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Wage Stickiness and Unemployment Fluctuations: An Alternative Approach

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Abstract

Erceg, Henderson and Levin (2000, *Journal of Monetary Economics*) introduce sticky wages in a New-Keynesian general-equilibrium model. Alternatively, it is shown here how wage stickiness may bring unemployment fluctuations into a New-Keynesian model. Using Bayesian econometric techniques, both models are estimated with U.S. quarterly data of the Great Moderation. Estimation results are similar and provide a good empirical fit, with the crucial difference that our proposal delivers unemployment fluctuations. Thus, second-moment statistics of U.S. unemployment are replicated reasonably well in our proposed New-Keynesian model with sticky wages. In the welfare analysis, the cost of cyclical fluctuations during the Great Moderation is estimated at 0.60% of steady-state consumption.

Key words: Wage Rigidity, Price Rigidity, Unemployment

JEL classification numbers: C32, E30

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1 INTRODUCTION

The simple version of the New-Keynesian model (Woodford, 2003; chapter 3) has been extended in recent years to incorporate the endogenous determination of unemployment fluctuations in the labor market. For instance, Walsh (2005) and Trigari (2009) combined search frictions of the kind introduced in the Mortensen-Pissarides literature with sticky prices *à la* Calvo (1983).

Alternatively, this paper incorporates wage stickiness as the source for unemployment fluctuations in the New-Keynesian model. As a close reference, Casares (2007, 2008) describes a model where sticky wages produce mismatches between hours of labor supply and labor demand. Sticky wages bring non-renegotiated labor contracts implying a difference between the total hours supplied by households and those demanded by the firms. Here, we modify the labor market structure of Casares (2008) in order to obtain a model with fixed hours per worker and labor fluctuations at the extensive margin (employment and unemployment). In turn, labor fluctuations are driven exclusively by changes in the level of employment which might be considered a fair simplification.[1] Thus, labor contracts are signed at a fixed number of hours as assumed in Hansen (1985), and other papers.[2] Consequently, the household's disutility of work only varies when there are changes in the number of family members employed. This difference becomes crucial when bringing the models to the data, as observed unemployment fluctuations can be observed from the data whereas the difference between total hours supplied and total hours demanded is not observable.

We follow a Bayesian econometric strategy to estimate the model using U.S. quarterly data during the Great Moderation period (1984-2008). The estimation results provide a good fit of the model to the data and suggest that the measures of price and wage stickiness are quantitatively high and similar. We also estimate the model suggested by Erceg, Henderson, and Levin (2000) which provides a natural benchmark for a sticky-wage model but displays no unemployment fluctuations.

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[1] It is generally accepted that most variability of U.S. total hours worked is explained by changes in the number of employed people (extensive margin) whereas the number of hours at work (intensive margin) has significantly less influence. Quoting the abstract of Cho and Cooley (1994): "Approximately one quarter of the adjustment in total hours of employment over the business cycle represents adjustments in hours, while the remainder is explained by changes in employment".

[2] See Cooley and Hansen (1989), Merz (1995) and, more recently, Blanchard and Galí (2007)

Throughout the paper, EHL is the acronym used to refer to the model based on the paper by Erceg, Henderson, and Levin (2000) whereas CMV is the name of the alternative sticky-wage model (CMV comes from the initials of our last names). While the parameter estimates are rather similar across models, the estimates obtained for Calvo probabilities suggest slightly shorter price stickiness and longer wage stickiness in CMV compared to EHL. Moreover, the estimate of the price inflation inertial component is lower in CMV than in EHL, yielding a more forward-looking inflation process. By comparing second moment statistics (standard deviations, correlations with output and first-order autocorrelations) of output, inflation, wage inflation and the nominal interest rate obtained from actual data with those obtained from the two estimated models, we observe that both models provide a similar fit of the cyclical features characterizing the Great Moderation period. More importantly, unlike EHL, the estimated CMV is able to reproduce a large extent of the second moment statistics of unemployment.

Finally, this paper also makes a contribution to the calculation of the welfare cost of business cycles. The analysis is carried out using the estimated parameters of the CMV and EHL models with U.S. data of the Great Moderation. Short-run fluctuations cause a welfare loss measured as a permanent 0.60% of consumption in the CMV model (extensive margin) and as 0.86% of consumption in the EHL model (intensive margin). These numbers for the welfare cost of business cycles are significantly higher than the one suggested by Lucas (2003).

The paper proceeds as follows. Section 2 describes the CMV model and compares it with the EHL model. Section 3 introduces the estimation procedure and shows the parameter estimates. Section 4 presents the empirical fit of the two models whereas a robustness analysis of the CMV estimation results is carried out in Section 5. Next, Section 6 computes the welfare cost of cyclical fluctuations estimated with either model. Section 7 concludes.

2 THE MODEL

Let the labor market of our proposed CMV model provide employment fluctuations at the extensive margin. For that purpose, we assume indivisible labor hours as in Hansen (1985), so that workers spend a constant number of daily hours at work. Thus, variations on total hours are exclusively driven by changes in the number of employed people.

As in Merz (1995) and most papers of the Mortensen-Pissarides literature, the representative household is a large family and their members pool differentiated labor income to be evenly split up in consumption shares in a way that they all are perfectly insured against unemployment. Let us define h as the constant number of hours per employee at work and $n_t(i,j)$ as the number of household members working in the industry characterized by some specific i-th nominal wage and j-th price. Thus, total hours worked at the (i,j) industry are $n_t(i,j)h$. Assuming constant relative risk aversion, the utility function for the representative household is given by

$$U(\chi_t, c_t, n_t^s(i,j)) = \exp(\chi_t)\frac{[c_t]^{1-\sigma}}{1-\sigma} - \Psi \int_0^1 \int_0^1 \frac{[n_t^s(i,j)h]^{1+\gamma}}{1+\gamma} didj,$$

where c_t is current household's consumption, $n_t^s(i,j)h$ are total hours supplied in the firm holding the i-th wage and the j-th price, and χ_t is a consumption preference shock that follows an exogenous AR(1) process. Defining $\overline{\Psi} = \Psi h^{1+\gamma}$, we can rewrite the utility function as

$$U(\chi_t, c_t, n_t^s(i,j)) = \exp(\chi_t)\frac{[c_t]^{1-\sigma}}{1-\sigma} - \overline{\Psi} \int_0^1 \int_0^1 \frac{[n_t^s(i,j)]^{1+\gamma}}{1+\gamma} didj. \tag{1}$$

Regarding firms' behavior, we follow Casares (2008) by considering a model with profit-maximizing sticky prices set by monopolistically competitive firms, sticky wages affecting labor contracts, and a production technology with constant capital and diminishing labor returns. Both sticky prices and sticky wages are specified by respective constant probabilities as assumed initially by Calvo (1983). Therefore, firms can be distinguished according to specific prices and wages. The only difference from the model of Casares (2008) is that the negotiation of wage contracts occurs here at the extensive margin and not at the intensive margin. Wage setting is aimed at an intertemporal matching between the number of job applicants supplied by the household and the number of jobs demanded by the firms, provided a constant number of hours per job. Thus, there are jobs-clearing wage contracts in our model (extensive margin) while there were hours-clearing wage contracts (intensive margin) in Casares (2008). At first, the difference between the two models may seem irrelevant because the two models share identical economic dynamics (more precise, the log-linear representations of both models coincide), but it becomes relevant when estimating the two models because the model introduced in this paper generates employment fluctuations in the extensive margin, so unemployment time series can be used in the estimation procedure.

