Centre for Applied Macroeconomic Analysis

The Australian National University

CAMA Working Paper Series **April, 2008**

Inflation Dynamics with Search Frictions: A Structural Econometric Analysis

Michael U. Krause
Deutsche Bundesbank

David Lopez-Salido
Federal Reserve Board

Thomas A. Lubik
Federal Reserve Bank of Richmond

CAMA Working Paper 6/2008
http://cama.anu.edu.au

Inflation Dynamics with Search Frictions: A Structural Econometric Analysis*

Michael U. Krause
Deutsche Bundesbank

David Lopez-Salido
Federal Reserve Board

Thomas A. Lubik†
Federal Reserve Bank of Richmond

March 2008

Abstract

The New Keynesian Phillips curve explains inflation dynamics as being driven by current and expected future real marginal costs. In competitive labor markets, the labor share can serve as a proxy for the latter. In this paper, we study the role of real marginal cost components implied by search frictions in the labor market. We construct a measure of real marginal costs by using newly available labor market data on worker finding rates. Over the business cycle, the measure is highly correlated with the labor share. Estimates of the Phillips curve using GMM reveal that the marginal cost measure remains significant, and that inflation dynamics are mainly driven by the forward-looking component. Bayesian estimation of the full New Keynesian model with search frictions helps us disentangle which shocks are driving the economy to generate the observed unit labor cost dynamics. We find that mark-up shocks are the dominant force in labor market fluctuations.

JEL Classification: E24; E32; J64.

Key Words: Phillips curve; Bayesian estimation; marginal costs; labor market frictions.

*This paper was prepared for the Carnegie-Rochester Conference on Public Policy, November 9-10, 2007. We are grateful for comments by our discussant Miguel Casares, as well as Olivier Blanchard, Bill English, Marvin Goodfriend, Ben McCallum, Per Krusell, Julio Rotemberg, Carlos Thomas, Carl Walsh, and the participants at the Carnegie-Rochester Conference. We also like to thank seminar audiences at the Federal Reserve Bank of Dallas, the University of Montreal, and the Hungarian National Bank. The views expressed in this paper are those of the authors and should not be interpreted as those of the Deutsche Bundesbank, the Federal Reserve Bank of Richmond, the Board of Governors, or the Federal Reserve System.

†Corresponding author: Research Department, P.O. Box 27622, Richmond, VA 23261. Email: thomas.lubik@rich.frb.org.

1 Introduction

This paper studies the determinants of real marginal cost fluctuations when there are search frictions in the labor market. Without such frictions, or any other type of labor adjustment costs, real marginal costs are identical to unit labor costs. Search frictions are a particular form of labor adjustment costs that are determined by aggregate labor market conditions, rather than being internal to the firm. They therefore give rise to long-term employment relationships since both firm and worker save future search costs by continuing their match. This dual role of search frictions motivates our interest in how they alter the nature of real marginal costs, which in turn are the key determinants of inflation dynamics in business cycle models with monopolistic price setting and price rigidities.

We illustrate the linkages between inflation and real marginal costs in a New Keynesian model with search and matching frictions in the labor market.[1] We first use the model to derive a (linearized) equation for real marginal costs. Our strategy is then to generate a synthetic time series for real marginal costs by calibrating the additional parameters in the equation. We use newly available labor market data for 1960 to 2005 on job finding rates, vacancies, unemployment and wages, to construct the series. This, in turn, forms the basis of a limited-information (GMM) estimation of the hybrid New Keynesian Phillips curve (NKPC) from the model. In a third step, we estimate the full general equilibrium model, using the same variables, to further understand the interaction between labor market variables and inflation, and the driving forces of their joint dynamics.

We find that search frictions do indeed matter for inflation dynamics, in that they tend to reduce the role of backward-looking price setting for generating persistence, and by changing the sensitivity of inflation to real marginal costs. At the same time, the synthetic measure of real marginal costs is fairly closely related to unit labor costs. We also find that, among the variables that matter for real marginal costs, the real wage has become more volatile since the 1980s, even though consumption is less volatile. Furthermore, real marginal costs have become procyclical from the 1980s, while they are countercyclical for the whole sample.

This paper is among the first to estimate an aggregate labor market search and matching model in a full-information setting.[2] The estimation allows us to disentangle the determinants of the joint fluctuations of labor market variables and inflation. Our findings confirm

[1] We follow a literature that has adopted the labor market model by Pissarides (2000) into dynamic general equilibrium frameworks, such as Merz (1995), Andolfatto (1996), and Den Haan et al. (2000) in real models, and Walsh (2005), Trigari (2006), and Krause and Lubik (2007a) for monetary models.

[2] Other recent contributions are Christoffel et al. (2006), and Gertler et al. (2007).

those from the calibration-based analysis in that search and matching frictions do not dramatically alter inflation dynamics. However, this conclusion hides three aspects of marginal cost dynamics that are not apparent from a limited-information perspective.

First, the main driving force of labor market variables are mark-up shocks, which substantiates the argument of Rotemberg (2006). Mark-up shocks generate volatile vacancies and unemployment, since they do not lead to wage increases that reduce firms' incentive to post vacancies. Second, we find that unit labor costs and real marginal costs can move together positively or negatively depending on the underlying shock. Whether labor market frictions are helpful in capturing inflation dynamics therefore depends on the incidence of specific shocks. We argue that over our sample period mark-up shocks played overall a smaller role, hence the measured conclusion regarding the importance of the labor market for inflation dynamics. Finally, we emphasize the importance of a fully structural analysis in addressing these questions. We extract an implied marginal cost series from the estimation that differs significantly from the calibrated series. The smoothing algorithm decomposes the 'residual' in the NKPC into an endogenous variable component and an exogenous shock component. In other words, the persistence and volatility of inflation stems from sources besides those already captured by the imputed marginal cost series.

The model we employ is standard in most of its components. We deviate from the search and matching model in that we assume that hiring of workers is instantaneous rather than with a lag as in most models. In this respect we unify the specifications of Rotemberg (2006) and Blanchard and Galí (2007). The former author assumes large firms with costs of job creation that are concave in the number of vacancies posted,[3] while the latter authors make this timing assumption to allow a representation of the New Keynesian Phillips curve in terms of inflation and unemployment, rather than the output gap. The virtue of this specification is that real marginal costs can be expressed in terms of observable labor market variables. In contrast, the standard model implies a real marginal cost expression in terms of unobservable shadow values of employment. However, we note that the timing assumption as such does not deliver substantially different dynamics.

The paper proceeds as follows. The next section describes the full New Keynesian DSGE model. In section 3, we derive an equation for real marginal costs from the model's job creation condition that explicitly shows the role of the labor market variables implied by search frictions and discuss the construction of a real marginal cost series using calibrated parameters and labor market data. Section 4 conducts the GMM estimation of the NKPC

[3] The standard model features constant-returns-to-scale job creation costs.

under labor market frictions. In section 5, we take a general equilibrium perspective and estimate the full model using Bayesian methods. Section 6 concludes, while an Appendix provides key derivations.

2 A New Keynesian model with search frictions

Consider an economy that consists of households, firms, a government, and a central bank. Households choose consumption over time and the allocation of consumption across differentiated products. They supply labor at both the intensive and extensive margins: workers search in order to find employment, and when employed, they supply hours and earn wages determined in bilateral Nash bargaining. Firms simultaneously choose hiring and prices subject to hiring and price adjustment costs. They hire workers in a frictional labor market and separate from them at an exogenous rate, and choose the price of their differentiated product in a monopolistically competitive product market. Employment is the outcome of firms' and workers' search behavior, while wages and hours worked are the outcome of bargaining. Wages are fully flexible. The government issues a one period bond and levies a lump-sum tax. The central bank sets the nominal interest rate in response to inflation and output.

2.1 Households

Households are distributed along the unit interval and consist of a continuum of workers of measure one. The welfare of household i is given by

$$\mathcal{W}(n_{it}) = \max_{\{c_{it}\}_{t=0}^{\infty}} E_t \sum_{t=0}^{\infty} \beta^t \zeta_t \left[\frac{(c_{it} - \varsigma c_{t-1})^{1-\sigma} - 1}{1-\sigma} - \chi_t n_{it} \frac{h_{it}^{1+\mu}}{1+\mu} \right], \tag{1}$$

where $\beta \in (0,1)$ is the discount factor, c_{it} consumption, c_{t-1} aggregate consumption, where ςc_{t-1} is an index of external habits, and n_{it} the number of employed workers. The welfare function already assumes that all members of the household consume the same amount of goods, and supply the same amount of hours h_{it} when employed. The parameter σ governs risk aversion, and μ is the inverse Frisch elasticity of labor supply. The labor market will be considered in more detail later on. Finally, we allow household welfare to be affected by an intertemporal preference shock ζ_t and an intratemporal labor supply shock χ_t.

All households consume the familiar constant-elasticity-of-substitution bundles of differentiated goods

$$c_{it} = \left(\int_0^1 c_{it}(j)^{(\epsilon_t - 1)/\epsilon_t} dj \right)^{\epsilon_t/(\epsilon_t - 1)}, \tag{2}$$

with ϵ_t the stochastic elasticity of substitution between goods. The associated minimum-expenditure price index is

$$p_t = \left(\int_0^1 p_t(j)^{1-\epsilon_t} dj \right)^{1/(1-\epsilon_t)}, \tag{3}$$

where $p_t(j)$ are the prices charged by each monopolistic competitor producing variety j.

The households' flow budget constraint is

$$c_{it} + \frac{B_{it}}{p_t} = R_{t-1} \frac{B_{it-1}}{p_t} + w_t n_{it} h_{it} + (1 - n_{it}) b + d_{it} + T_{it}, \tag{4}$$

where households enter period t with bonds B_{it-1}, that pay a gross interest rate R_{t-1}. At the beginning of the period, they receive lump-sum nominal transfers T_{it}, labor income $w_t n_{it} h_{it}$, where w_t denotes the real wage, and a nominal dividend d_{it} from firms, which are owned by the households. The term $(1 - n_{it})b$ denotes income of unemployed household members, which can be interpreted as total output of a home production sector where the technology parameter $b > 0$. Alternatively, this parameter captures the access to unemployment benefits by the non-working members of the household.

The first-order conditions with respect to bonds and consumption imply

$$\lambda_{it} = \zeta_t (c_{it} - \varsigma c_{t-1})^{-\sigma}, \tag{5}$$

$$1 = \beta E_t \left[R_t \frac{\lambda_{it+1}}{\lambda_{it}} \frac{p_t}{p_{t+1}} \right], \tag{6}$$

where λ_{it} is the marginal utility of consumption. In general equilibrium, this condition governs the stochastic discount factor used in the firms' problem. Due to perfect risk sharing, the sole problem of the household is to determine the consumption path of its members. There is no explicit household labor supply choice as it is chosen at the firm level during negotiations.

2.2 The labor market

The labor market is subject to search and matching frictions. In order to form new employment relationships, workers must search, and firms must post vacancies. We assume that the number of matches M_t depends on the aggregate matching function

$$M_t = m_t u_t^{\xi} v_t^{1-\xi}, \tag{7}$$

which gives the number of new employment relationships available at the beginning of period t. u_t represents the number of searching workers, v_t is the total number of vacancies posted; m_t is stochastic match efficiency, and $0 < \xi < 1$ is the elasticity of the matching function with respect to unemployment.

The evolution of aggregate employment is given by

$$n_t = (1-\rho)n_{t-1} + M_t, \tag{8}$$

where ρ is an exogenous rate of job destruction, which takes place at the end of a period. Note that we assume hiring to be contemporaneous, that is, at the beginning of period t, firms observe the realization of the stochastic variables and post vacancies accordingly. These vacancies are matched with the pool of searching workers which are given by the workers not employed at the end of period $t-1$, so that $u_t \equiv 1-(1-\rho)n_{t-1}$.[4]

The matching function is homogeneous of degree one, increasing in each of its arguments, concave, and continuously differentiable. Homogeneity implies that a vacancy gets filled with probability $q(\theta_t) \equiv \frac{m_t u_t^{\xi} v_t^{1-\xi}}{v_t} = m_t \theta_t^{-\xi}$, which is decreasing in the degree of labor market tightness $\theta_t \equiv v_t/u_t$. Similarly, an unemployed worker finds a job with probability $p(\theta_t) \equiv \frac{m_t u_t^{\xi} v_t^{1-\xi}}{u_t} = \theta_t q(\theta_t)$, which is increasing in θ_t. Note that θ_t is taken as given by both firms and households.

