistence in real wages. Finally, the model is able to fit the observed persistence of the nominal interest rate. Overall, the model provides a good description of the observed persistence in key macroeconomic variables.

3.8 Sub-samples Analysis

To check the stability of the structural parameters, this section compares the estimates obtained using subsamples split around 1980. The first subsample runs from 1960:1 to 1979:4, the period known as the Great Inflation. The second sub-sample ranges from 1983:1 to 2007:4, which corresponds to the Great Moderation, a period in which there was a substantial decrease in the observed volatility of output and inflation. Table 3 presents the posterior distributions of the parameters across periods. In estimating the model, the present paper assumes that households adjust their wages every 4 quarters on average.

Table 3: Subsample Estimation Results

Parameters	Pre-1979 estimate		Post-1983 estimate	
	Posterior mean	95% of confidence interval	Posterior mean	95% of confidence interval
α_p	0.80	[0.76 , 0.83]	0.83	[0.79 , 0.86]
β	0.99	[0.97 , 1.00]	0.99	[0.97 , 1.00]
σ	0.13	[0.08 , 0.17]	0.09	[0.06 , 0.11]
$\bar{c}$	74.9	[50.6 , 99.4]	83.6	[55.4, 109.9]
φ	0.64	[0.56 , 0.72]	0.61	[0.55, 0.66]
γ	0.37	[0.26 , 0.47]	0.33	[0.24 , 0.43]
ρ	0.72	[0.67, 0.78]	0.84	[0.81 , 0.86]
α_π	1.34	[1.22 , 1.47]	2.07	[1.90 , 2.23]
α_y	0.56	[0.41 , 0.69]	0.46	[0.32 , 0.60]
δ_π	0.08	[0.01 , 0.16]	0.05	[0.01 , 0.10]
δ_y	0.88	[0.82 , 0.94]	0.94	[0.90 , 0.98]
δ_α	0.87	[0.80 , 0.94]	0.91	[0.87 , 0.96]
σ_π	0.26	[0.21 , 0.31]	0.19	[0.16 , 0.22]
σ_y	0.04	[0.03 , 0.06]	0.02	[0.02 , 0.03]
σ_i	0.21	[0.19 , 0.24]	0.15	[0.13 , 0.17]
σ_w	0.34	[0.29 , 0.39]	0.51	[0.45 , 0.58]
σ_α	0.67	[0.59 , 0.76]	0.47	[0.41 , 0.52]

Note: This table shows Bayesian estimation results for DSGE model. The number of draws is 50,000. I keep 25,000 draws. The Metropolis-Hastings algorithm is used to obtain the posterior distribution is used.

The degree of price stickiness is estimated to be stable across subsamples. Regarding wage rigidities, although the average duration of one year is assumed, wage stickiness associated with the quadratic costs is robustly found across subsamples.

Interestingly, the posterior mean of $\bar{c}$ has increased in the second period. This finding implies that the wage adjustment costs could be relatively lower for the high inflation period. However, considering the 95% confidence intervals of $\bar{c}$, the difference is not significantly different. Overall, the dual wage stickiness model is once again supported by the data.

The findings indicate that there have been substantial changes in monetary policy and the volatility of the various shocks. The estimates of ρ describing the degree of interest rate smoothing are significantly different across periods (and that the 95% confidence intervals across periods do not overlap). The estimate of α_{π} measuring the Fed's response to inflation for the pre-1979 period is greater than the one for the post-1983 period. The Federal Reserve seems to have reacted more aggressively to changes in inflation in the second period. These results are consistent with the findings of Clarida et al (2000), and are in contrast to the findings of Kim and Nelson (2006) and Smets and Wouters (2007), which suggest only a moderate change in monetary policy. Differences between these two periods are also found in the standard errors of the demand, interest rate, technology shock, and cost-push shock. The decrease in the volatility of these shocks indicates that they could have been a potential source of the Great Moderation. In contrast, the estimated standard error of the wage-push shock increases in the post-1983 period. Although the details are not reported in this paper, the volatility of the wage-push shock has been increasing since around 2000.

3.9 Counterfactual Analysis

While Clarida et al (2000) point to a shift in monetary policy as a source of the reduction in volatility of macroeconomic variables in the post-1983 period, Stock and

Watson (2003), Smets and Wouters (2007), and others provide evidence that the decline of the shocks plays a major role in lowering the volatility of key macroeconomic variables. In response to this debate, it will be useful to examine the potential source of the Great Moderation using a counterfactual exercise with the model estimates reported in Table 3.