We now introduce wage rigidities. Let η_w be the constant probability *à la* Calvo (1983) that the firm and the household cannot get together to negotiate a new wage contract. If that is the case, the nominal wage is adjusted by the indexation rule introduced below and the household is required to supply as many jobs as needed to meet demand.[3] Otherwise, with a probability $1 - \eta_w$, the firm and the household sit down to find the nominal wage that satisfies the following jobs-clearing condition

$$E_t \sum_{j=0}^{\infty} \beta^j \eta_w^j \left[n_{t+j}^s(i,j) - n_{t+j}^d(i,j) \right] = 0, \tag{2}$$

where $n_{t+j}^s(i,j)$ and $n_{t+j}^d(i,j)$ are respectively the quantity of jobs supplied and demanded in the specific industry, E_t is the rational expectation operator conditional to the lack of wage contract revisions in the future, and $\beta \in (0,1)$ is the discount factor. Firms post demand for jobs and households supply a number of job seekers. The first-order condition of the household for the supply of labor implies a constant elasticity of substitution, $1/\gamma$, across wage-specific industries. This condition can be expressed in terms of log-deviations from steady-state values:

$$\widehat{n}_t^s(i,j) = \frac{1}{\gamma} \left(\widehat{W}_t(i,j) - \widehat{W}_t \right) + \widehat{n}_t^s, \tag{3}$$

where $\widehat{W}_t = \int_0^1 \int_0^1 \widehat{W}_t(i,j) di dj$ is the log-deviation of the average nominal wage from its steady-state level and $\widehat{n}_t^s = \int_0^1 \int_0^1 \widehat{n}_t^s(i,j) di dj$ is the log-deviation of the average labor supply from the steady-state level of employment. Meanwhile, labor demand is the amount required to produce as many units of output as demanded in the monopolistically competitive market. The production technology relates firm-specific output to the demand for total hours of labor, $n_t^d(i,j)h$, and an AR(1) technology shock, z_t, as follows: $y_t(i,j) = \exp(z_t) \left[n_t^d(i,j)h \right]^{1-\alpha}$ with $0 < \alpha < 1$ which implies diminishing returns of labor. In log-deviations from steady-state, we get:

$$\widehat{y}_t(i,j) = (1-\alpha) \widehat{n}_t^d(i,j) + z_t.$$

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[3] The arrival of a Calvo signal that impedes setting the jobs-clearing nominal wage would oblige the household to meet labor demand. It is a similar situation that faces the firm that cannot set the optimal price. Thus, the effective amounts of output and labor are demand determined.

Combining the last expression with a log-linearized Dixit-Stiglitz demand curve commonly used in the New-Keynesian literature, we obtain

$$\widehat{n}_t^d(i,j) = -\frac{\theta}{1-\alpha}\left(\widehat{P}_t(i,j) - \widehat{P}_t\right) + \widehat{n}_t, \tag{4}$$

where $\theta > 0$ denotes the Dixit-Stiglitz elasticity of substitution and $\widehat{n}_t = \int_0^1 \int_0^1 \widehat{n}_t^d(i,j)didj$ is the aggregate level of employment expressed in terms of log-deviation from its steady-state value.

Summarizing, jobs-clearing wages are set whenever market frictions permit labor at the value that solves the log-linear version of (2), provided current and future expressions of equations (3) and (4), which respectively govern supply and demand for labor. Wage rigidities explain the arrival of mismatches between the number of jobs demanded and the number of workers who wish to work. At the industry level, we have

$$u_t(i,j) = \widehat{n}_t^s(i,j) - \widehat{n}_t^d(i,j).$$

The aggregation across sectorial unemployment leads to the following expression for the rate of unemployment[4]

$$u_t = \int_0^1 \int_0^1 u_t(i,j)didj = \widehat{n}_t^s - \widehat{n}_t.$$

Moreover, the system (2)-(4) brings a connection between pricing behavior and wage setting at industry level (absent in standard Mortensen-Pissarides frameworks). The optimal price decision will be affected by the firm-specific circumstances (the history of Calvo probabilities) yielding nominal wage differentiation across firms. Meanwhile, nominal wages are set at different values depending upon particular pricing conditions. For instance, after an expansionary demand shock firms that can price optimally and hold nominal wages above the average wage will increase prices further up because they are facing higher marginal costs. In addition, firm-specific wages will be lower for a firm that has a higher price than the average because labor demand is much weaker with high prices. In particular, it can be proved that there is a positive relationship between the firm-specific relative optimal price and relative past wages, $\widehat{P}_t^*(i,j) = \widehat{P}_t^* + \tau_1\left(\widehat{W}_{t-1}(i,j) - \widehat{W}_{t-1}\right)$, where

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[4] Blanchard and Galí (2007) and Casares (2007, 2008) also use this definition for the rate of unemployment in scenarios where employees work fewer hours than they would like (that is, employment fluctuations occur in the intensive margin).

the (i, j) index distinguishes industry-specific variables from economy-wide averages. Also, there is a negative dependence between relative wages and relative prices, $\widehat{W}_t(i,j) = \widehat{W}_t - \tau_2 \left(\widehat{P}_t(i,j) - \widehat{P}_t\right)$.[5]

Endogenous inertia on price and wage dynamics can be added to improve the empirical fit of the model. Thus, firms that cannot price optimally will apply a price indexation rule built as a weighted reaction to the previous rate of inflation and the steady-state rate of inflation plus a stochastic white-noise deviation:

$$P_t(i,j) = P_{t-1}(i,j) \left[(1+\pi^p_{t-1})^{\delta_p}(1+\pi^p+\upsilon^p_t)^{1-\delta_p}\right],$$

where π^p_{t-1} is economy-wide lagged inflation, π^p is the steady-state rate of inflation and υ^p_t is a price indexation shock. The parameter $\delta_p \in [0,1]$ measures the weight assigned to lagged inflation in the indexation rule. The particular setting $\delta_p = 0$ eliminates the influence of lagged inflation on the price indexation rule and leaves out the inertial dynamics of inflation.

Firms and households agree on a wage indexation rule for the nominal wage contracts that cannot be renegotiated. Similarly to prices, the wage indexation rule reflects a weighted reaction to lagged wage inflation and steady-state wage inflation plus a stochastic white-noise deviation, as follows:

$$W_t(i,j) = W_{t-1}(i,j) \left[(1+\pi^w_{t-1})^{\delta_w}(1+\pi^w+\upsilon^w_t)^{1-\delta_w}\right],$$

where $W_t(i,j)$ is the firm-specific nominal wage set in period t, π^w_{t-1} is lagged wage inflation, π^w is the steady-state rate of wage inflation, and υ^w_t is a white-noise wage indexation shock. The parameter $\delta_w \in [0,1]$ accommodates the weight of lagged wage inflation in the indexation rule. If $\delta_w = 0$, the indexation rule lacks from a backward-looking pattern.

The full CMV model can be expressed as the following linearized system of equations:

$$\pi^p_t = \tfrac{\delta_p}{1+\beta\delta_p}\pi^p_{t-1} + \tfrac{\beta}{1+\beta\delta_p}E_t\pi^p_{t+1} + \tfrac{\kappa_p}{1+\beta\delta_p}\widehat{\psi}_t + \tfrac{1-\delta_p}{1+\beta\delta_p}\upsilon^p_t, \tag{5}$$

$$\widehat{\psi}_t = \widehat{w}_t - (\widehat{y}_t - \widehat{n}_t), \tag{6}$$

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[5] Analytical expressions of τ_1 and τ_2 are found to be

$$\tau_1 = \frac{(1-\beta\eta_p)\eta_w}{(1-\beta\eta_p\eta_w)\left(1+\frac{\alpha\theta}{1-\alpha}+\tau_2\left(1-\frac{(1-\beta\eta_p)\eta_w}{1-\beta\eta_p\eta_w}\right)\right)} \text{ and } \tau_2 = \frac{\gamma\theta(1-\beta\eta_w)}{(1-\alpha)(1-\beta\eta_w\eta_p)\left(1+\frac{\tau_1\beta\eta_w\gamma\theta}{(1-\alpha)}\left(1-\frac{\eta_p(1-\beta\eta_w)}{1-\beta\eta_w\eta_p}\right)\right)}.$$

See Casares (2008) for the proof.

$$\pi_t^w = \tfrac{\delta_w}{1+\beta\delta_w}\pi_{t-1}^w + \tfrac{\beta}{1+\beta\delta_w}E_t\pi_{t+1}^w - \tfrac{\kappa_w}{1+\beta\delta_w}u_t + \tfrac{1-\delta_w}{1+\beta\delta_w}\upsilon_t^w, \tag{7}$$

$$\widehat{w}_t = \widehat{w}_{t-1} + \pi_t^w - \pi_t^p, \tag{8}$$

$$\widehat{y}_t = (1-\alpha)\widehat{n}_t + z_t, \tag{9}$$

$$u_t = \widehat{n}_t^s - \widehat{n}_t, \tag{10}$$

$$\widehat{n}_t^s = \frac{1}{\gamma}(\widehat{w}_t - \sigma\widehat{y}_t + \chi_t), \tag{11}$$

$$\widehat{y}_t = E_t\widehat{y}_{t+1} - \tfrac{1}{\sigma}\left(R_t - E_t\pi_{t+1} - (1-\rho_\chi)\chi_t\right), \tag{12}$$

$$R_t = (1-\mu_R)\left[\mu_\pi\pi_t^p + \mu_y(\widehat{y}_t - \widehat{\widehat{y}}_t)\right] + \mu_R R_{t-1} + \varepsilon_t^R, \tag{13}$$

$$\left(\tfrac{\alpha+\gamma}{1-\alpha} + \sigma\right)\widehat{\widehat{y}}_t = \tfrac{1+\gamma}{1-\alpha}z_t + \chi_t. \tag{14}$$