2.3 Firms

We assume that there is a continuum of firms of measure one. Each firm is a monopolistic competitor and produces a differentiated good sold to households. Let p_{jt} and y_{jt} denote nominal price and output for firm j, and y_t aggregate income. A firm's output is sold in a monopolistically competitive market with demand, derived from consumer preferences, given by

$$y_{jt} = \left(\frac{p_{jt}}{p_t}\right)^{-\epsilon_t} y_t, \tag{9}$$

where $y_t = \left(\int_0^1 y_{jt}^{(\epsilon_t-1)/\epsilon_t} dj\right)^{\epsilon_t/(\epsilon_t-1)}$, consistent with the consumption bundles consumed by households. A firm produces its differentiated good using n_{jt} workers according to the following technology

$$y_{jt} = A_t \left(n_{jt} h_{jt}\right)^{\alpha}, \tag{10}$$

where A_t is aggregate productivity, and $0 < \alpha < 1$.

[4] Equivalently, u_t is the number of workers not employed in period $t-1$, $1-n_{t-1}$ plus those workers, ρn_{t-1}, who lost their jobs at the end of the period. This timing convention is exactly analogous to that of Rotemberg (2006) and Blanchard and Galí (2007), but in the notation familiar from the search and matching literature.

During period t, a firm sets its nominal price p_{jt} subject to the requirement that demand be satisfied. Following Rotemberg (1982), the firm faces a quadratic cost of adjusting its nominal price between periods, measured in terms of aggregate output and given by

$$\mathcal{P}_{jt} = \frac{\psi}{2}\left(\frac{1}{\widetilde{\pi}_{t-1}}\frac{p_{jt}}{p_{jt-1}} - 1\right)^2 y_t, \tag{11}$$

with $\psi > 0$ controlling the importance of price adjustment costs, and $\widetilde{\pi}_{t-1} = \pi_{t-1}^{\gamma}\pi^{1-\gamma}$. Inflation is defined as gross inflation $\pi_t = p_t/p_{t-1}$. The parameter $0 \leq \gamma \leq 1$ governs the degree of backward-looking price setting; and finally, π represents steady-state inflation, which is equal to the central banks inflation target (Ireland, 2007).

This cost function penalizes deviations of the firms price change from an average between past aggregate inflation π_{t-1} and steady-state inflation π. When $\gamma = 0$, price setting is purely forward-looking, in the sense that it is costless for firms to increase their prices in line with steady-state inflation. When $\gamma = 1$, price setting is purely backward-looking, in the sense that it is costless for firms to increase their prices in line with the previous period's actual rate of inflation. This formulation yields a Phillips curve analogous to the one derived from Calvo-price setting with backward-looking firms, as in Galí and Gertler (1999), or with backward indexation, as in Christiano et al. (2005).

The evolution of employment at the firm level corresponds to that of aggregate employment. We assume that the new matches at firm j at the beginning of period t are proportional to the ratio of its vacancies to total vacancies posted, v_{jt}/v_t, so that $v_{jt}M_t/v_t = v_{jt}q(\theta)$ is hiring by firm i. Evolution of employment at firm j can then be written as

$$n_{jt} = (1-\rho)n_{jt-1} + v_{jt}q(\theta_t). \tag{12}$$

For its posted vacancies v_{jt}, the firm has to pay a flow labor adjustment cost $\mathcal{N}_{jt} = c(v_{jt})$. Allowing for $c'' \neq 0$ follows Rotemberg (2006) and departs from the standard search and matching model where costs of recruiting are assumed to be linear (Pissarides, 2000).[5] As emphasized by Rotemberg (2006), if this is interpreted as the cost of advertising openings in an information source it can easily be subject to economies of scale at the firm level, so that $c'' < 0$.

Firms produce differentiated goods in a monopolistically competitive product market and they maximize the present value of discounted flow profits

$$\mathcal{J}_t(n_{jt}) = E_0 \sum_{t=0}^{\infty} \beta^t \lambda_t \left[\left(\frac{p_{jt}}{p_t}\right)^{1-\epsilon_t} y_t - w_{jt}n_{jt}h_{jt} - \mathcal{N}_{jt} - \mathcal{P}_{jt}\right], \tag{13}$$

[5] Note that in models in which firms consist of only one worker, the assumption of returns to scale in vacancy posting would be immaterial.

with respect to p_{jt}, n_{jt}, and $v_{jt,}$ subject to the constraint that demand (9) equals production (10), the employment constraint (12), and labor and price adjustment costs, $\mathcal{N}_{jt}$ and $\mathcal{P}_{jt}$, respectively. The discount factor $\beta^t \lambda_t$ derives from consumer preferences in the presence of perfect capital markets and is taken as exogenous by firms.

The first-order conditions for prices, employment, and vacancies are

$$\psi\left(\frac{\pi_{jt}}{\widetilde{\pi}_{t-1}}-1\right)\frac{\pi_{jt}}{\widetilde{\pi}_{t-1}} = E_t\beta_{t+1}\psi\left(\frac{\pi_{jt+1}}{\widetilde{\pi}_t}-1\right)\frac{\pi_{jt+1}}{\widetilde{\pi}_t}\frac{y_{t+1}}{y_t}+ \\ +(1-\epsilon_t)\left(\frac{p_{jt}}{p_t}\right)^{1-\epsilon_t}+\epsilon_t mc_{jt}\left(\frac{p_{jt}}{p_t}\right)^{-\epsilon_t}, \tag{14}$$

$$\mu_{jt} = mc_{jt}\alpha A_t n_{jt}^{\alpha-1}h_{jt}^{\alpha} - w_{jt}h_{jt} + (1-\rho)E_t\beta_{t+1}\mu_{jt+1}, \tag{15}$$

$$\frac{c'(v_{jt})}{q(\theta_t)} = \mu_{jt}, \tag{16}$$

where $\beta_{t+1} = \beta\lambda_{t+1}/\lambda_t$ is the stochastic discount factor and μ_{jt} is the Lagrange-multiplier associated with the employment constraint. It represents the current-period marginal value of workers for the firm.[6] The first equation is the optimal price setting condition, which in its linearized form reduces to the familiar New Keynesian Phillips curve. The multiplier mc_{jt} on the constraint that demand equals production is the contribution of an additional unit of output to revenue and is equal to the firm's real marginal cost. Combining the latter two conditions yields the *job creation condition*

$$\frac{c'(v_{jt})}{q(\theta_t)} = mc_{jt}\alpha A_t n_{jt}^{\alpha-1}h_{jt}^{\alpha} - w_{jt}h_{jt} + (1-\rho)E_t\beta_{t+1}\frac{c'(v_{jt+1})}{q(\theta_{t+1})}. \tag{17}$$

Intuitively, firms expand employment up to the point where the benefit from employing an additional worker (the right-hand side) is equal to the cost of posting a vacancy (the left-hand side). In symmetric equilibrium, $v_{jt} = v_t$, for all t, and the indices j disappear.

A few remarks concerning the job creation condition are in order. With symmetry in vacancy posting, we implicitly assume that all firms have equal employment levels and that all workers work the same amount of hours. Given the assumed homogeneity of employed workers and of firms, this turns out to be true in equilibrium.

A second point concerns the implied dynamics of vacancies. As a firm increases vacancies, it immediately increases employment. If the derivative of the vacancy cost function is sufficiently small (that is, negative enough), raising vacancies reduces the marginal cost of a vacancy. At the same time, rising employment lowers the marginal product of labor. Thus, in partial equilibrium, marginal posting costs must not fall too quickly for incentives

[6] This is not to be confused with the Frisch labor supply elasticity μ, which is not subscripted.

to post vacancies to be exhausted at some point. In general equilibrium, however, this effect may be mitigated if $q(\theta_t)$ increases fast enough.

The third point to note is that firms take wages as given when choosing employment (and vacancies). Strictly speaking, large firms' employment adjustment should take into account that employment potentially affects wages if they depend on the marginal product of labor. This will indeed be the case under Nash bargaining. In fact, Rotemberg (2006) takes this 'intra-firm bargaining' effect into account. Here, we deviate for two reasons. One is merely computational convenience. The other is that intra-firm bargaining is not likely to significantly affect business cycle dynamics, as shown in Krause and Lubik (2007b).

2.4 Wage determination

In general equilibrium, job creation incentives are affected by wages, and wages in turn depend on labor market conditions. We assume, as in most of the labor search literature, that worker and firm bargain at the individual level over the joint surplus of their match, split according to the Nash bargaining solution. Bargaining takes place both over hours per worker and the wage, in order to maximize the Nash product

$$\left(\frac{1}{\lambda_t}\frac{\partial \mathcal{W}_t(n_t)}{\partial n_t}\right)^{\eta}\left(\frac{\partial \mathcal{J}_t(n_t)}{\partial n_t}\right)^{1-\eta}, \tag{18}$$

where the two terms are, respectively, the marginal contribution of a worker to household's welfare, and to the present value of profits of the firm.[7] The parameter $0 < \eta < 1$ reflects the bargaining power of the worker. The two resulting optimality conditions are a wage equation

$$\begin{aligned} w_t h_t = \eta \left[mc_t \alpha A_t n_t^{\alpha-1} h_t^{\alpha} + (1-\rho) E_t \beta_{t+1} \theta_{t+1} c'(v_{t+1})\right] \\ + (1-\eta)\left[b + \frac{1}{\lambda_t}\chi_t \zeta_t \frac{h_t^{1+\mu}}{1+\mu}\right], \end{aligned} \tag{19}$$

and a labor supply equation

$$h_t = \left(\frac{mc_t \alpha^2 A_t n_t^{\alpha-1}}{\chi_t \zeta_t}\lambda_t\right)^{\frac{1}{1+\mu-\alpha}}. \tag{20}$$

The first equation is familiar from the equilibrium unemployment literature (e.g. Pissarides, 2000). It expresses the total wage payment to the worker as a weighted average between the marginal revenue product of the worker plus the cost of replacing the worker, and the outside option of the worker plus the marginal disutility of labor, at the level of hours worked h_t.

[7] From now on, we ignore household and firm indices for ease of exposition.

The bargaining weight determines how close the wage is to either the marginal product or to the outside option of the worker. A new element is the presence of *expected* labor market tightness and marginal vacancy posting cost, whereas the standard setup features current values of these variables. The intuition is that, in case negotiations break down, worker and firm will have to look for partners in next period's matching market. This saving of search costs is incorporated in the wage.[8]

The second equation determines the amount of hours worked. It is derived from a condition that equalizes the marginal product of hours worked with the worker's marginal rate of substitution between leisure and consumption

$$\text{mrs}_t = \frac{1}{\lambda_t}\zeta_t \chi_t h_t^{\mu} = mc_t \alpha^2 A_t n_t^{\alpha-1} h_t^{\alpha-1} = \text{mpl}_t. \tag{21}$$

Thus, hours are chosen as in a competitive labor market. However, optimal hours are independent of the wage. The condition also highlights the driving forces of hours variation in the search model. Higher marginal utility of wealth λ, and higher labor productivity increase hours supply, while it declines whenever the disutility of labor or the intertemporal preference increase.[9]

2.5 Closing the model

The model is closed by specifying monetary and fiscal policies. The government's budget constraint is

$$R_{t-1}\frac{B_{t-1}}{p_t} = \frac{B_t}{p_t} + T_t, \tag{22}$$

where T_t is the sum of transfers, and B_t is the aggregate of bonds held by the public. The central bank is assumed to set the nominal interest rate R_t according to the Taylor-type interest rate rule:

$$\frac{R_t}{R^*} = \left(\frac{R_{t-1}}{R^*}\right)^{\rho_r} \left[\left(\frac{\pi_t}{\pi^*}\right)^{r_\pi} \left(\frac{y_t}{y^*}\right)^{r_Y}\right]^{1-\rho_r} \varepsilon_t^R, \tag{23}$$

where $0 < \rho_r < 1$ captures interest rate smoothing, and where $r_\pi \geq 0$ and $r_Y \geq 0$. An asterisk denotes the steady state value of the corresponding variable.