This counterfactual exercise examines whether the estimated monetary policy rule of the 1960s and 1970s could have induced an increase in the volatility of output and price inflation in the period of the Great Moderation, that is, assuming that the loose monetary policy was still in effect in the second period. The counterfactual exercise also replaces the estimated standard deviations of the second subsample with those of the first subsample to examine how it affects the volatility of key macroeconomic variables in the post-1983 period.

Table 4: Counterfactual Analysis

	Counterfactual Analysis: 1983:1-2007:4				
	Data	Policy	Shocks	Structure	Policy & Shocks
Output	1.24	0.84	1.35	1.00	1.31
Price Inflation	2.76	1.59	1.40	0.89	2.50

Note: This table shows counterfactual analysis using the DSGE model estimates in Table 3. The first column shows the ratio of the standard deviation of each variable in the first sample period to the one obtained in the second period. The remaining columns display the ratio of the standard deviation of each variable generated from the counterfactual experiment to the model-implied standard deviation in the second sample period.

The first column of Table 4 displays the ratio of the standard deviation of each variable in the pre-1980 period to the one in the post-1983 period. The ratios indicate that the standard deviations of output and inflation in the first sample period are 1.24 and 2.76 times greater than the ones obtained using the second sample period. The remaining columns show the ratios of counterfactual standard deviations of the model to implied standard deviations of the variables in the second subsample.

The second column of Table 4 shows that replacing the estimated Taylor rule of the second sample period with the one obtained in the first subsample can lead to a rise in the volatility of price inflation in the second period, but not in volatility of output. The increased volatility of price inflation by 59% arises from the weaker response of the Fed to inflation in the first sample period. In contrast to price inflation, the volatility of output even declines in this exercise because the estimated Taylor rule implies a relatively stronger response to the economic activity in the first sample period. These results are broadly consistent with Boivin and Giannoni (2006) and Justiniano and Primiceri (2008). In this respect, a shift in monetary policy is not likely to be a source of lower volatility of output, although it contributes to the reduction of price inflation volatility.

On the other hand, when the estimated standard deviations of the shocks in the second sample period are replaced with the ones from the first period, the variability of the two variables increase by 35% and 40%, respectively, in the second sample period. Although the ratio for output is somewhat larger than the data, the results point to the shocks as a main source of the Great Moderation with respect to output. This paper confirms the findings of Stock and Wotson (2003), Smets and Wouters (2007) and Justiniano and Primiceri (2008).

These findings indicate that a shift in monetary policy is the most important source of the lower inflation volatility. However, the ratio for price inflation produced using the counterfactual exercise regarding monetary policy is still much smaller than the one computed using the data. Hence, a change in monetary policy is not enough to account for the observed ratio of price inflation.

The fourth column reports the results when the first sample estimates of all structural coefficients except for both the Taylor rule coefficients and the standard deviations of the shocks are used in the counterfactual analysis. A change in economic structure fails to explain considerable changes in volatility of output and price inflation.

Finally, when both the estimated tight monetary policy and lower volatility of the shocks in the post-1983 period are replaced with the ones from the first period, the predicted ratios get quite close to the values computed using the data, which measure the relative volatility between the two periods. This experiment suggests that the economy could have experienced volatility of price inflation in the second period as high as that experienced in the first period if there had not been changes in both monetary policy and the volatility in the shocks across subsamples. For output volatility, it is worth noting that while the estimated Taylor rule in the first sample period can reduce output variability, a higher volatility of the shocks induces a higher variability of the variable. This experiment implies that a combination of tight monetary policy and reduced shocks better explains the decline in output volatility of the second sample period.

4 Conclusion

This paper develops a model of wage inflation dynamics that is able to provide not only a better description of wage dynamics for policy analysis, but also to replicate the reverse dynamic correlation between wage inflation and output. In particular, this paper proposes a novel framework that successfully combines two types of wage stickiness. The dual wage stickiness model is favored by U.S. data in terms of marginal likelihood as well as the ability to explain the dynamic correlation between wage inflation and output. Furthermore, estimation results are robust across periods and DSGE model specifications as shown in Table 2 and 3. These results imply that although wage contracts are renewed at discrete time intervals, wage setters cannot fully adjust their wages, therefore supporting the presence of dual wage stickiness. The findings also indicate substantial changes in the standard errors of the shocks and monetary policy. Based on these findings and counterfactual analysis, the reduction in volatility of the shocks is the most important driver of the decline of output variation. For price inflation, a shift in monetary policy plays a relatively more important role in reducing inflation volatility. However, changes in both monetary policy and shocks are necessary to account reasonably well for lower variations of price inflation.

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