There are ten endogenous variables: the rate of price inflation, π_t^p; the rate of wage inflation, π_t^w; the real marginal cost, $\widehat{\psi}_t$; the real wage, $\widehat{w}_t$; output, $\widehat{y}_t$; the unemployment rate, u_t; the average labor supply, $\widehat{n}_t^s$; the average (effective) labor demand, $\widehat{n}_t$; the nominal interest rate, R_t; and potential (natural-rate) output $\widehat{\widehat{y}}_t$. Variables topped with a hat symbol represent log-deviations from their respective steady-state levels, whereas the remaining variables represent the difference in levels with respect to their respective steady-state rates. Model variability comes from five exogenous shocks: z_t, χ_t, υ_t^p, υ_t^w, and ε_t^R. Only the technology shock (z_t) and the consumption preference shock (χ_t) are serially correlated; the other three (nominal) shocks are considered white-noise independent processes. The quasi-slope coefficients κ_p and κ_w have the same analytical expressions as in the forward-looking model shown in Casares (2008):

$$\kappa_p = \frac{(1-\beta\eta_p)(1-\eta_p)}{\eta_p\left(1+\frac{\alpha\theta}{1-\alpha}+\tau_2\left(1-\frac{\eta_w(1-\beta\eta_p)}{1-\beta\eta_p\eta_w}\right)\right)}$$

and

$$\kappa_w = \frac{\gamma(1-\beta\eta_w)(1-\eta_w)}{\eta_w\left(1+\tau_1\frac{\beta\eta_w\theta\gamma}{1-\alpha}\left(1-\frac{\eta_p(1-\beta\eta_w)}{1-\beta\eta_p\eta_w}\right)\right)}.$$

Let us briefly describe the model equations (5)-(14). The price-inflation equation, (5), is a hybrid New-Keynesian Phillips curve that combines both backward and forward-looking dynamics. It is obtained from log-linearizing the first-order condition of the optimal price in a monopolistically competitive economy with Calvo-type frictions on price setting and on jobs-clearing nominal wages. Equation (6) is a log-linear definition of the real marginal cost where labor productivity is obtained from a technology with diminishing marginal returns. Wage-inflation dynamics are governed by equation (7), that resembles the *seminal* Phillips (1958) curve because it displays a negative relationship between wage inflation and unemployment. In a similar way to price inflation, there are both backward and forward-looking components characterizing wage inflation dynamics, the former due to the assumption of indexation on lagged wage inflation. Jobs-clearing wage setting, Calvo-style sticky wages and a wage indexation rule result in the wage inflation dynamics implied by equation (7). Actually, sticky wages are crucial to explain employment fluctuations in the extensive margin (as well as in the intensive margin, as discussed in Casares (2007 and 2008)). Those non-renegotiated nominal wages deliver a mismatch between the household's supply of labor measured as the number of job seekers and the firm's demand for labor measured as the number of jobs posted, which after aggregation corresponds to our measure of unemployment.

Real wage dynamics are provided by equation (8). The Cobb-Douglas production technology with constant capital and a technology shock is log-linearized in equation (9). The rate of unemployment is endogenously defined by equation (10) as the log-difference between average supply of labor and the average labor demand measured as the number of jobs (extensive margin).

The labor supply function and the IS curve (equations (11) and (12)) are obtained from the household's optimizing behavior using the utility function specification (1). Concretely, the combination of consumption and labor first-order equations together with the market-clearing condition that equates consumption and output, leads to the labor supply equation (11). The IS-type equation (12) is obtained from log-linearizing the consumption Euler equation.

Next, monetary policy follows a Taylor (1993)-type rule with a smoothing component and an interest-rate shock described in equation (13). The nominal interest rate changes endogenously in response to changes in the rate of inflation, the output gap and the lagged nominal interest rate. The output gap is calculated as the log-deviation between current output and potential (natural-rate) output. Finally, fluctuations of potential output are obtained from equation (14), which provides deviations of output from steady state if the economy were released from nominal rigidities, i.e. setting $\eta_p = \eta_w = 0$.

2.1 A comparison with the EHL (2000) model

EHL (2000) introduce sticky wages in a New Keynesian model. Staggered nominal wages reproduce the constant probability scheme of Calvo (1983)-type contracts that are applied to pricing decisions. Thus, there are both sticky prices and sticky wages *à la* Calvo (1983). In spite of having wage rigidities, the EHL model is known as a dynamic stochastic general equilibrium (DSGE) model. The labor market is at equilibrium in every period, with no room for excess labor supply (unemployment). Households own a differentiated labor service that gives them market power to set the nominal wage. Letting η_w be the Calvo probability that unables optimal wage setting and adding a wage indexation rule identical to the CMV model described above, fluctuations of wage inflation in the EHL model are given by the following forward-looking equation:

$$\pi_t^w = \tfrac{\delta_w}{1+\beta\delta_w}\pi_{t-1}^w + \tfrac{\beta}{1+\beta\delta_w}E_t\pi_{t+1}^w + \tfrac{(1-\eta_w)(1-\beta\eta_w)}{\eta_w(1+\gamma\theta_f)}\left(\widehat{mrs}_t - \widehat{w}_t\right) + \tfrac{1-\delta_w}{1+\beta\delta_w}\upsilon_t^w, \tag{15}$$

where $\widehat{mrs}_t - \widehat{w}_t$ is the log-difference between the household's marginal rate of substitution (mrs) and the real wage, and θ_f is the labor demand elasticity of substitution.

Remarkably, the CMV model features a semi-loglinear relationship between the rate of unemployment and the gap that drives wage inflation fluctuations in the EHL model, $\widehat{mrs}_t - \widehat{w}_t$. Hence, inserting the equation (11) that determines fluctuations of the labor supply in the unemployment definition (10), it yields

$$u_t = \frac{1}{\gamma}(\widehat{w}_t - \sigma\widehat{y}_t + \chi_t) - \widehat{n}_t. \tag{16}$$

Meanwhile, the expression for $\widehat{mrs}_t$ implied by the utility function specified above is[6]

$$\widehat{mrs}_t = \gamma\widehat{n}_t - \chi_t + \sigma\widehat{y}_t. \tag{17}$$

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[6] Provided the same specification for the instantaneous utility function used in the CMV model (see expression 1 from Section 2), the marginal rate of substitution between the supply of i-type jobs at the firm j and consumption is:

$$mrs_t(i,j) = \frac{\overline{\Psi} n_t^s(i,j)^\gamma}{\exp(\chi_t) c_t^{-\sigma}}.$$

Log-linearizing this expression, using the equilibrium condition $\widehat{c}_t = \widehat{y}_t$, and aggregating across job types and firms lead to the expression shown in the main text.

Comparing (16) and (17), it is straightforward to see that

$$\widehat{mrs}_t - \widehat{w}_t = -\gamma u_t, \tag{18}$$

which obviously is only a valid statement for the CMV model, since in the EHL model there are not such job mismatches.

The relationship between unemployment and the mrs-wage gap implied by (18) can be substituted in the wage inflation equation of the CMV model, equation (7), to obtain

$$\pi_t^w = \tfrac{\delta_w}{1+\beta\delta_w}\pi_{t-1}^w + \tfrac{\beta}{1+\beta\delta_w}E_t\pi_{t+1}^w + \tfrac{\kappa_w}{1+\beta\delta_w}\tfrac{1}{\gamma}\left(\widehat{mrs}_t - \widehat{w}_t\right) + \tfrac{1-\delta_w}{1+\beta\delta_w}\upsilon_t^w. \tag{19}$$

Hence, the labor market structures of the CMV and EHL models are different in two aspects. First, the interpretation of aggregate labor fluctuations, $\widehat{n}_t$, is different. Thus, $\widehat{n}_t$ represents total number of hours at work (intensive margin) in the EHL model whereas it does the total number of workers employed (extensive margin) in the CMV model. Secondly, the analytical expression that governs wage inflation dynamics is different. Comparing the EHL equation (15) with its jobs-clearing counterpart (19), it can be noticed how the slope coefficient in (19) depends upon the value of κ_w which collects the connections between pricing and wage setting. Such connections are absent in the EHL model.