We assume a symmetric equilibrium throughout, which entails identical choices for all variables. Defining aggregates as the averages of firm specific variables, we have that $n_t = n_{jt} = \int_0^1 n_{jt} dj$, and $v_t = v_{jt} = \int_0^1 v_{jt} dj$. Furthermore, as $p_{jt} = p_t$, $y_{jt} = y_t$, for all t and j. Thus, all firms produce the same amounts of output, employ equal amounts of

[8] The details of the derivation are given in the Appendix.

[9] In models where firms choose the amount of hours (such as in the right-to-manage setup of Trigari, 2006, and Christoffel and Linzert, 2006), hours are determined to equate their marginal product of labor with the bargained wage.

labor, and, in particular, face the same marginal costs mc_t. Similarly, for all households $T_t = T_{it} = \int_0^1 T_{it} di$. Finally, using the household budget constraint, firms profits, and the government budget constraint, the resulting aggregate income identity is $y_t = c_t + c(v_t)$. Output is used for consumption and for posting vacancies.[10]

3 The cyclical behavior of marginal costs

In this first part of our empirical analysis, we use the model's equilibrium condition on the posting of vacancies to derive an expression for real marginal costs in the presence of search frictions. We construct a synthetic measure of real marginal costs, based on data on the labor share and other labor market variables associated with search frictions. With this measure at hand, we then proceed to estimate the New Keynesian Phillips curve using limited-information techniques. The empirical analysis is complemented by Bayesian estimation of the full model in section 5.

3.1 Real marginal costs and search frictions

We show that a first-order approximation to real marginal cost can be decomposed into real unit labor costs – as in the standard model without search – and terms that arise in the presence of search frictions. We use the job creation condition (17)

$$\frac{c'(v_t)}{q(\theta_t)} = mc_t \alpha \frac{y_t}{n_t} - W_t + (1-\rho) E_t \beta_{t+1} \frac{c'(v_{t+1})}{q(\theta_{t+1})}, \tag{24}$$

where $W_t = w_t h_t$ denotes the wage per worker, and $y_t/n_t = A_t n_t^{\alpha-1} h_t^{\alpha}$. Note that, by symmetry, the condition is the same for all jobs.

The key equation for understanding the role of search frictions in the labor market is obtained by rewriting the equation above

$$mc_t = \frac{W_t}{\alpha(y_t/n_t)} + \frac{\frac{c'(v_t)}{q(\theta_t)} - (1-\rho) E_t \beta_{t+1} \frac{c'(v_{t+1})}{q(\theta_{t+1})}}{\alpha(y_t/n_t)}. \tag{25}$$

In the presence of search frictions, a firm's real marginal cost has two components: unit labor costs (the labor cost over the marginal product of labor), and a correction for the current unit hiring cost relative to expected hiring costs next period. This latter term can be interpreted either as cost savings from not needing to hire the worker again next period. Equivalently, it equals the future marginal benefit of that worker, which needs to be subtracted from current costs.

[10] See the Appendix for a summary of the model's equilibrium conditions and constraints, its steady state, as well as specification of the stochastic variables.

In more compact form, the previous expression can be written as

$$mc_t = s_t(1 + x_t), \tag{26}$$

where $s_t = \frac{W_t n_t}{\alpha y_t}$ is real unit labor costs, which equals the labor income share divided by the elasticity of output to employment. The term

$$x_t = \frac{1}{W_t}\left[\frac{c'(v_t)}{q(\theta_t)} - (1-\rho)E_t\beta_{t+1}\frac{c'(v_{t+1})}{q(\theta_{t+1})}\right], \tag{27}$$

captures the effects of labor adjustment costs relative to the real wage. In the absence of labor market frictions, $mc_t = s_t$. This is familiar from New Keynesian models with competitive labor markets: real marginal costs are proportional to the labor share, $S_t = \alpha s_t$.

In the steady state, Eq. (14) implies that real marginal cost is a constant that solely depends on the demand elasticity ϵ. That is, $mc = (1 - 1/\epsilon)$, which in turn is the inverse of the steady-state markup. This is the standard implication of monopolistic competition. In addition, it follows that

$$(1 - \frac{1}{\epsilon})MPL = W(1 + x), \tag{28}$$

where $MPL = \alpha\frac{y}{n}$ is the marginal product of labor. This equation shows that the benefit of hiring an additional employee – the marginal revenue product of labor – equals the marginal cost of adjusting labor that include the hiring decisions. Thus, Eq. (28) is our representation of expression (19) in Rotemberg (2006). In steady state, it follows that $W(1+x) = W + \frac{c'(v)}{q(\theta)}\left[1 - (1-\rho)\beta\right]$. On average, real marginal revenue covers the wage plus the annuity costs of hiring per period.

As mentioned above, Rotemberg (2006) uses the large firm assumption for the purpose of motivating increasing returns to vacancy posting at the firm level. To see the effects of this assumption, we assume that vacancy posting costs are specified as

$$c(v_{jt}) = c_v v_{jt}^{\epsilon_c}, \tag{29}$$

where $\epsilon_c = 1$ corresponds to the linear case discussed by Pissarides (2000). Together with the functional form of the matching function, the correction factor x_t then becomes

$$x_t = \frac{1}{W_t}\left[\frac{\epsilon_c c_v}{m}\theta_t^{\xi}{v_t}^{\epsilon_c - 1} - (1-\rho)E_t\beta_{t+1}\frac{\epsilon_c c_v}{m}\theta_{t+1}^{\xi}v_{t+1}^{\epsilon_c - 1}\right]. \tag{30}$$

Noting that total hirings in this model are $\mathfrak{h}_t = \theta_t q(\theta_t) = m_t\theta_t^{1-\xi}$. This implies $\theta_t^{\xi} = m_t^{-\xi/(1-\xi)}\mathfrak{h}_t^{\xi/(1-\xi)}$, so that

$$x_t = \frac{1}{W_t}\left[B\mathfrak{h}_t^{\xi/(1-\xi)}{v_t}^{\epsilon_c - 1} - (1-\rho)E_t\beta_{t+1}B\mathfrak{h}_t^{\xi/(1-\xi)}v_{t+1}^{\epsilon_c - 1}\right], \tag{31}$$

where $B = \epsilon_c c_v m^{-1/(1-\xi)}$. Linearizing $mc_t = s_t(1+x_t)$ then yields

$$\widehat{mc}_t = \widehat{s}_t + \frac{1-\phi}{1-\widetilde{\beta}}\left[\frac{\xi}{1-\xi}(\widehat{\mathfrak{h}}_t - \widetilde{\beta}E_t\widehat{\mathfrak{h}}_{t+1}) + (\epsilon_c - 1)(\widehat{v}_t - \widetilde{\beta}E_t\widehat{v}_{t+1}) - \widetilde{\beta}E_t\widehat{\beta}_{t+1} - (1-\widetilde{\beta})\widehat{w}_t\right], \tag{32}$$

where $\phi = \frac{s}{mc} = \frac{1}{1+x}$, and $\widetilde{\beta} = \beta(1-\rho)$.

In a Walrasian labor market, $mc = s$, so that $\phi = 1$ and hence $\widehat{mc}_t = \widehat{s}_t$. This corresponds to the baseline specification in Rotemberg and Woodford (1999) and Galí and Gertler (1999). Marginal costs are affected by the stochastic discount factor, $E_t\widehat{\beta}_{t+1} = E_t\widehat{\lambda}_{t+1} - \widehat{\lambda}_t$. The variable $\mathfrak{h}_t$ has two alternative interpretations. First, from the workers' perspective, it represents the probability of being hired in period t, that is, the job-finding rate. Second, it is an index of labor market tightness since it is proportional to the ratio of aggregate vacancies to the unemployment rate.

Our general marginal cost equation nests two cases. For linear utility, β_t is constant, so that the discount factor is irrelevant for first-order dynamics. This corresponds to the model by Rotemberg (2006). On the other hand, when $\epsilon_c = 1$, we obtain the equation implied by the model of Blanchard and Galí (2007), who include a stochastic discount factor.[11]

3.2 Calibration

We now study the properties of real marginal costs based on the derivations above. We calibrate the parameters of the model and use data on labor market variables to generate the implied marginal cost series. We then describe the statistical properties of this series, and, in particular, contrast it with proxies that have typically been used in empirical studies.

Each period is assumed to correspond to a quarter. With regard to preference parameters, the benchmark value of the relative risk aversion parameter σ is set equal to 1 (as in Blanchard and Galí, 2007), although we also consider the case of linear preferences as in Shimer (2005a) and Rotemberg (2006). We set the discount factor $\beta = 1.03^{-\frac{1}{4}}$ which implies a 3 percent annual real interest rate. We keep the steady state labor income share S equal to 0.64 as in Cooley and Prescott (1995).

The (quarterly) steady-state rate of exogenous and endogenous separation $\rho = 0.05$, a value consistent with evidence by Yashiv (2006), slightly higher than 0.034 of Den Haan et al. (2000), but lower than 0.086, the value used by Merz and Yashiv (2007). We set $\epsilon = 11$ as our benchmark value, which implies a steady state mark-up of 10 percent, and

[11] The Appendix shows the corresponding derivations.

which is consistent with the evidence presented in Basu and Fernald (1997). We set the short run elasticity of output to labor $\alpha = 0.75$. Using this calibration, the steady state value for marginal recruiting costs over the marginal product is $\phi = 0.95$. This value is in line with the calibration in Rotemberg (2006) and Blanchard and Galí (2007). Finally, given the calibration of β and ρ the discount factor $\widetilde{\beta} = 0.943$, so that the contribution of the labor market variables to the fluctuations of the real marginal costs becomes small, i.e., $\frac{1-\phi}{1-\widetilde{\beta}} = 0.055$.

We conduct some sensitivity analysis below that focuses on the calibration of the elasticity of the matching function with respect to vacancies, $1 - \xi$, and the concavity of the hiring costs, ϵ_c. The elasticity of the matching function with respect to vacancies determines how the job-finding rate responds to changes in its driving forces but it also determines the sensitivity of marginal costs to the tightness ratio and the finding rate. Thus, the lower $1 - \xi$, the higher is the sensitivity of marginal costs variations to the relevant labor market variables. We set the elasticity of the matching function with respect to vacancies, $1 - \xi$, equal to 0.5 as our benchmark value. This value is in line with the upper bound of the range reported by Petrongolo and Pissarides (2001) in their review of the literature on the matching function, and it has recently been used by Blanchard and Galí (2007) and Mortensen and Nagypal (2007). Nevertheless, we also consider the alternative value 0.3 in line with the estimates by Shimer (2005a). Regarding the elasticity of vacancy creation ϵ_c we follow Pissarides (2000) and assume that recruiting costs are linear in vacancies posted, i.e., $\epsilon_c = 1$. As a robustness check, we follow Rotemberg (2006) and also consider concave recruiting costs, which implies a value of $\epsilon_c = 0.2$.

3.3 Results

Figure 1 presents a brief summary of some basic stylized facts about unemployment, vacancies and the finding rates.[12] As shown in the top panel, the unemployment rate is strongly countercyclical, and sometimes with large fluctuations. Vacancies (measured as the help-wanted index) are even more strongly procyclical, so that the vacancy-unemployment ratio (labor market tightness) is procyclical (see the bottom panel of Fig. 1.) Finally, as evident from the bottom panel the correlation between labor market tightness and the finding rate is very high (in fact, 0.9). Recessions are periods when there is a substantial fall in the probability of finding a job, and are periods where the vacancy-unemployment ratio is low relative to its average level.

[12] A complete description of the data used in the paper can be found in the Appendix.

Figure 2 depicts our imputed measure of marginal cost and real unit labor cost s_t in the baseline calibration. We also plot the three main components of marginal cost associated with the presence of search frictions, i.e. Eq. (32): the contribution of the expected changes in the finding rates, $(1-\phi)/(1-\widetilde{\beta})\xi/(1-\xi)(\widehat{\mathfrak{h}}_t - \widetilde{\beta} E_t \widehat{\mathfrak{h}}_{t+1})$, the contribution of the stochastic discount factor, $(1-\phi)/(1-\widetilde{\beta})\widetilde{\beta} E_t \widehat{\beta}_{t+1} = (1-\phi)/(1-\widetilde{\beta})\widetilde{\beta}[E_t \widehat{\lambda}_{t+1} - \widehat{\lambda}_t]$, and the contribution of the cyclical component of the real wage, $(1-\phi)\widehat{w}_t$.[13]

The top left panel compares the typical marginal cost proxy in the New Keynesian Phillips-curve literature, real unit labor cost, with our synthetic measure. As the figure shows, the two series are very similar. At first glance, it appears that the influence of search and matching frictions on inflation dynamics is not very strong. The two series comove closely, with similar turning points, and exhibit similar persistence and volatility. From the 1980s, though, the new series is somewhat less volatile and smoother. As can be seen from Figure 3, this result remains qualitatively unchanged if we set the elasticity of the matching function with respect to vacancies $(1-\xi)$ equal to 0.7, and use the tightness ratio as an observable. The stochastic properties of real marginal costs remain unaltered.[14] Overall, this alternative calibration tends to reduce the volatility of marginal costs.

The reason for this result is illustrated in the other three panels of Fig. 2. The contribution of the stochastic discount factor and the cyclical variation of the real wage are negligible relative to the variability of unit labor costs. There is an interesting pattern, however. Consistent with the 'great moderation' period, after the mid-80s the reduction in the variability of consumption growth reduces the contribution of the stochastic discount factor to the variation in the marginal costs. Notwithstanding, the variation in the real wage is somewhat higher, but its contribution is still very small.

Table 1 reports some basic statistics underlying the visual evidence in Figs. 2 and 3. In particular, we report second moments for quadratically detrended (log) output as an indicator of the business cycle, real unit labor costs, and two measures of real marginal costs for the model with the calibration following Rotemberg (mc^R) and Blanchard and Galí (mc^{BC}), respectively. Note first that the percent standard deviation of real marginal costs is larger than the one of detrended output and real unit labor costs.[15] In the Rotemberg calibration, where marginal costs depend explicitly on the variation in the cost of vacancies,

[13] The trend component was obtained using the HP filter method with a smoothing parameter $\lambda = 100,000$.

[14] This result is not surprising given the high correlation between the finding rate and tightness (see Fig. 1).

[15] Furthermore, the role of job separations as a means to smooth hiring is eliminated. See also Krause et al. (2007) for more details on the computation of the marginal costs in models where the separation rate is endogenous.

we accordingly obtain a reduction in the variation of the marginal costs.

In addition, the departures of marginal costs from steady state are persistent, but less than the persistence of output and real unit labor costs. Over the first part of the sample marginal costs are somewhat negatively correlated with detrended output, while over the second marginal costs are more procyclical. We conclude that for the second half of the sample period the presence of search frictions enhances the countercyclical movement in the price mark-up by making marginal cost more procyclical (e.g., Rotemberg and Woodford, 1999).

In Figure 4 we display the robustness of real marginal costs consistent with the Rotemberg calibration. Under this specification, marginal costs inherit the effects of the expected changes in vacancies. The importance of this effect for marginal cost dynamics depends on the value of the elasticity of vacancy creation ϵ_c. The bottom panel of Fig. 4 presents the time series of this component, viz. the contribution of vacancies corresponds to $(1-\phi)(\epsilon_c - 1)/(1-\widetilde{\beta})(\widehat{v}_t - \widetilde{\beta} E_t \widehat{v}_{t+1})$. As can be seen from Fig. 4 and Table 1, both volatility and persistence remain similar to the specification by Blanchard and Galí, albeit marginal costs under the Rotemberg specification are slightly less volatile (see Table 1).

To summarize, we find that adding search and matching frictions in the labor market appears to affect the cyclical behavior of marginal costs only slightly in terms of comovement, persistence and volatility. A typical proxy measure for real marginal costs, such as unit labor costs, behaves similarly. This does not, however, allow us to conclude that these measures have no substantial effects on inflation dynamics. We investigate this issue further along two dimensions. First, we look at the correlation between inflation and marginal cost using a limited information approach. Second, we analyze empirically how the presence of search frictions affect inflation dynamics from a general equilibrium perspective.

4 Inflation and marginal costs: a limited-information approach

In this section we extend the analysis of Galí and Gertler (1999) to the case with search frictions in the labor market. We present estimates of the New Keynesian Phillips curve using the measure of real marginal costs constructed in the previous section. We begin by noting that a log-linear approximation of the price setting condition (14) yields the familiar New Keynesian Phillips curve, which describes inflation as driven by lagged inflation, expected future inflation, and real marginal cost:

$$\hat{\pi}_t - \gamma \hat{\pi}_{t-1} = \beta E_t[\hat{\pi}_{t+1} - \gamma \hat{\pi}_t] + \kappa \ \widehat{mc}_t - \frac{1}{\psi} \widehat{\epsilon}_t. \tag{33}$$

$\hat{\pi}_t$ is price inflation expressed as a log deviation from steady state, $\widehat{mc}_t$ represents real marginal cost, and $\widehat{\epsilon}_t$ represents exogenous variations in the mark-up associated with changes in the elasticity of demand. Since we allow for partial indexation to lagged inflation, current inflation is affected by inflation in the previous period. Finally, the pass-through from marginal costs to inflation, κ, is a function of the elasticity of demand ϵ and the price adjustment cost parameter ψ. Given a value for the elasticity of demand, the slope coefficient $\kappa = \frac{\epsilon-1}{\psi}$ pins down the price adjustment cost parameter. The previous expression can be rewritten in a more familiar form as a hybrid New Keynesian Phillips curve

$$\widehat{\pi}_t = \gamma_f E_t \widehat{\pi}_{t+1} + \gamma_b \widehat{\pi}_{t-1} + \frac{\kappa}{1+\beta\gamma}\widehat{mc}_t - \frac{1}{\psi(1+\beta\gamma)}\widehat{\epsilon}_t, \tag{34}$$

where $\gamma_f = \beta/(1+\beta\gamma)$, and the parameter on past inflation $\gamma_b = \gamma/(1+\beta\gamma)$. As in the original model of Galí and Gertler (1999), Eq. (34) corresponds to the hybrid NKPC. When $\gamma = 0$, the model corresponds to Rotemberg's (1982) original contribution, so that the model reduces to the purely forward-looking NKPC.

In this paper, we deviate from the analysis in Krause et al. (2007), where we use Eq. (34) to define the set of orthogonality conditions for all t: $E_t\{(\pi_t - \gamma^b \, \pi_{t-1} - \gamma^f \, E_t\{\pi_{t+1}\} - \frac{\kappa}{1+\beta\gamma} \, \widehat{mc}_t) \, \mathbf{z}_t\} = 0$, which can then be used to estimate the model using generalized method of moments (GMM). Instead, we rewrite Eq. (33) as a relationship between inflation and the expected discounted value of the future values of real marginal cost and mark-up variations:[16]

$$\widehat{\pi}_t = \gamma \widehat{\pi}_{t-1} + \kappa \sum_{k=0}^{\infty} \beta^k E_t \left[\widehat{mc}_{t+k} + \varphi \widehat{\epsilon}_{t+k}, \right]. \tag{35}$$

To estimate our model using (35), we need to forecast real marginal cost. Define $\widehat{mc}_t = \rho_{mc}$ $\widehat{mc}_{t-1} + u_t$, where $0 < \rho_{mc} < 1$, and the innovation u_t is an i.i.d. innovation that is uncorrelated with $\widehat{\epsilon}_{t+k}$.[17] It is straightforward to compute the forecasts as follows: $E_t \widehat{mc}_{t+k} = \rho_{mc}^k$ $\widehat{mc}_t$. Consequently, the equation for inflation that we estimate is:

$$\hat{\pi}_t = \gamma \hat{\pi}_{t-1} + \frac{\kappa}{1-\beta\rho_{mc}} \widehat{mc}_t + \epsilon_{\pi t}. \tag{36}$$

We jointly estimate the inflation equation and the AR(1) process for marginal costs. Since the exogenous variation in markups may be correlated with our measures of marginal costs, we use lagged variables as instruments. Our benchmark set of instruments includes one lag of inflation, one lag of marginal costs, and two lags of the output gap, measured as the

[16] The methodology closely parallels the present-value approach used in the empirical finance literature.
[17] We used the Box-Jenkins methodology to pin down the best AR model for marginal costs.

deviation of non-farm business sector output from a quadratic trend.[18]

In Tables 2 and 3 we present the results for the hybrid model over the period 1985:I to 2005:IV, for the specification of the marginal costs under the Blanchard-Galí and Rotemberg-calibration, respectively. We distinguish the baseline calibration of marginal costs from the alternative calibration, as specified in the previous section. Finally, we also present the robustness of the results to alternative ways of calculating marginal costs, i.e., using information on the finding rates or labor market tightness. The first two columns report the estimates of the indexation parameter γ, and the slope coefficient κ. The next column gives the implied backward-looking parameter γ_b obtained from the value of γ and the calibrated discount factor β. The final column shows the J_T test of overidentifying restrictions and below its corresponding p-value in parenthesis.

The degree of indexation is well estimated across all the specifications and it ranges between 0.6 and 0.7. Hence, even if the forward-looking component is slightly more relevant, the backward-looking component plays a significant role on inflation dynamics with a value for the coefficient γ_b around 0.4. These estimates are fairly stable across specifications, and are in line with the results of Galí et al. (2005). Finally, the slope coefficient on the marginal costs is significant but somewhat less precisely estimated, and implies that the estimated probability of changing prices, i.e., the duration of prices being fixed, is slightly larger than the one estimated in the literature.[19]

5 Inflation and marginal costs: a Bayesian full-information approach

We now turn to an analysis of inflation and marginal cost dynamics in a full information setting and estimate the full model. Our motivation is twofold. First, we are interested in the plausibility and robustness of the calibration and limited-information analysis. The

[18] Since it is possible that our instruments are only weakly correlated with the endogenous variables in our model, we follow Stock et al. (2002) and Stock and Yogo (2002) and check for the presence of weak instruments based on the g_{min} statistic of Cragg and Donald (1993). We compare this statistic against the critical values compiled by Stock and Yogo (2002), who show how to test for the presence of weak instruments based on this test statistic.

[19] As shown by Sbordone (2002), Rotemberg's menu cost model of price rigidity due to firms facing convex adjustment costs is observationally equivalent to a model based on Calvo (1983), where the price rigidity is determined by a random draw of the firms that are allowed to change prices. The slope coefficient $\kappa = \frac{\epsilon-1}{\psi}$ under the first interpretation is equal to $\kappa = \frac{(1-\beta\omega)(1-\omega)}{\omega}$ under the second one, where ω represents the probability of changing prices. Hence, it is possible to use the slope coefficient κ to pin down the probability of chaging prices, ω. For the baseline calibration, the Blanchard-Galí model implies a value or $\omega = 0.85$. As recently shown by Thomas (2007), introducing strategic complementarities in a search setup allows reinterpretation of the slope coefficient in terms of a lower ω.

model is richly parameterized and includes labor market parameters for which quantitative information is difficult to come by or which are controversial in the literature.[20] Full information estimates might thus give us an indication to what extent the marginal cost series is correctly imputed. Furthermore, we are interested in the unobservable marginal cost series that is consistent not only with the dynamics of inflation, but with full aggregate dynamics. This allows us to ascertain not only the contribution of individual shocks, but also to decompose the movements of inflation into endogenous components (those arising from marginal costs and of lagged and future inflation itself) and exogenous driving forces. It is precisely the latter aspect that is neglected in the limited information setting and that may offer clues as to the small role of the labor market in explaining inflation.