Regarding the price inflation equation, firms set prices under Calvo nominal rigidities in both models. When receiving the right market signal, the optimal price depends positively on both the aggregate price level and the real marginal cost. To make the version of the EHL model used here comparable to the CMV model, it is assumed constant capital and the same price indexation rule for the cases of non-optimal pricing. When abstracting from variable capital, the real marginal cost is firm-specific which implies a flatter slope of the Phillips curve (Sbordone, 2002). Thus, the Phillips curve that drives inflation dynamics in the version of the EHL model with constant capital and a price indexation rule is

$$\pi_t^p = \tfrac{\delta_p}{1+\beta\delta_p}\pi_{t-1}^p + \tfrac{\beta}{1+\beta\delta_p}E_t\pi_{t+1}^p + \tfrac{(1-\eta_p)(1-\beta\eta_p)}{\eta_p(1+\alpha\theta/(1-\alpha))(1+\beta\delta_p)}\widehat{\psi}_t + \tfrac{1-\delta_p}{1+\beta\delta_p}\upsilon_t^p. \tag{20}$$

The only difference with the Phillips curve of the CMV model is the slope coefficient. By comparing the slopes of (20) and (5) and noting the analytical expression that determines κ_p, we can conclude that the slope coefficient is lower in the CMV model. Therefore, the reaction of inflation to changes in the real marginal cost is smaller in the CMV model. This difference can again be explained by the connections between wage setting and price setting that are present in the CMV model (see Casares, 2008). In short, any price increase that comes after a rise of the real marginal cost would reduce firm-specific labor demand and, subsequently, the jobs-clearing nominal wage. A falling nominal wage would partially compensate the initial increase in the real marginal cost in a way that would cut the price hike. In turn, the price level and inflation would have a weaker response to changes in the aggregate real marginal cost (lower slope coefficient).

3 ESTIMATION

3.1 Data and estimation procedure

The Great Moderation period (1984:1Q-2008:2Q) has been characterized by mild fluctuations of most (both real and nominal) aggregate variables (see Stock and Watson, 2002, among others). Thus, we would expect not to suffer from any important misspecification sources, such as parameter instability in both the private sector -for instance, Calvo probabilities (Moreno, 2004)- and the monetary policy reactions to inflation or output (Canova, 2009). Indeed, some authors argue that a sound monetary policy implementation is the main factor behind the low aggregate volatility since the mid-1980's (Clarida, Galí and Gertler, 1999). In the robustness exercises conducted below, we compare the results obtained during the Great Moderation with those found in the pre-Volcker period.

The CMV and EHL models are estimated with U.S. quarterly data of the Great Moderation. The variables used in the estimation are the real Gross Domestic Product (GDP), the price inflation rate obtained from the implicit GDP deflator, the wage inflation rate obtained from nominal compensation per hour, the 3-month Treasury bill rate and the unemployment rate. Real GDP was logged and linearly detrended to extract the cyclical component of output. The data were retrieved from the Federal Reserve of St. Louis (FRED) database. In the robustness section below, we also show that results are not specific to the detrending method (or to the use of output growth instead of detrended output) as well as to the inclusion of a measure of employment in the set of variables.

We estimate the alternative models using a two-step Bayesian procedure. In the first step, the log posterior function is maximized in a way that combines the prior information of the parameters with the empirical likelihood of the data. In a second step, we perform the Metropolis-Hastings algorithm to compute the posterior distribution of the parameter set. Notice that the slope coefficients in the price and wage inflation equations are implicit functions of the undertermined coefficients τ_1 and τ_2. These coefficients can be analytically solved through a non-linear two-equation system. We pick the positive values associated with these solutions, as implied by theory.

The selection of prior distributions for the model parameters is based on similar related studies (Smets and Wouters, 2007, and Gertler *et al.* 2008). The priors for the utility function parameters σ and γ are set at 2.0 and 4.0, respectively; with standard deviations 0.1 and 0.5, respectively. The prior for the elasticity of substitution across goods (θ) is set at 6, which implies a 20% mark-up in steady state. The prior distribution for the two backward-looking parameters in the price and wage inflation equations (δ_p, δ_w) is a normal with mean 0.5 and standard deviation 0.1. Exactly the same priors are chosen for the Calvo probabilities of price and wage adjustment (η_p, η_w), implying an average duration of both wage and price contracts of six months. The priors of the production function parameter and the subjective time discount factor (α and β) are the standard values of 0.36 and 0.99, respectively; with standard deviation of 0.01. Following Gertler *et al.* (2008), monetary policy parameters are set at 0.75 for the endogenous persistence parameter, 1.7 for the long-run response to inflation and 0.125 for the response to cyclical output. Also following their priors, the standard deviations of the innovations to the shocks come from an inverse gamma distribution with mean and standard deviation 0.15, whereas the autocorrelation parameters of the technology and preference shocks are set at 0.5, with standard deviation 0.1.

3.2 Estimation results

Table 1 reports the prior and posterior distributions of each parameter in our proposed CMV model, together with the 5 and 95 percentiles of the posterior distributions. The table also compares the posterior distributions with those obtained -using the same priors- in the estimation of the version of the EHL model described in Section 2.

Table 1 shows that all parameter estimates are statistically different from zero, with statistical confidence bands varying in size, but small overall. In several cases, the posteriors are close to the priors, where in some instances, they are significantly distant. In particular, the posterior of the "deep" parameters (preferences, technology and market structure) are very close to the priors. The estimate for the curvature of the consumption utility function σ is 2.11, showing a moderate sensibility of output to real interest rate changes. As for the labor disutility parameter γ, it is estimated at 4.66, implying a relatively low labor supply elasticity consistent with most microeconomic evidence. The parameter measuring the Dixit-Stiglitz demand elasticity, θ, is estimated to be 6.18. The capital share in the production function, α, matches the prior level of 0.36, the same as the time discount parameter, β, which remains at 0.99. We find values of the backward-looking parameters in the price and wage inflation equations below the prior value of 0.50. In contrast, the parameters that measure the Calvo-type price and wage rigidities are estimated to be around 0.84, much higher than the 0.5 prior, implying high price and wage rigidities.[7] These values for the Calvo parameters are somewhat higher than those obtained for the Great Moderation by Smets and Wouters (2007) in their New-Keynesian model with sticky wages *à la EHL*, i.e. without unemployment.[8] The price adjustment parameter is similar to that estimated by Gertler, Sala and Trigari (2008), whereas our estimate of the wage adjustment parameter is quite higher (they estimate it to be 0.71). The values obtained for the monetary policy parameters are in line with those reported in the literature for the period considered: a high coefficient on the lag of the interest rate parameter (0.84), a large

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[7] Nevertheless, sticky prices do not imply firm-specific constant prices in the models. It should be recalled that firms that cannot price optimally will adjust current prices by applying the indexation rule that takes into account lagged inflation, the steady-state rate of inflation and the price indexation shock. With a similar wage indexation rule, nominal wages also change every period. A greater extent of nominal rigidities result in a larger fraction of price/wage adjustment that follow the indexation rule.

[8] Apparently, a large extent of both price and wage stickiness might seem counterintuitive during the Great Moderation period. However, the low-inflation scenario featuring this period would reduce variability on relative prices and, therefore, the average cost of deviating from optimal pricing. Thus, the presence of menu costs or information costs could more easily postpone the search of the optimal price during the Great Moderation. The high estimates of η_p found here may capture this effect.

interest rate response to inflation (2.00) and a lower response to output (0.70). Finally, the size of the IS innovation is significantly higher than those of the other shocks.