Our empirical approach is Bayesian. We log-linearize the non-linear model around a deterministic steady state and write the linearized equilibrium conditions in a state-space form. After solving the model, we employ the Kalman-filter to evaluate the likelihood function of the observable variables which we then combine with the prior distribution of the model parameters to obtain the posterior distribution. We evaluate the posterior numerically by employing the random-walk Metropolis-Hastings algorithm. We report posterior means and 90% coverage intervals as our estimation results. Further details on the computational procedure can be found in Lubik and Schorfheide (2005) or An and Schorfheide (2006).

We proceed as follows. We first discuss selection of the priors and the data employed in the estimation. The posterior estimates are reported next, followed by impulse response functions and variance decompositions which we use to discuss the sources of fluctuations in our estimated model. We then report and discuss the filtered, model-consistent marginal cost series and contrast it with the calibrated series from above. We conclude this section by offering an interpretation of the role of labor market frictions in explaining inflation dynamics.

5.1 Priors and data

We choose priors for the Bayesian analysis from a variety of sources. We roughly distinguish between two groups of parameters, those associated with production and preferences, and the labor market parameters. We choose tight priors for the former, but fairly uninformative priors for the latter. One aspect of our analysis is a characterization of the information content of the data with respect to these parameters. Share parameters are assigned a Beta-

[20] Chief examples are the bargaining parameter η and the worker's outside option b.

distribution with support on the unit interval, while Gamma-distributions are employed for positive-valued parameters. The priors are reported in Table 4.

The discount factor β is fixed at 0.98. All other parameters are estimated. We choose fairly wide priors for the intertemporal substitution elasticity σ and the (inverse of) the labor supply elasticity μ with a mean of one for both parameters. Similarly, the mean of the habit parameter $\varsigma = 0.5$. The labor input elasticity α is tightly centered around 0.67, the average labor share in the U.S. economy, while the demand elasticity ϵ is set to a mean value of 11 which implies a steady state mark-up of 10%, a customary value in the literature. The prior mean of the firm's price adjustment cost ψ is set to 20, and the indexation parameter γ to 0.5.

The priors of the matching function parameters are chosen to be consistent with two labor market facts, the observed job finding rate of 70% per quarter (Shimer, 2005a) and the average unemployment rate over the sample of 6.3%. This leads to a prior mean of 0.7 for the match elasticity ξ and of 0.7 for the match efficiency parameter $\overline{m}$. We set the mean separation rate at $\rho = 0.1$, which is the value reported in den Haan et al. (2000). The elasticity parameter of the vacancy creation cost function ϵ_c is chosen to have a mean of one with a wide coverage region. It is centered at the baseline value in the literature, which typically assumes constant creation costs. This allows us to evaluate the empirical evidence provided in Yashiv (2006) against the calibration in Rotemberg (2006) who selects $\epsilon_c \ll 1$.

We choose to be agnostic about the bargaining parameter η and use a uniform prior over the unit interval. Similarly, the value of the outside option of the worker is crucial to the debate on whether the search and matching model is consistent with labor market fluctuations (Hagedorn and Manovskii, 2008). We pick a mean value of $b = 0.4$ with a wide standard deviation, which implies a replacement ratio of slightly more than one-half of the aggregate wage.

Finally, we choose a prior mean of the response of the monetary authority to inflation γ_π to 1.5, and to output $\gamma_Y = 0.25$. The prior mean of the interest rate smoothing parameter ρ_r is 0.7. These values are commonly found in empirical Taylor rules. We consider a Beta distribution for the autocorrelation parameters of the shocks and an Inverse Gamma density for the standard deviation of the shocks, which are assumed to have a high degree of persistence and identical innovation variances with a wide coverage region. The baseline specification of the model consists of six exogenous shocks: production technology, matching technology, monetary policy, mark-up, discount factor, and the disutility of working. This would allow us to estimate the model on at most 6 data series. For our baseline estimation, however, we use five series only.[21]

We estimate the model on five data series: output, inflation, the interest rate, unemployment and vacancies. Our data are quarterly and cover a sample period from 1984:1 to 2007:1. Although observations on all variables are available at least from 1964 onward, we concentrate on a time period which is characterized by a single monetary policy regime, i.e., the tenures of Paul Volcker and Alan Greenspan as Federal Reserve Chairmen. The macroeconomic variables were extracted from the Haver database. All series, except interest and inflation rates are passed through a Hodrick-Prescott filter with smoothing parameter 1600 and are demeaned prior to estimation. The output series is real GDP in chained 2000$, which we scale by the labor force measured as over-16-year-old employed civilians. The interest rate is the quarterly effective federal funds rate, while inflation is the percentage change in the GDP deflator. Unemployment is measured by the unemployment rate of over 16 year olds. The series for vacancies is the index of help-wanted advertisements in the 50 major metropolitan areas.

5.2 Parameter estimates

We report posterior means and 90% coverage intervals in Table 5. Three estimates stand out. First, the labor supply parameter μ has a posterior mean of 5.06 with a 90% coverage region ranging from 3.4 to 6.8. This is quite high and considerably shifted away from the prior, which indicates that the data are informative with respect to this parameter. Since the model is estimated without data on hours worked, identification of the hours supply parameter might be regarded as problematic. However, the estimation procedure constructs an implied hours series to be consistent with the comovement in the observables.

The estimated value implies that hours do not vary much over the business cycle. Workers are unwilling to substitute out of leisure, once employed, in order to incrementally work longer. This is not to say that the overall labor supply elasticity for *total* hours worked is low. It simply implies that labor input adjusts mainly along the extensive margin in line with the findings of Cho and Cooley (1994).[22] Workers do not have direct control over the level of employment since it is governed by the matching process. However, firms can increase employment by posting more vacancies, subject to two constraints: hiring costs $c_v v_t^{\epsilon_c}$

[21] Estimation turned out to be unstable, on account of likely identification problems, when the model was specified with five exogenous disturbances. Adding an additional shock helped disentangle this. Furthermore, in our robustness exercise, we add additional information in form of an observable to investigate the stability of the estimates.

[22] It is likely that this finding is not robust to changes in the specification of the disutility of work. This is left to future research, however.

and wage payments, both of which reduce a firm's incentive to seek employees. Since wages and hours are jointly chosen in the bargaining process, they represent a 'benefits package' that resolves the relative volatilities of the intensive and extensive margin by smoothing hours.

The posterior estimate of η is 0.67 with a 90% coverage region that lies between 0.38 and 0.97. Recall that the prior on η is uniform. The estimation shifts probability mass towards stronger worker bargaining power. Wages, therefore, are more closely in line with the marginal product, which depresses vacancy creation and thus increased movement in employment. At the same time, the elasticity ϵ_c is estimated with a posterior mean of 3.35, which makes vacancy creation very costly and compounds the effect of a fairly high degree of wage flexibility. In other words, the algorithm largely shuts down the labor market as a source of persistence and volatility, which echoes the findings in Krause and Lubik (2007a).[23]

Estimates of the other labor market parameters are much less dramatic. All of them show substantial overlap with the priors. The benefit parameter b is estimated at almost the prior mean of 0.4, but is more concentrated. This indicates that aggregate data, seen through the prism of this DSGE model, would adjudicate in favor of the Shimer (2005a) calibration and its implication that the standard search and matching model cannot replicate the dynamics of unemployment and vacancies.[24] The posterior means of the matching function parameters are in line with other values in the literature. The match elasticity ξ of 0.68 is not far away from the prior, as is the match efficiency parameter $\overline{m}$. Finally, the estimate of the level parameter in the vacancy cost function c_v simply replicates the prior, and therefore is not identified in an econometric sense. This is to some extent an artifact of the specific parameterization of the cost function.

The demand elasticity ϵ and the labor share parameter α come in close to the prior. Since the specific data set used appears to be uninformative, we fix both parameters at their prior means of $\epsilon = 11$ and $\alpha = 0.67$ in the rest of the paper.[25] The estimate of σ as 0.92 is not implausible and reasonably tight and different from the prior. Since identifying

[23] These estimates are substantially different from what is typically assumed in the calibration literature. In most papers, vacancy creation costs are linear, i.e. $\epsilon_c = 1$. Rotemberg (2006) even assumes values as low as $\epsilon_c = 0.2$. In contrast, Yashiv (2006), estimates a convex cost function ($\epsilon_c > 1$), albeit using micro-data and a slightly different specification.

[24] Hagedorn and Manovskii (2008) argue that values of b as high as 0.9 are more plausible, to which, however, the posterior distribution assigns zero probability.

[25] Estimating the baseline version with either or both parameters fixed shows virtually no differences in parameter estimates. Using marginal data densities as measures of fit, we find that the preferred specification allows for variation in ϵ. The differences in posterior odds are tiny, however, and it is well known that they are sensitive to minor specification changes.

information on this parameter comes largely from the optimal hours choice we leave this parameter unrestricted.

The estimates of the habit parameter and the inflation indexation parameter are somewhat surprising. Both are commonly seen as sources of intrinsic inflation persistence in the NKPC. The habit parameter is effectively zero, while the posterior mean of γ is 0.29. Both parameter distributions are locationally different from their respective priors and quite concentrated. The model thus relies on extrinsic sources of persistence, which, given our discussion of the estimates of the labor market parameters, are likely to be the exogenous shocks. This confirms the findings in Galí and Gertler (1999) who argue for a small, but significant degree of indexation in price-setting, and, at the same time, confirms the results above from the calibration and limited information exercise. The model generates enough of a propagation mechanism to not have to rely on an intrinsic source of inflation persistence. What the Bayesian estimation shows is that this is almost exclusively coming through the exogenous shocks, rather than the elements added by the search and matching frictions in the labor market. This is confirmed by the estimates (not reported) of the autoregressive coefficients of the shocks which are largely clustered around 0.95.

We conduct one robustness check by adding more information to the model in the form of an additional observable, namely the labor share. Our main concern is how this helps with the identification of the labor market parameters. The series is the same as used before in the limited information analysis; it is the total wage bill in the non-farm business sector scaled by the respective output. Posterior estimates are reported in Table 6. The most notable finding is that the labor share series adds persistence to implied marginal cost and, therefore, inflation. This is evident from the reduction of the intrinsic persistence parameter from 0.3 to 0.2. As an observable the labor share captures enough of the second moments inherent in inflation to serve as a good proxy for the unobserved marginal cost (which is a main reason why this variable has been used from Galí and Gertler, 1999, on forward). Search and matching frictions add to this, so that only a smaller component of inflation persistence is explained by the backward-looking term.

However, the estimates also reveal potential identification problems. The posterior for the benefit parameter b essentially overlaps with the prior, while the vacancy cost elasticity ϵ_c is not markedly different from unity. The price stickiness parameter is now estimated an order of magnitude smaller than the prior mean, which stems from the use of the labor share as an observable. The labor supply elasticity μ is much smaller than in the baseline, but still shifted away from the prior. This indicates that an inelastic hours supply is required to match the joint behavior of the labor market and inflation, unless there are other sources of persistence.

5.3 Impulse response functions and variance decomposition

We report the impulse responses of the observables to the structural shocks in Figure 5. The effects of a one-standard-deviation technology shock are standard. Output increases, and firms respond by posting vacancies and letting current employees work longer. This stands in contrast to the widely-discussed finding by Galí (1999) that a technology shock has a contractionary effect on hours worked.[26] The difference lies in the labor market framework. Persistent technology shocks raise the value of a job to the firm. In order to cover the required outlays for vacancy postings, firms produce more output through higher hours. This obtains despite a low estimated hours supply elasticity and convex vacancy costs.

The effects of shocks to the demand elasticity ϵ are virtually identical to those of technology shocks, except for scaling. This addresses the suggestion by Rotemberg (2006) that demand shocks can help explain the volatility puzzle in search and matching models. Technology shocks raise the marginal product of labor and thereby put upward pressure on wages, which in turn reduces the incentive of firms to post vacancies. In contrast, expansionary demand shocks, which amount to a reduction in market power, make firms want to increase employment, but at the same time reduce marginal revenue and thus wage pressures. Consequently, incentives to post vacancies remain high. Note also that the output response is of the same order of magnitude as under a technology shock, while the response of unemployment and vacancies is much larger for this type of demand shock. Both shocks generate similar endogenous propagation and appear as equally important driving forces for labor market variables. Finally, innovations to the match efficiency m_t have a strong negative effect on unemployment and vacancy creation, but are on balance expansionary (although not to the same degree as technology shocks).

Impulse response analysis can only give an indication as to the most important driving forces of the business cycle. We compute the model's variance decomposition in order to investigate this issue further. The results are reported in Table 7. In the estimated model, unemployment and vacancies are exclusively driven by mark-up and matching shocks. This is not surprising since the latter are identified from the employment equation as the innovation to the rate of transformation of old into new employment. This is reminiscent of an investment-specific shock in the RBC literature. Similarly, the mark-up shock mainly

[26] Note that *total* hours also increase over the entire adjustment path.

operates through the job creation condition as it affects the expected value of a job. An important implication of this finding is that search and matching models that do not include either shock offer an incomplete characterization of business cycle dynamics.

The picture for the other variables is more balanced. 67% of output variations are explained by technology shocks, and 27% by the mark-up shock, the effect identified by Rotemberg (2006). The labor supply shock χ has virtually no effect on the model's estimated business cycle behavior. The shock to the discount factor ζ, on the other hand, almost fully explains the behavior of the nominal interest rate. The intertemporal preference shock functions as the residual in the Euler-equation. Since the model implies consumption smoothing and the anti-inflationary policy renders inflation less volatile, variations in the nominal interest rate are picked up by the unobserved component, that is, ζ_{t+1}/ζ_t.

This also helps explain the slightly counterintuitive behavior of inflation, which is driven to almost 75% by the policy shock. This is due to two factors. First, the model is estimated over a period during which monetary policy was conducted in an anti-inflationary manner, as evidenced by the high estimated reaction coefficient. Disturbances are counteracted by the endogenous policy reaction with the result that inflation does not move much. Whatever dynamics there are, are explained by the exogenous component to policy, the policy shock. Second, the variance decomposition indicates that independent movements in the components of marginal cost effectively counteract each other. While mark-up and matching shocks are the main driving forces of unemployment and vacancies, their contribution to inflation is minimal, which supports the conclusion arrived at before that search and matching frictions are seemingly negligible for marginal costs dynamics.

When we include the labor share in our set of observables, the variance decomposition reveals some differences to the baseline (see Table 6). The labor share is explained to 66% by the mark-up shock, which is due to its impact on the marginal revenue product. This also affects the role of mark-up shocks for vacancy fluctuations, whose main driving forces are now matching shocks. Interestingly, the determinants of movements in unemployment are roughly unchanged. As in the baseline version, these three shocks do not have any influence on interest and inflation dynamics.

To summarize, evidence from the baseline estimates confirms the findings from the calibration-based analyses above. Search and matching frictions in the labor market do not seem to matter much for the dynamics of inflation. However, the contributions of individual shocks are not robust to the inclusion of additional information.

5.4 Model-consistent marginal costs

We now extract the implied marginal cost series by using the Kalman-smoother at the posterior mean. This procedure is essentially similar to the approach pursued in the calibration analysis as we attempt to describe the behavior of an unobservable by using observable variables. The crucial difference is that the likelihood-based estimation imposes the optimal instruments and the cross-equation restrictions from the model. More importantly, however, the smoother extracts the pure marginal cost series conditional on the model's shocks. The imputed series is reported in Figure 6 along with the calibrated series from the baseline specifications using the Rotemberg and Blanchard-Galí timing conventions.

Two observations are immediate. The filtered series is more persistent and volatile, and, second, the turning points do not line up. At first glance, the two types of series appear to be unrelated. The explanation for this seeming disconnect is that the calibrated series include the contributions of the exogenous shocks impacting the economy, while the filtered series is constructed such as to strip them out. In the reduced form of the full model, the equation associated with the NKPC can be decomposed into endogenous variables, which make up the implied marginal cost term, and the model's shocks. The filtered series is thus conditional on the identified shocks, whereas the calibrated series shows the average, unconditional behavior of marginal cost over the business cycle.

The flip side of this argument is that search and matching frictions do contribute significantly to marginal cost dynamics. Their contribution, however, is obscured by the fact that the variables in the model are buffeted by shocks that imply specific comovement. Consequently, the contribution of the labor market is reduced. In that sense, the calibrated version of the marginal cost series is truly from a partial equilibrium, reduced-form perspective, whereas the filtered series depicts the endogenous contribution of marginal costs to aggregate dynamics inclusive of labor market frictions. This suggests that our calibration analysis, and therefore the limited information approach, is not well primed to address this question in the absence of explicitly modeling the interactions of the endogenous and exogenous variables. This, of course, is akin to conducting a full-information analysis.

5.5 Interpretation

Estimation of the full New Keynesian model using likelihood-based methods allows us to draw a few conclusions regarding inflation and marginal cost dynamics. The first observation concerns the robustness of the parameter estimates. While the matching function parameters ξ and $\overline{m}$ are tightly estimated across specifications, there is scarce information in the data about, notably, the benefit parameter b. The source of intrinsic persistence is robust over all specifications: habit formation plays virtually no role; on the other hand, backward-looking price-setting, i.e., the lag coefficient in the NKPC, is significant but small. For other parameters, the estimates vary widely, across specifications. The labor supply parameter μ and the bargaining share η are a case in point. Essentially, they are not identified, both in an econometric sense (which judicious use of a Bayesian prior can remedy) and an economic sense. The use of more information, such as data on hours worked and wages can potentially alleviate this. However, this leads us to the *caveat* that a calibration-based analysis which rests on these parameter values should be approached with caution.

The second conclusion concerns the results from the limited-information analysis. Search and matching frictions do not appear to add much explanatory power for marginal cost and inflation dynamics. The two most important determinants in that respect are the labor share (as a proxy for unit labor cost) and a lagged inflation term. The full-information approach, however, illuminates subtle qualifications to this conclusion. The calibration-based approach from above is essentially an unconditional analysis. It captures the average behavior of inflation, marginal cost and labor market variables over the business cycle. Moreover, the calibrated marginal cost series, which we use as input for the GMM estimation, may violate the cross-equation restrictions that are implicit when we estimate the full model as a data-generating process. When we impute the unobservable marginal cost series, we use individual data series irrespective of how they were generated. This procedure therefore conflates the responses of endogenous variables and the exogenous impact of shocks.

Third, we find that mark-up shocks are the main driving forces behind labor market variables, but they are not as important in explaining output fluctuations. Vice versa, technology shocks have low explanatory power for the labor market. This result is in line with the Shimer (2005a) puzzle, which essentially demonstrates a disconnect between the labor market side and aggregate dynamics (see also the discussion in Krause and Lubik, 2007a). We also substantiate the argument in Rotemberg (2006) who demonstrates the importance of mark-up shocks. As already evident from the simple sample correlations in section 3, comovement between marginal cost and inflation has changed both over time and across the incidence of shocks. We would therefore argue that findings in the empirical NKPC literature which identify marginal cost as a variably unimportant driving force of inflation rest on specific historical episodes.

Finally, we also offer a few perspectives on the labor market literature. Based on our estimates, the aggregate evidence points towards a low replacement ratio. Contrary to

Hagedorn and Manovskii (2008) high values of b appear not to be a solution to the Shimer-puzzle, as the estimation puts very low probability weight on their values. We also identify mark-up shocks and matching shocks as crucial for explaining labor market dynamics.

6 Conclusion

In this paper, we develop and estimate a baseline New Keynesian model with labor market frictions. We find a relatively low impact of search frictions on the cyclical variation of real marginal costs beyond that of real unit labor costs. From the structural estimation of the full model we identify the sources of macroeconomic fluctuations that are needed to explain labor market dynamics and inflation. Exogenous movements in the marginal revenue product of labor associated with changes in desired mark-ups help explain vacancy and unemployment fluctuations without any effect on inflation.

We arrive at these results using both limited- and full-information estimation techniques. The limited-information estimation based on GMM, shows that the labor share (or unit labor costs) and real marginal costs exhibit very similar dynamics, which appear unaffected by the inclusion of labor market variables. The full-information Bayesian estimation of the model confirms the dichotomy between labor market frictions and inflation, and furthermore identifies the importance of mark-up shocks as a driving force of business cycles.

Whether mark-up shocks are to be regarded as structural shocks, or endogenous responses of mark-ups through some unmodeled channel, is an issue for further research. Mark-ups do vary over the business cycle, as has been observed before (see, for example, Rotemberg and Woodford, 1999). We do not take a stand on the ultimate sources of mark-up variations. But their ability to generate realistic labor market dynamics in the search and matching framework casts doubt on the pessimistic assessments by Hall (2005) and Shimer (2005a), who solely focused on real supply shocks as the driving forces of vacancy and unemployment fluctuations. Allowing for demand shocks potentially changes the picture.

Appendix

1. Derivation of the wage equation under Nash bargaining and endogenous hours

Firms and workers bargain each period over how the joint surplus of their match is divided. The solution maximizes the Nash product

$$\left(\frac{1}{\lambda_t}\frac{\partial \mathcal{W}_t(n_t)}{\partial n_t}\right)^{\eta}\left(\frac{\partial \mathcal{J}_t(n_t)}{\partial n_t}\right)^{1-\eta},$$

the arguments of which are what each party would lose, if the match broke up. The surplus of the workers is equal to the marginal value of the job to household i

$$\frac{1}{\lambda_{it}}\frac{\partial \mathcal{W}_t(n_t)}{\partial n_{it}} = w_{it}h_{it} - b - \frac{1}{\lambda_{it}}\zeta_t\chi_t\frac{h_{it}^{1+\mu}}{1+\mu} + E_t\beta_{t+1}\frac{1}{\lambda_{it+1}}\frac{\partial \mathcal{W}_{t+1}^{i}(n_{it+1})}{\partial n_{it+1}}\left[(1-\rho)(1-\theta_{t+1}q(\theta_{t+1}))\right].$$

This is the derivative of the household's value function with respect to employment n_{it}. Division by λ_{it} translates the utility units of $\mathcal{W}$ in terms of goods. The firm's surplus is the marginal value of a worker:

$$\frac{\partial \mathcal{J}_t^{j}(n_{jt})}{\partial n_{jt}} = mc_tA_t\alpha n_{jt}^{\alpha-1}h_{jt}^{\alpha} - w_{jt}h_{jt} + E_t\beta_{t+1}\left[\frac{\partial \mathcal{J}_{t+1}^{j}(n_{jt+1})}{\partial n_{jt+1}}(1-\rho)\right].$$

The first-order condition with respect to the wage is (dropping the indices j and i):

$$(1-\eta)\frac{1}{\lambda_t}\frac{\partial \mathcal{W}_t(n_t)}{\partial n_t} = \eta\frac{\partial \mathcal{J}_t(n_t)}{\partial n_t}.$$