Table 1 also shows that the parameter estimates of the CMV model are quite similar to those obtained in the estimation of the EHL model.[9] Indeed, the confidence intervals associated with each parameter estimate, obtained from the two models, always overlap except for μ_y, showing that parameter estimate differences between the two models are not statistically significant. However, based on the point estimates, there are some differences that deserve discussion. The estimate of the backward-looking parameter δ_p for inflation dynamics is lower in our proposed CMV model (0.47) compared to the figure obtained in the EHL model (0.59). The values for the Calvo-adjustment probabilities are found to be similar across models (around 0.84). Nevertheless, the EHL estimates imply somewhat lower wage rigidities, but higher price rigidities. The estimates of the monetary policy rule parameters are again similar, with a higher output response in the CMV model. Finally, the standard deviation of the innovations to price inflation shocks is smaller in the CMV model, whereas the standard deviation of the innovations to IS shocks is estimated to be higher in the EHL model.

4 EMPIRICAL FIT

This section compares the performance of CMV and EHL models along three dimensions. First, we analyze the ability of the two models to reproduce business cycle statistics obtained from actual data. Second, we study the contribution of each structural shock in explaining the total variance decomposition of important endogenous variables. Finally, we carry out an impulse-response analysis.

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[9] In the estimation of the EHL model, the U.S. time series of total hours was used in replacement of unemployment, which is absent in that model. Thus, the time series of "Hours of All Persons in the Nonfarm Business Sector" was logged and linearly detrended to extract the business cycle component that was added to the set of observable variables.

4.1 Second-moment statistics

Table 2 shows second-moment statistics obtained from actual U.S. data (first panel), and the ones found in the estimated CMV (second panel) and EHL (third panel) models. In general, the two models do a good job in reproducing the cyclical features of the data. Thus, both models capture the volatility of output, the interest rate and wage inflation and the low volatility of price inflation. Moreover, the two models replicate reasonably well the first-order autocorrelation of all variables. However, the CMV model outperforms the EHL model in two important dimensions. First, the CMV reproduces the mildly cyclical correlation of the nominal interest rate and price inflation, while the EHL model gives a slightly positive correlation of these variables with output. Second, and more importantly, the CMV model endogenously explains unemployment fluctuations, unlike the EHL model, where the labor market is always at equilibrium. Indeed, the CMV model provides business cycle statistics on volatility, correlation with output and autocorrelation that describe accurately the unemployment fluctuations observed in U.S. data. Perhaps, the only significant discrepancy is that the CMV model underpredict a bit the observed unemployment persistence.

4.2 Variance decomposition

Tables 3-4 show the total variance decomposition analysis for the CMV and EHL models, respectively. The two models show similar variance decompositions patterns for most variables. Thus, output variance is mainly driven by IS shocks, χ, whereas productivity innovations, z, play a secondary role. The opposite is true for potential output. Labor (demand and supply) variance is fundamentally determined by IS innovations in the two models. Price and wage inflation variance are almost entirely determined by their own exogenous shocks (υ^p and υ^w, respectively). Real wage variance is also driven by υ^p and υ^w, with the latter having a larger share.

A large share of interest rate variance is determined by IS innovations in the CMV model with the interest rate innovations, (ε^R), playing a minor role. By contrast, these two innovations have a similar share in the interest rate variance decomposition associated with the EHL model. The variance decomposition of unemployment fluctuations is only reported in the CMV model because the EHL model does not include unemployment. As Table 3 shows, the CMV model reveals quite dispersion in the sources of unemployment variability. Monetary policy shocks and IS shocks take approximately two thirds of total variability, whereas supply-side shocks only contribute to explain around one fourth of changes in unemployment. Among the latter, the wage indexation shock causes one fifth of total variability while technology innovations have little influence (less than 10%) on unemployment variability.

4.3 Impulse-response functions

Figure 1 shows the estimated impulse responses to the alternative structural shocks in the CMV and EHL models. The shock impulse has been normalized to one standard deviation of the innovation in all cases. Some differences across models can be noticed when observing Figure 1. For instance, the response of price inflation, output and interest rate to a wage inflation shock is larger in the EHL model than in the CMV model. The opposite is true for the response of both price and wage inflation and the interest rate to an IS shock. After a technology shock, there is a stronger output response and a weaker price inflation reaction in the CMV model. More importantly, the CMV model explains how unemployment reacts to alternative shocks. As expected, positive price, wage, interest rate and productivity shocks increase unemployment whereas a positive IS shock reduces it.

5 ROBUSTNESS ANALYSIS

This section analyzes the robustness of the empirical evidence reported in the previous section along three dimensions. First, we consider three additional alternative measures for the cyclical component of output. Second, we include U.S. data of payroll employment in addition to the five time series studied in the estimation of the CMV model. Finally, we estimate the model using data from the pre-Volcker period and compare the estimation results with those found for the Great Moderation.

5.1 Output filters

As emphasized by Canova and Ferroni (2009), among other authors, the dynamic properties of estimated macro models can vary depending on the filter used for output. We now show that our parameter estimates are robust across filtering schemes. Table 5 displays the parameter estimates of the CMV model under three alternative definitions of cyclical output. The first definition is obtained implementing a quadratic-trend decomposition. The second is given by Hodrick-Prescott (HP) filter. Finally, the third considers directly the rate of growth of real GDP, which also captures the high frequency fluctuations of output. The estimation results are very similar for the four definitions of output cyclical component studied. Moreover, the cyclical features of the CMV model analyzed in Section 4 are also robust to the use of alternative cyclical components.[10]

5.2 Introducing employment and a labor supply shock

The benchmark estimation of the CMV model considers only unemployment time series as the single variable describing labor market capacity. By contrast, the EHL model estimation includes a measure of labor (total hours) instead of unemployment. In this subsection, we consider U.S. data of payroll employment in addition to the five time series studied in the benchmark case. The inclusion of an additional time series forces us to introduce an additional shock.[11] In particular, we introduce an autocorrelated labor supply (disutility) shock, ζ_t, that would appear in equations governing fluctuations on both labor supply, (11), and potential output, (14). Table 6 shows the estimation results using the set of six time series that includes both unemployment and payroll employment. They are again quantitatively similar to those obtained for the benchmark model reported in Table 1.

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[10] Not shown due to space limitations. These results are available upon request to the authors.

[11] As discussed by Ireland (2004), there is a long-standing tradition of introducing additional disturbances into DSGE models until the number of shocks equals the number of data series used in estimation. The reason is that models of this type are quite stylized and introduce fewer shocks than observable variables, which implies that models are stochastically singular. That is, the model implies that certain combinations of endogenous variables are deterministic. If these combinations do not hold in the data, any approach that attempts to estimate the complete model will fail.

5.3 Pre-Volcker period (1957:Q1-1979:Q2)

This subsection analyzes the pre-Volcker period. Table 7 shows the estimation results in the CMV and EHL models. Following Smets and Wouters (2007), the Pre-Volcker sample starts in 1957 and finishes right before the arrival of Paul Volcker as Federal Reserve chairman, who introduced changes in the operating procedures of the Fed. When comparing these estimation results with those obtained for the Great Moderation data set, it is useful to distinguish four sets of parameters. The first is composed by the so called deep parameters (σ, γ, θ, θ_{ehl}, α and β). The estimates are robust across models and samples. The second set is formed by the indexation parameters (δ_p and δ_w) and Calvo parameters (η_p and η_w). Indexation parameters are slightly larger during the Great Moderation than in the pre-Volcker period. However, there are important differences in the Calvo parameter estimates. A comparison of the estimation results from the two samples shows that the difference between wage and price stickiness parameters in the two models becomes significant when the pre-Volcker period is considered, as wage stickiness was higher and price stickiness was lower compared to the more recent period of the Great Moderation.

The third set of parameter estimates consists of the policy rule parameters (μ_r, μ_π and μ_y). The estimates from the pre-Volcker period are similar to those found for the Great Moderation period, except for the inflation coefficient, which is significantly lower for the two models in the pre-Volcker period. This result is in line with previous evidence reported in the literature (Lubik and Schorfheide, 2004; Canova, 2009). Moreover, the estimated inflation coefficient, lower than one, associated with the CMV model implies that the Taylor principle did not hold during this period. The fourth set comprises the autoregressive and standard deviation of shocks. On the one hand, the autoregressive parameters (ρ_χ and ρ_z) show a great deal of persistence in the pre-Volcker shocks. On the other hand, the standard deviation of price, productivity and, to a lesser extent, IS shocks are larger in the pre-Volcker than in the Great Moderation period. By contrast, the standard deviation of wage and interest rate shocks are similar across samples.