This equation can be interpreted as a sharing rule according to which each party obtains a fraction of the joint surplus. That is: $\frac{1}{\lambda_t}\frac{\partial \mathcal{W}_t(n_t)}{\partial n_t} = \eta\left(\frac{\partial \mathcal{J}_t(n_t)}{\partial n_t} + \frac{1}{\lambda_t}\frac{\partial \mathcal{W}_t(n_t)}{\partial n_t}\right)$ and accordingly for the firm. To find the wage, insert the value functions into the sharing rule

$$(1-\eta)\left(w_th_t - b - \frac{1}{\lambda_t}\zeta_t\chi_t\frac{h_t^{1+\mu}}{1+\mu} + E_t\beta_{t+1}\left[(1-\rho)(1-\theta_{t+1}q(\theta_{t+1}))\frac{1}{\lambda_{t+1}}\frac{\partial \mathcal{W}_{t+1}(n_{t+1})}{\partial n_{t+1}}\right]\right)$$
$$= \eta\left(mc_tA_t\alpha n_t^{\alpha-1}h_t^{\alpha} - w_th_t + E_t\beta_{t+1}\left[(1-\rho)\frac{\partial \mathcal{J}_{t+1}(n_{t+1})}{\partial n_{t+1}}\right]\right),$$

and rearrange:

$$w_th_t = \eta mc_tA_t\alpha n_t^{\alpha-1}h_t^{\alpha} + (1-\eta)\left(b + \frac{1}{\lambda_t}\chi_t\zeta_t\frac{h_t^{1+\mu}}{1+\mu}\right) - (1-\eta)E_t\beta_{t+1}\left[(1-\rho)(1-\theta_{t+1}q(\theta_{t+1}))\frac{1}{\lambda_{t+1}}\frac{\partial \mathcal{W}_{t+1}(n_{t+1})}{\partial n_{t+1}}\right] + \eta E_t\beta_{t+1}\left[(1-\rho)\frac{\partial \mathcal{J}_{t+1}(n_{t+1})}{\partial n_{t+1}}\right].$$

Because of continuous renegotiation, the sharing rule must also hold in the future $(1-\eta)\frac{1}{\lambda_{t+1}}\frac{\partial\mathcal{W}_{t+1}(n_{t+1})}{\partial n_{t+1}} = \eta\frac{\partial\mathcal{J}_{t+1}(n_{t+1})}{\partial n_{t+1}}$. Simplifying, yields:

$$w_t h_t = \eta mc_t A_t \alpha n_t^{\alpha-1} h_t^{\alpha} + (1-\eta)\left(b + \frac{1}{\lambda_t}\chi_t\zeta_t\frac{h_t^{1+\mu}}{1+\mu}\right) + \eta E_t\beta_{t+1}\left[(1-\rho)\theta_{t+1}q(\theta_{t+1})\frac{\partial\mathcal{J}_{t+1}(n_{t+1})}{\partial n_{t+1}}\right].$$

Use the first-order condition for vacancies posted, noting that the Lagrange multiplier of the firms optimization problem is $\mu_{t+1} = \partial\mathcal{J}_{t+1}(n_{t+1})/\partial n_{t+1}$

$$\frac{c'(v_{t+1})}{q(\theta_{t+1})} = \frac{\partial\mathcal{J}_{t+1}(n_{t+1})}{\partial n_{t+1}},$$

to arrive at the equation for the wage paid to a worker:

$$w_t h_t = \eta mc_t A_t \alpha n_t^{\alpha-1} h_t^{\alpha} + (1-\eta)\left(b + \frac{1}{\lambda_t}\chi_t\zeta_t\frac{h_t^{1+\mu}}{1+\mu}\right) + \eta(1-\rho)E_t\beta_{t+1}\theta_{t+1}c'(v_{t+1}).$$

To determine the choice of hours, maximize the Nash product

$$\left(\frac{1}{\lambda_t}\frac{\partial\mathcal{W}_t(n_t)}{\partial n_t}\right)^{\eta}\left(\frac{\partial\mathcal{J}_t(n_t)}{\partial n_t}\right)^{1-\eta},$$

with respect to hours and obtain (using the previous result $(1-\eta)\frac{1}{\lambda_t}\frac{\partial\mathcal{W}_t(n_t)}{\partial n_t} = \eta\frac{\partial\mathcal{J}_t(n_t)}{\partial n_t}$)

$$\frac{1}{\lambda_t}\chi_t\zeta_t h_t^{\mu} = mc_t\alpha^2 A_t n_t^{\alpha-1} h_t^{\alpha-1},$$

or:

$$h_t = \left(\frac{mc_t\alpha^2 A_t n_t^{\alpha-1}}{\chi_t\zeta_t}\lambda_t\right)^{\frac{1}{1+\mu-\alpha}}.$$

Hours are set so that the marginal rate of substitution of labor is equal to the marginal product of labor, just as in the competitive model.

3. Comparing the Rotemberg and Blanchard-Galí models

Blanchard and Galí (2007) analyze a version of the New Keynesian model with search and matching frictions that differs from our baseline specification in that *hiring* is instantaneous. That is, vacancies are assumed to be filled immediately by paying the hiring cost, which is assumed to be a function of labor market tightness. This implies that optimal hiring decisions are not determined by an intertemporal condition. Jobs are destroyed at the fixed rate ρ and employment evolves as:

$$n_{jt} = (1-\rho)n_{jt-1} + H_{jt}.$$

Current-period employment depends on last period's employment that survives the separation shock, and current period hiring. Hiring H_{jt} is given by $v_{jt}q(\theta_t)$ as before. Hiring costs per firm are $H_{jt}G_t$ where $G_t = Bh_t^{\delta}$, with $\mathfrak{h}_t = H_t/U_t$ and $\delta \geq 0$. B is a positive constant satisfying $\rho B < 1$. G_t and $q(\theta_t)$ are taken as given by firms. Thus, firm j hiring costs are $\mathcal{N}_{jt} = v_{jt}q(\theta_t)G_t$. The first-order condition for employment is

$$B\mathfrak{h}_t^{\delta} = mc_t\alpha\frac{y_t}{n_t} - W_t + (1-\rho)E_t\beta_{t+1}B\mathfrak{h}_{t+1}^{\delta},$$

which can be used to write the marginal costs as in our general expression (26), where now,

$$x_t = \frac{1}{W_t}[B\mathfrak{h}_t^{\delta} - (1-\rho)E_t\beta_{t+1}B\mathfrak{h}_{t+1}^{\delta}].$$

As emphasized by Blanchard and Galí, the first term in x_t captures the cost of hiring a marginal employed worker, while the second relates to the savings in hiring costs resulting from the reduced hiring needs in period $t+1$. To avoid potential confusion, note that our $\mathfrak{h}_t$ corresponds to their $x_t = H_t/U_t$. In our setup, $\mathfrak{h}_t = H_t/U_t = \theta_t q(\theta_t) = m\theta_t^{1-\xi}$, so that $\mathfrak{h}_t^{\delta} = m\theta_t^{(1-\xi)\delta}$. Rotemberg (2006) uses the large firm assumption to motivate increasing returns to vacancy posting at the firm level. To see the effects of this assumption, notice that the cost of posting v_{jt} can be specified by the following, in principle, non-linear function:

$$c(v_{jt}) = c_v v_{jt}^{\epsilon_c},$$

where $\epsilon_c \leq 1$, and $\epsilon_c = 1$ corresponds to the linear case discussed by Pissarides (2000). Crucially, Rotemberg assumes that the hiring costs are incurred one period later, and that aggregate conditions in $t+1$ are observed at the end of period t, *before* vacancies are chosen. Essentially, this amounts to hiring taking place contemporaneously, as in Blanchard and Galí above. Therefore, we write from the outset the following evolution of employment[27]

$$n_{jt} = (1-\rho)n_{jt-1} + v_{jt}q(\theta_t).$$

Note that in Rotemberg's specification vacancies and labor market tightness would be timed $t-1$. The difference to our baseline setup is that new jobs are not affected by job destruction. The first-order condition for this setup is therefore:

$$\frac{\epsilon_c c_v v_t^{\epsilon_c - 1}}{q(\theta_t)} = mc_t\alpha\frac{y_t}{n_t} - W_t + (1-\rho)E_t\beta_{t+1}\frac{\epsilon_c c_v v_{t+1}^{\epsilon_c - 1}}{q(\theta_{t+1})}.$$

It follows from the previous expressions that the only difference to Blanchard and Galí (2007) is the specification of the returns to scale in vacancy posting. This expression can

[27] In Rotemberg (2006), vacancies and labor market tightness would be timed $t-1$.

be used to write the marginal costs as in our general expression (26) with

$$x_t = \frac{1}{W_t}\left[B\theta_t^{\xi} {v_t}^{\epsilon_c - 1} - (1-\rho)E_t\beta_{t+1}B\theta_{t+1}^{\xi}V_{t+1}^{\epsilon_c - 1}\right],$$

where $B = \frac{\epsilon_c c_v}{m}$. Note that Rotemberg assumes that the households' utility of consumption is linear, so that $\beta_t = \beta$, for all t. For $\epsilon_v = 1$, and $\mathfrak{h}_t = \theta_t^{1-\xi} \Leftrightarrow \theta_t^{\xi} = \mathfrak{h}_t^{\xi/(1-\xi)}$, with $\delta = \xi/(1-\xi)$, this expression is equivalent to the formulation above, i.e. Blanchard and Galí (2007) is identical to Rotemberg (2006). The new element is the negative dependence of hiring costs on v_t, arising from returns to scale in vacancy posting when $\epsilon_c < 1$. It is worth mentioning that contrary to our Eq. (27), the two expressions have two distinctive features. First, the extra-term depends positively on current hiring, vacancies and labor market tightness and negatively upon expected values. This implies that the cyclical behavior of the marginal cost is modified in different forms depending upon the form and timing of both firing and hiring costs. Second, the last two expressions require the specification of a stochastic discount factor, β_{t+1}.

4. A complete description of the baseline model and the steady state

The Stochastic Model

Euler equation	$\lambda_t = E_t\beta\lambda_{t+1}\left[R_t\frac{P_t}{P_{t+1}}\right]$, $\lambda_t = \zeta_t(c_t - \varsigma C_{t-1})^{-\sigma}$
Production	$Y_t = A_t {n_t}^{\alpha} h_t^{\alpha}$
Resource constraint	$Y_t = C_t + c(V_t)$
Unemployment	$u_t = 1-(1-\rho)n_{t-1}$, $n_t = (1-\rho)\left[n_{t-1} + M_{t-1}\right]$, $M_t = m_t u_t^{\xi} v_t^{1-\xi}$
Job creation	$\frac{c'(v_t)}{M_t}v_t = (1-\rho)E_t\beta_{t+1}\left[mc_{t+1}\alpha A_t n_{t+1}^{\alpha-1}h_{t+1}^{\alpha} - w_{t+1}h_{t+1} + c'(v_{t+1})\frac{v_{t+1}}{M_{t+1}}\right]$
Wage	$w_t h_t = \eta mc_t \alpha A_t n_t^{\alpha-1}h_t^{\alpha} + (1-\eta)\left(b + \frac{1}{\lambda_t}\chi_t\zeta_t\frac{h_t^{1+\mu}}{1+\mu}\right) + \eta(1-\rho)E_t\beta_{t+1}\theta_{t+1}c'(v_{t+1})$
Hours	$h_t = \left(\frac{mc_t\alpha^2 A_t n_t^{\alpha-1}}{\chi_t\zeta_t}\lambda_t\right)^{\frac{1}{1+\mu-\alpha}}$
Inflation	$\psi\left(\pi_t\pi_{t-1}^{-\gamma}\pi^{\gamma-1} - 1\right)\pi_t\pi_{t-1}^{-\gamma}\pi^{\gamma-1}$
	$= E_t\beta_{t+1}\psi\left(\pi_{t+1}\pi_t^{-\gamma}\pi^{\gamma-1} - 1\right)\pi_{t+1}\pi_t^{-\gamma}\pi^{\gamma-1}\frac{Y_{t+1}}{Y_t} + (1-\epsilon_t) + \epsilon_t mc_t,$
Taylor rule	$\frac{R_t}{R^*} = \left(\frac{R_{t-1}}{R^*}\right)^{\rho_r}\left[\left(\frac{\pi_t}{\pi^*}\right)^{r_\pi}\left(\frac{Y_t}{Y^*}\right)^{r_Y}\right]^{1-\rho_r}\varepsilon_t^R$

The Steady State

Marginal utility	$\lambda = (1-\varsigma)^{-\sigma} C^{-\sigma}$
Euler equation	$1 = \beta R \pi^{-1}$
Production	$Y = (nh)^{\alpha}$
Resource constraint	$Y = C + c(v)$
Employment	$n = \rho^{-1}(1-\rho)M$
Unemployment	$u = 1 - (1-\rho)n$
Matching	$M = u^{\xi} v^{1-\xi}$
Job creation	$\frac{c'(v)}{M} v = (1-\rho)\beta \left[mc\alpha \frac{Y}{n} - wh + c'(v) \frac{v}{M} \right]$
Wage	$wh = \eta mc \alpha n^{\alpha-1} h^{\alpha} + (1-\eta)\left(b + \frac{1}{\lambda} \chi \frac{h^{1+\mu}}{1+\mu} \right) + \eta(1-\rho)\beta\theta c'(v)$
Hours	$h = \left(\frac{mc\alpha^2 n^{\alpha-1}}{\chi} \lambda \right)^{\frac{1}{1+\mu-\alpha}}$
Inflation	$mc = \frac{\epsilon-1}{\epsilon}$

4. Data

We take the series for the job separation and the job finding rate from Shimer (2005b). They are quarterly averages of monthly rates. Shimer calculates two different series for the job separation and job finding rate. The first two are available from 1948 up to 2004. He uses data from the Bureau of Labor Statistics for employment, unemployment, and unemployment duration to calculate the *instantaneous* rate at which workers move from employment to unemployment and vice versa. The two rates are computed under the assumption that workers do not make labor force participation decisions. Hence, they are an approximation to the true underlying labor market rates. Starting from 1967:2, Shimer also uses the monthly Current Population Survey microdata to directly calculate the flow of workers that move in and out of the three possible labor market states (employment, unemployment, and out of the labor force). With this information he calculates the instantaneous rates at which workers move in and out each state. This yields an exact instantaneous rate at which workers move from employment to unemployment and from unemployment to employment.