6 WELFARE COST OF BUSINESS CYCLE FLUCTUATIONS

Otrok (2001) and Lucas (2003) argue that the welfare cost of U.S. business cycles is small. They calculate a welfare loss around 0.05% of consumption. Such low welfare cost is obtained in a model with perfect competition and flexible prices. Costain and Reiter (2005) calculate the welfare cost of business cycles in a model with search frictions and flexible prices, finding numbers significantly larger than Otrok and Lucas, in the range between 0.25% and 0.33% of consumption.

Levin, Onatski, Williams, and Williams (2005) estimated the welfare cost of US post-war business cycles using a model that incorporated two sources of nominal rigidities: sticky prices and sticky wages. They found a welfare cost of 2.6% of steady-state consumption, which is much higher than numbers from previous studies. As pointed out in their paper, nominal rigidities can bring cross-sectional dispersion in relative prices and wages that produce large disparities in labor assignments and, therefore, welfare losses. For example, the high wage dispersion observed with persistent wage stickiness would result in a vast differentiation of hours that would damage total utility.

As our particular contribution to the literature, we have calculated the welfare cost of US business cycle in the estimated models. The welfare cost is measured at the corresponding business cycles during the Great Moderation, using the Bayesian estimation results reported in Table 1. Given the small macroeconomic volatility observed in that period, this exercise may bring a floor value for the economic cost of cyclical fluctuations. The welfare cost is obtained by quantifying the utility loss caused by short-run fluctuations. A three-step procedure is implemented. First, we take a second-order approximation to the instantaneous utility function (1) in order to find the influence of business cycle variabilities and price/wage dispersions. The second step consists of computing the unconditional expectation of the second-order approximation. It renders in the CMV model:[12]

$$\begin{aligned} E\left[U^{CMV}\right] &= U^{ss} - \tfrac{1}{2}\sigma var(c) - \tfrac{1}{2}\tfrac{1}{\sigma-1}var(\chi) + cov(c,\chi) - \tfrac{1}{2}\overline{\Psi}\gamma var(n) \\ &\quad -\tfrac{1}{2}\overline{\Psi}\gamma\left[\tfrac{\theta^2\eta_p}{(1-\alpha)^2(1-\eta_p)^2}var(\triangle^{\delta}\pi^{p}) + \tfrac{\theta^2\eta_w^2\tau_1^2}{(1-\alpha)^2(1-\eta_w)^2}\tfrac{(1-\eta_p)}{(1-\eta_w\eta_p)}var(\triangle^{\delta}\pi^{w})\right], \end{aligned}$$

where $var(a)$ refers to the unconditional variance of variable a, $cov(a,b)$ denotes the unconditional

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[12] The proof is written in a technical appendix available under request. Steady-state employment has been normalized to one, which implies unit steady-state consumption.

covariance between variables a and b, and both $\triangle^{\delta}\pi^{p} = \pi^{p} - \delta_{p}\pi_{-1}^{p}$ and $\triangle^{\delta}\pi^{w} = \pi^{w} - \delta_{w}\pi_{-1}^{w}$ are changes in price inflation and wage inflation adjusted using the indexation weights.[13] The last line of $E\left[U^{CMV}\right]$ collects the welfare cuts caused by nominal rigidities because it would be ruled out with both flexible prices and flexible wages, i.e. by setting $\eta_p = \eta_w = 0$. Finally, the third step measures the welfare cost of cyclical fluctuations as the percentage increase in consumption required to compensate for the utility loss caused by the short-run variability.

For a comparison, the unconditional expectation of the utility function was also calculated in the EHL model with this result

$$\begin{aligned} E\left[U^{EHL}\right] &= U^{ss} - \tfrac{1}{2}\sigma var(c) - \tfrac{1}{2}\tfrac{1}{\sigma-1}var(\chi) + cov(c,\chi) - \tfrac{1}{2}\overline{\Psi}\gamma var(n) \\ &\quad -\tfrac{1}{2}\overline{\Psi}\gamma\left[\tfrac{\theta^{2}\eta_{p}}{(1-\alpha)^{2}(1-\eta_{p})^{2}}var(\triangle^{\delta}\pi^{p}) + \tfrac{\theta_{f}^{2}\eta_{w}}{(1-\eta_{w})^{2}}var(\triangle^{\delta}\pi^{w})\right]. \end{aligned}$$

The difference between $E[U]$ and $E\left[U^{EHL}\right]$ is

$$E\left[U^{CMV}\right] - E\left[U^{EHL}\right] = -\tfrac{1}{2}\overline{\Psi}\gamma\left(\tfrac{\theta^{2}\eta_{w}^{2}\tau_{1}^{2}}{(1-\alpha)^{2}(1-\eta_{w})^{2}}\tfrac{(1-\eta_{p})}{(1-\eta_{w}\eta_{p})} - \tfrac{\theta_{f}^{2}\eta_{w}}{(1-\eta_{w})^{2}}\right)var(\triangle^{\delta}\pi^{w}),$$

which captures the distinct treatment of the labor market and wage setting between the two models.

Table 8 reports the results of the welfare cost of cyclical fluctuations measured by the consumption equivalent. The baseline CMV model estimates a 0.60% of steady-state consumption. The version of the sticky-wage model of EHL (2000) delivers a welfare loss estimate equal to 0.86% of steady-state consumption. These numbers are clearly larger than Lucas and Otrok's estimates, probably because they did not allow labor dispersion in his perfect competition setup. In addition, welfare losses of business cycle are larger than the number found by Costain and Reiter (2005), which suggests that search frictions are not as influential as nominal rigidities. However, the numbers obtained here are approximately one third of the values provided by Levin *et al.* (2005) in a model also featuring sticky prices and sticky wages. Such difference can be due to two reasons: i) Levin *et al.* (2005)'s number is obtained with post-war data that shows higher cyclical variability, and ii) Levin *et al.* (2005)'s model includes real money balance in the utility function which adds welfare losses coming from monetary fluctuations.

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[13] It should be noticed that the adjusted change of price inflation gives a measure of "price dispersion" since it is proportional to the log deviation between optimal prices and the aggregate price level, $\triangle^{\delta}\pi^{p} = \frac{1-\eta_{p}}{\eta_{p}}\log\left(\frac{P^{*}}{P}\right)$. The same kind of relationship applies to nominal wages, $\triangle^{\delta}\pi^{w} = \frac{1-\eta_{w}}{\eta_{w}}\log\left(\frac{W^{*}}{W}\right)$.

Table 8 shows that the CMV model gives a lower welfare cost than the EHL model (0.60% *versus* 0.86%). The lower welfare cost found in the CMV model can be explained by the buffering effect of job-clearing wages. When labor demand is rising (falling), nominal wages increase (decrease) to clear the positive (negative) gap between labor demand and supply. The EHL model introduces a wage setting behavior driven by the mrs gap, which is has no direct implication on reducing labor dispersion.

The last term on the expressions for $E\left[U^{CMV}\right]$ and $E\left[U^{EHL}\right]$ shown above brings the contribution of nominal rigidities to the welfare cost of business cycles. Actually, Table 8 reports that nominal rigidities cause most welfare cost of business cycle. If flexible prices or wages are imposed in the model the welfare loss due to cyclical fluctuations falls significantly. Thus, having flexible prices in the estimated CMV model cuts welfare cost in approximately half (from 0.6% to 0.28%). A similar reduction is observed when having flexible wages (from 0.60 to 0.31).[14] Therefore, price stickiness and wage stickiness have similar weights on the guilt of welfare losses due to cyclical fluctuations.

In the EHL model, however, the relative influence of price or wage stickiness brings very different conclusions in the welfare analysis. Thus, the EHL model with flexible prices reduces the welfare loss to approximately one fourth (from 0.86% to 0.22%). Thus, price rigidities explain most welfare cost of business cycle. Meanwhile, setting the EHL model with flexible wages would bring an increase in welfare loss! Having flexible wages would increase the welfare cost from 0.86% to 0.98% of steady-state consumption. This unexpected results is found because the increase in wage inflation volatility with fully-flexible wages is exported to price inflation through higher marginal cost dispersion.

Finally, if both sources of nominal rigidities (sticky prices and sticky wages) were eliminated from the model, the welfare loss would be further reduced to 0.23% in the CMV model and 0.08% in the EHL model. These numbers are much closer to Lucas' estimate than the ones obtained in the baseline version of the models. Moreover, these numbers are slightly smaller than Lucas' estimates

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[14] Jung and Kuester (2009) find a welfare cost of business cycles close to 0.20% of steady-state consumption in a model that combine sticky prices, search frictions and flexible wages.

when shutting down consumption preference shocks.

7 CONCLUSIONS

Only in recent times, the New-Keynesian model has incorporated endogenous fluctuations of unemployment due to search frictions (Trigari, 2009; Walsh, 2005) or, alternatively, to sticky wages (Casares, 2007, 2008). We have estimated a modified version of the latter variant (the CMV model) using U.S. data from the "Great Moderation" period (1984-2008). Our estimation results suggest that price and wage rigidities are both significantly high and of similar size. Compared to the pre-Volcker period (1957:1-1979:2), price stickiness has increased while wage rigidities have diminished a bit. In addition, we found that the inertial components of price and wage inflation dynamics are not very large, which implies that both variables are mainly driven by forward-looking dynamics. Demand (IS) shocks are the main driving force over the business cycle, as they explain most of the observed variability in output, labor, and the nominal interest rate. Results are similar in an estimated version of the sticky-wage model of Erceg *et al.* (2000), referred here as the EHL model.

Unlike the EHL model, the CMV model provides a measure of unemployment fluctuations based on staggered wage contracts: the fraction of non-renegotiated wage contracts delivers unemployment as a mismatch between labor supply and labor demand in the extensive margin. The estimated CMV model provides a good matching of the second-moment statistics of unemployment obtained in the data (standard deviation, correlation with output and autocorrelation). Impulse-response functions show that unemployment is procyclical with demand shocks and countercyclical with supply shocks. In the variance decomposition, demand-side shocks, such as consumption preference innovations and monetary policy shocks, explain most unemployment variability. We also estimated the model under alternative detrending techniques and without employment as an observable variable. In all cases, the results are robust. For the pre-Volcker period (1957:1-1979:2), wage stickiness was higher and that the interest rate response to inflation was significantly lower than after 1984.

Finally, the welfare cost of nominal rigidities during the Great Moderation has been estimated to be 0.60% of steady-state consumption in the CMV model and 0.86% in the EHL model. These numbers are clearly higher than the estimate obtained by Lucas (2003), but lower than the number reported by Levin *et al.* (2005) using a sticky-price, sticky-wage estimated model with post-war U.S. data.

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Table 1. Priors and estimated posteriors of structural parameters

	Priors			Posteriors					
				CMV			EHL		
	Distr	Mean	Std D.	Mean	5%	95%	Mean	5%	95%
σ	Normal	2.00	0.10	2.11	1.95	2.25	2.11	1.95	2.27
γ	Normal	4.00	0.50	4.66	3.99	5.35	4.34	3.78	4.91
θ	Normal	6.00	0.50	6.18	5.45	6.83	6.30	5.81	6.85
θ_f	Normal	4.00	0.50				4.18	3.62	5.02
α	Normal	0.36	0.01	0.36	0.34	0.37	0.36	0.35	0.37
β	Normal	0.99	0.01	0.99	0.97	1.00	0.99	0.97	1.00
δ_p	Normal	0.50	0.10	0.47	0.36	0.55	0.59	0.48	0.69
δ_w	Normal	0.50	0.10	0.38	0.29	0.48	0.33	0.24	0.44
η_p	Beta	0.50	0.10	0.82	0.78	0.86	0.88	0.84	0.91
η_w	Beta	0.50	0.10	0.85	0.81	0.88	0.82	0.77	0.87
μ_r	Beta	0.75	0.10	0.84	0.80	0.87	0.83	0.79	0.86
μ_π	Normal	1.70	0.30	2.00	1.74	2.36	2.02	1.67	2.29
μ_y	Gamma	0.125	0.10	0.70	0.51	0.95	0.35	0.23	0.50
ρ_χ	Beta	0.50	0.15	0.94	0.91	0.96	0.90	0.87	0.93
ρ_z	Beta	0.50	0.15	0.87	0.83	0.92	0.91	0.87	0.93
σ_p	Inv Gamma	0.15	0.15	0.43	0.35	0.53	0.60	0.43	0.76
σ_w	Inv Gamma	0.15	0.15	1.12	0.90	1.33	0.95	0.79	1.12
σ_r	Inv Gamma	0.15	0.15	0.16	0.15	0.18	0.15	0.13	0.16
σ_z	Inv Gamma	0.15	0.15	0.44	0.38	0.49	0.45	0.39	0.49
σ_χ	Inv Gamma	0.15	0.15	2.46	1.76	3.08	1.76	1.44	1.98

Table 2. Business cycle statistics - Linear Trend

	$\widehat{y}$	π^p	π^w	R	u
U.S. data, 1984:1-2008:2					
Standard deviation	1.60	0.25	0.60	0.54	1.06
Correlation with output	1.0	0.03	0.25	0.23	-0.59
Autocorrelation	0.95	0.48	0.15	0.97	0.98
Estimated CMV model					
Standard deviation	1.30	0.26	0.66	0.41	0.98
Correlation with output	1.0	0.11	0.18	0.15	-0.48
Autocorrelation	0.89	0.51	0.31	0.91	0.72
Estimated EHL model					
Standard deviation	1.30	0.28	0.63	0.35	–
Correlation with output	1.0	-0.19	0.04	-0.21	–
Autocorrelation	0.88	0.56	0.29	0.89	–

Table 3. Forecast error variance decomposition of CMV model

			Shock		
	υ^p	υ^w	ε^R	z	χ
Output	0.0201	0.0034	0.0612	0.3164	0.5988
Potential output	0.0000	0.0000	0.0000	0.6078	0.3922
Labor supply	0.0104	0.0818	0.0104	0.0722	0.8252
Labor demand	0.0281	0.0049	0.0866	0.0847	0.7957
Unemployment	0.0610	0.2017	0.3626	0.0637	0.3109
Real wage	0.2054	0.6277	0.0502	0.0287	0.0879
Price inflation	0.7624	0.0479	0.0102	0.0313	0.1482
Wage inflation	0.0125	0.9002	0.0277	0.0045	0.0551
Nom. interest rate	0.0722	0.0129	0.2221	0.1266	0.5662

Table 4. Forecast error variance decomposition of EHL model

	Shock				
	υ^p	υ^w	ε^R	z	χ
Output	0.0603	0.0392	0.0891	0.2815	0.5298
Potential output	0.0000	0.0000	0.0000	0.7838	0.2162
Total hours	0.0753	0.0477	0.1109	0.1089	0.6572
MRS	0.1844	0.1162	0.2729	0.0475	0.3790
Real wage	0.2582	0.7056	0.0044	0.0230	0.0088
Price inflation	0.8256	0.1201	0.0029	0.0248	0.0266
Wage inflation	0.0055	0.9808	0.0028	0.0017	0.0092
Nom. interest rate	0.2143	0.0781	0.3131	0.1231	0.2714

Table 5. Estimates under alternative cyclical components of output.

	Quadratic			HP			Growth rate		
	Mean	5%	95%	Mean	5%	95%	Mean	5%	95%
σ	2.11	1.98	2.24	2.09	1.94	2.27	2.08	1.97	2.29
γ	4.52	3.81	4.99	4.76	4.09	5.40	4.72	4.13	5.34
θ	6.20	5.39	6.92	6.09	5.39	6.86	6.05	5.35	6.79
α	0.36	0.34	0.37	0.36	0.34	0.37	0.36	0.34	0.37
β	0.99	0.97	1.00	0.99	0.97	1.00	0.99	0.97	1.00
δ_p	0.45	0.33	0.54	0.44	0.35	0.51	0.47	0.37	0.60
δ_w	0.36	0.26	0.43	0.41	0.29	0.53	0.36	0.24	0.50
η_p	0.82	0.79	0.87	0.82	0.78	0.85	0.82	0.78	0.86
η_w	0.85	0.82	0.88	0.84	0.81	0.87	0.86	0.83	0.89
μ_r	0.85	0.82	0.88	0.84	0.81	0.88	0.86	0.83	0.88
μ_π	1.97	1.55	2.48	1.86	1.58	2.21	1.98	1.66	2.32
μ_y	0.73	0.47	0.94	0.70	0.46	0.89	0.73	0.46	0.99
ρ_χ	0.94	0.91	0.96	0.93	0.90	0.96	0.94	0.92	0.96
ρ_z	0.85	0.78	0.91	0.81	0.77	0.86	0.89	0.83	0.93
σ_p	0.41	0.34	0.50	0.39	0.33	0.45	0.44	0.33	0.57
σ_w	1.07	0.90	1.30	1.21	0.90	1.53	1.07	0.82	1.33
σ_r	0.16	0.14	0.18	0.17	0.15	0.21	0.16	0.13	0.18
σ_z	0.45	0.36	0.51	0.41	0.36	0.47	0.49	0.40	0.57
σ_χ	2.38	1.69	2.84	2.14	1.65	2.54	2.37	1.74	2.81

Table 6. Estimation results using Employment time series.

	Priors			Posteriors		
					CMV	
	Distr	Mean	Std D.	Mean	5%	95%
σ	Normal	2.00	0.10	2.11	1.97	2.21
γ	Normal	4.00	0.50	5.64	5.23	6.36
θ	Normal	6.00	0.50	6.30	5.58	7.37
α	Normal	0.36	0.01	0.35	0.34	0.37
β	Normal	0.99	0.01	0.99	0.97	1.01
δ_p	Normal	0.50	0.10	0.57	0.44	0.73
δ_w	Normal	0.50	0.10	0.39	0.31	0.48
η_p	Beta	0.50	0.10	0.78	0.73	0.82
η_w	Beta	0.50	0.10	0.83	0.81	0.87
μ_r	Beta	0.75	0.10	0.80	0.77	0.83
μ_π	Normal	1.70	0.30	1.78	1.60	2.13
μ_y	Gamma	0.125	0.10	0.57	0.36	0.72
ρ_χ	Beta	0.50	0.15	0.89	0.86	0.91
ρ_z	Beta	0.50	0.15	0.94	0.91	0.96
ρ_ζ	Beta	0.50	0.15	0.96	0.95	0.98
σ_p	Inv Gamma	0.15	0.15	0.60	0.38	0.89
σ_y	Inv Gamma	0.15	0.15	1.12	0.92	1.23
σ_r	Inv Gamma	0.15	0.15	0.17	0.15	0.19
σ_z	Inv Gamma	0.15	0.15	0.44	0.39	0.48
σ_χ	Inv Gamma	0.15	0.15	1.58	1.31	1.87
σ_ζ	Inv Gamma	0.15	0.15	1.85	1.61	2.05

Table 7. Estimation results for the pre-Volcker period.

	Priors			Posteriors					
				CMV			EHL		
	Distr.	Mean	Std D.	Mean	5%	95%	Mean	5%	95%
σ	Normal	2.00	0.10	2.00	1.83	2.14	1.99	1.87	2.16
γ	Normal	4.00	0.50	4.04	3.24	4.68	4.14	3.39	5.13
θ	Normal	6.00	0.50	6.31	5.05	7.16	5.95	5.43	6.63
θ_f	Normal	4.00	0.50				3.87	2.99	4.46
α	Normal	0.36	0.01	0.35	0.34	0.37	0.35	0.34	0.36
β	Normal	0.99	0.01	0.98	0.97	1.00	0.99	0.98	0.99
δ_p	Normal	0.50	0.10	0.61	0.49	0.76	0.55	0.44	0.67
δ_w	Normal	0.50	0.10	0.52	0.46	0.61	0.57	0.48	0.68
η_p	Beta	0.50	0.10	0.71	0.63	0.79	0.58	0.52	0.62
η_w	Beta	0.50	0.10	0.92	0.89	0.95	0.85	0.84	0.85
μ_r	Beta	0.75	0.10	0.76	0.70	0.82	0.84	0.80	0.87
μ_π	Normal	1.70	0.30	0.89	0.66	1.11	1.03	0.82	1.28
μ_y	Gamma	0.5/4	0.10	0.67	0.52	0.79	0.63	0.40	0.98
ρ_χ	Beta	0.50	0.15	0.93	0.91	0.96	0.90	0.87	0.93
ρ_z	Beta	0.50	0.15	0.94	0.91	0.98	0.92	0.87	0.96
σ_p	Inv Gamma	0.15	0.15	1.19	0.87	1.64	0.98	0.75	1.33
σ_w	Inv Gamma	0.15	0.15	1.11	0.89	1.32	1.27	0.98	1.58
σ_r	Inv Gamma	0.15	0.15	0.15	0.13	0.18	0.14	0.12	0.17
σ_z	Inv Gamma	0.15	0.15	1.01	0.83	1.18	0.75	0.69	0.83
σ_χ	Inv Gamma	0.15	0.15	2.98	2.26	3.85	2.95	2.55	3.42

Table 8. Welfare cost of business cycle fluctuations (% of steady-state consumption).

	CMV model	EHL model
Baseline estimation	0.60	0.86
Imposing flexible prices and wages ($\eta_p = \eta_w = 0$)	0.23	0.08
Imposing flexible wages ($\eta_w = 0$)	0.31	0.98
Imposing flexible prices ($\eta_p = 0$)	0.28	0.22
Imposing flexible prices and wages and no IS shocks ($\eta_p = \eta_w = var(\chi) = 0$)	0.04	0.02

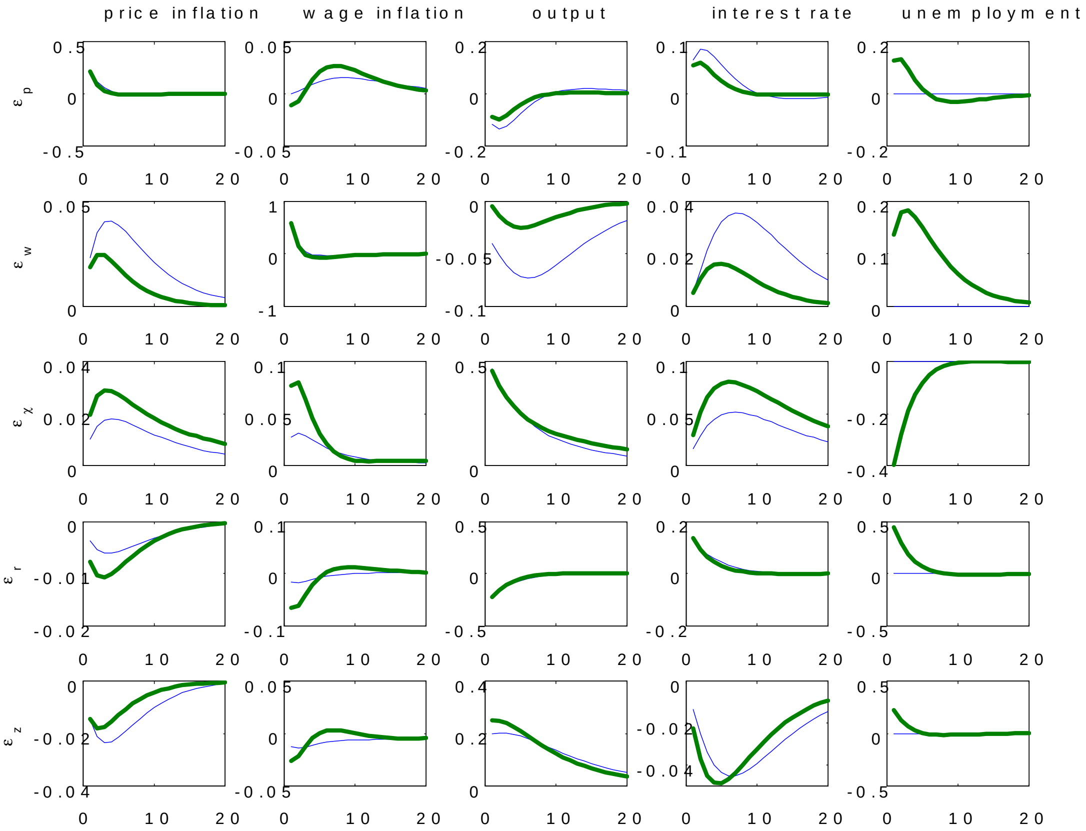

Figure 1: Impulse Response Functions from estimated CMV (thick) and EHL (thin) models.