We also compare the results by using two data sets of two recent studies that have modified and extended Shimer's original calculation. We first use the hazard rates series from Fujita and Ramey (2006). The series are available at monthly frequency and cover the period of January 1976 through December 2005. We compute the quarterly averages of monthly rates. These authors correct by potential margin error –inconsistency in the stock-flow identities– in the CPS. In addition, they also account for time aggregation problems. Elsby et al. (2007) also propose some refinements of the correction methods used by Shimer based on publicly available data from the CPS. Interestingly, they also distinguish employment-to-unemployment flows stemming from job loss and from job leaving, and they show that these two flows have very different cyclical properties. Thus, we use their disaggregated analysis of unemployment where we distinguish three categories: job losers, job leavers, and labor force entrants.

We use the index of help-wanted advertisements released by the Conference Board as an approximation for vacancies (`HW`). We also use the stock of unemployed –16 years and over– from the BLS, and the Unemployment Index equals to $\frac{U(t)}{U(June87)}$, which is consistent with HW Index. We construct the quarterly averages of monthly rates that are available starting at January 1951. Finally, our measure of marginal costs corresponds to the Nonfarm Business Sector. The data are drawn from FRED®II database and the variables correspond to: real output (`OUTNFB`), the output deflator (`IPDNBS`), the aggregate number of hours worked (`HOANBS`), and the compensation per hour (`COMPNFB`), respectively. Real consumption corresponds to the sum of real non-durable (`PCNDGC96`) and services (`PCESVC96`), respectively. Finally, `CNP16OV` is the civilian non institutional population.

References

[1] An, Sungbae, and Frank Schorfheide (2007): "Bayesian Analysis of DSGE Models," *Econometric Reviews*, 26(2-4), 113-172..

[2] Andolfatto, David (1996): "Business Cycles and Labor Market Search". *American Economic Review*, 86, 112-132.

[3] Basu, Susanto and John G. Fernald, (1997): "Returns to Scale in U.S. Production: Estimates and Implications," *Journal of Political Economy*, 105, 249-283.

[4] Blanchard, Olivier and Jordi Galí (2007): "A New Keynesian Model with Unemployment". Manuscript.

[5] Calvo, Guillermo (1983): "Staggered Contracts in a Utility-maximizing Framework". *Journal of Monetary Economics,* 12, 383-98.

[6] Cho, Jang-Ok, and Thomas F. Cooley (1994): "Employment and hours over the business cycle". *Journal of Economic Dynamics and Control*, 18(2), 411-32.

[7] Christiano, Lawrence J., Martin Eichenbaum, and Charles Evans (2005): "Nominal Rigidities and the Dynamic Effects of a Shock to Monetary Policy". *Journal of Political Economy* 113, 1-45.

[8] Christoffel, Kai, and Tobias Linzert (2006): "The Role of Real Wage Rigidities and Labor Market Frictions for Unemployment and Inflation Dynamics", Deutsche Bundesbank Discussion Paper 11/2006.

[9] Christoffel, Kai, Tobias Linzert, and Keith Kuester (2006): "Identifying the Role of Labor Markets for Monetary Policy in an Estimated DSGE model," Deutsche Bundesbank Discussion Paper 17/2006.

[10] Cooley, Thomas F., and Edward C. Prescott (1995): "Economic Growth and Business Cycles". In: Thomas F. Cooley, ed., *Frontiers of Business Cycle Analysis*, Princeton University Press.

[11] Cragg, John.G., and Stephen G. Donald (1993): "Testing Identifiability and Specification in Instrumental Variable Models". *Econometric Theory*, 9, 222-240.

[12] Den Haan, Wouter, Garey Ramey, and Joel Watson (2000): "Job Destruction and Propagation of Shocks". *American Economic Review*, 90, 482-498.

[13] Elsby, Michael, Gary Solon, and Ryan Michaels (2007): "The Ins and Outs of Cyclical Unemployment". NBER Working Paper No.12853, January 2007.

[14] Fujita, Shigeru and Garey Ramey (2006): "The cyclicality of job loss and hiring". Federal Reserve Bank of Philadelphia Working Paper 06-17, UC San Diego Discussion Paper 06-08, November.

[15] Galí, Jordi (1999): "Technology, Employment, and the Business Cycle: Do Technology Shocks Explain Aggregate Fluctuations?" *American Economic Review*, 89(1), 249-71.

[16] Galí, Jordi and Mark Gertler (1999): "Inflation Dynamics: A Structural Econometric Analysis". *Journal of Monetary Economics*, 44(2), 195-222.

[17] Galí, Jordi, Mark Gertler, and David Lopez-Salido (2005): "Robustness of Estimates of the Hybrid New Keynesian Phillips Curve". *Journal of Monetary Economics*, 52, 1107-1118.

[18] Gertler, Mark, Luca Sala, and Antonella Trigari (2007): "An Estimated Monetary DSGE Model with Unemployment and Staggered Nominal Wage Bargaining". Manuscript.

[19] Hagedorn, Marcus, and Iourii Manovskii (2008): "The Cyclical Behavior of Equilibrium Unemployment and Vacancies Revisited". *American Economic Review*, forthcoming.

[20] Hall, Robert (2005): "Employment Fluctuations with Equilibrium Wage Stickiness". *American Economic Review*, 95(1), 50-65.

[21] Ireland, Peter N. (2007): "Changes in the Federal Reserve's Inflation Target: Causes and Consequences". *Journal of Money, Credit and Banking*, 39, 1851-1882.

[22] Krause, Michael U., and Thomas A. Lubik (2007a): "The (Ir)relevance of Real Wage Rigidity in the New Keynesian Model with Search Frictions" *Journal of Monetary Economics*, 54(3), 706-727.

[23] Krause, Michael U., and Thomas A. Lubik (2007b): "Does Intra-Firm Bargaining Matter for Business Cycle Dynamics". Deutsche Bundesbank Discussion Paper 17/2007.

[24] Krause, Michael U., David Lopez-Salido, and Thomas A. Lubik (2007): "Do Search Frictions Matter for Inflation Dynamics?" Manuscript.

[25] Lubik, Thomas A., and Frank Schorfheide (2005): "A Bayesian Look at New Open Economy Macroeconomics". *NBER Macroeconomics Annua*l, 313-366

[26] Merz, Monika (1995): "Search in the Labor Market and the Real Business Cycle". J*ournal of Monetary Economics*, 36, 269-300.

[27] Merz, Monika, and Eran Yashiv (2007): "Labor and the Market Value of the Firm". *American Economic Review*, 97(4), 1419-1431.

[28] Mortensen, Dale T., and Eva Nagypal (2007): "More on Unemployment and Vacancy Fluctuations". *Review of Economic Dynamics*, forthcoming.

[29] Petrongolo, Barbara, and Christopher Pissarides (2001): "Looking into the Black Box: A Survey of the Matching Function". *Journal of Economic Literature*, 39, 390-431.

[30] Pissarides, Christopher (2000): *Equilibrium Unemployment Theory*. MIT Press.

[31] Rotemberg, Julio (1982): "Monopolistic Price Adjustment and Aggregate Output". *Review of Economic Studies*, 49, 517-531.

[32] Rotemberg, Julio (2006): "Cyclical Wages in a Search-and-Bargaining Model with Large Firms". Manuscript.

[33] Rotemberg, Julio, and Michael Woodford (1999): "The Cyclical Behavior of Prices and Costs". In: John Taylor and Michael Woodford (eds.): *Handbook of Macroeconomics*. North-Holland: Elsevier Science Publishers.

[34] Sbordone, Argia (2002): "Prices and Unit Labor Costs: A New Test of Price Stickiness". *Journal of Monetary Economics*, 49, 265-292.

[35] Shimer, Robert (2005a): "The Cyclical Behavior of Equilibrium Unemployment and Vacancies". *American Economic Review*, 95(1), 25-49.

[36] Shimer, Robert (2005b): "Reassessing the Ins and Outs of Unemployment". Manuscript.

[37] Stock, James H., Jonathan H. Wright, and Motohiro Yogo (2002): "A Survey of Weak Instruments and Weak Identification in Generalized Methods of Moments". *Journal of Business and Economics Statistics*, 20, 518-529.

[38] Stock, James H., and Motohiro Yogo (2002): "Testing for Weak Instruments in Linear IV Regression". NBER Technical Working Papers 0284.

[39] Thomas, Carlos (2007): "Search Frictions, Real Rigidities, and Inflation Dynamics". Manuscript.

[40] Trigari, Antonella (2006): "The Role of Search Frictions and Bargaining for Inflation Dynamics". IGIER Working Paper 304.

[41] Walsh, Carl .E. (2005): "Labor Market Search, Sticky Prices, and Interest Rate Policies". *Review of Economic Dynamics*, 8, 829-849.

[42] Yashiv, Eran (2006): "U.S. Labor Market Dynamics Revisited". IZA Dicussion Paper # 2445.

Table 1. Basic Statistics: Baseline Calibration

	Sample Period : 1960 − 2005					*Sample Period* : 1985 − 2005				
Variable	s.d.(%)	ρ	Cross Correlation			s.d.(%)	ρ	Cross Correlation		
			s	mc^{BG}	mc^{R}			s	mc^{BG}	mc^{R}
y	2.95	.95	-0.12	-0.10	-0.14	1.93	.95	0.30	0.28	0.21
s	2.09	.92	1	0.83	0.84	1.78	.91	1	0.76	0.75
mc^{BG}	2.62	.69		1	0.97	2.27	.53		1	0.97
mc^{R}	2.39	.63			1	2.08	.45			1

Table 2. GMM Estimates: 1985-2005

Blanchard-Galí Specification	γ	κ	γ_b	J_T
Finding Rates:				
Baseline Calibration	0.682 (0.124)	0.013 (0.007)	0.407 (0.045)	6.55 (0.044)
Alternative Calibration	0.635 (0.119)	0.026 (0.013)	0.389 (0.045)	6.26 (0.044)
Using Tightness:				
Baseline Calibration	0.698 (0.124)	0.0062 (0.0037)	0.406 (0.044)	7.17 (0.044)
Alternative Calibration	0.692 (0.124)	0.0085 (0.005)	0.410 (0.043)	6.97 (0.044)

Note: In all cases the dependent variable is quarterly inflation measured using the GDP Deflator. The sample period is 1985:I-2004:IV. Standard errors are shown in brackets. The instrument set includes two lags of detrended output, and one lag of real marginal costs. The hazard rates are from Shimer (2005b). The results are unchanged under alternative hazard rates.

Table 3. GMM Estimates: 1985-2005

Rotemberg Specification	γ	κ	γ_b	J_T
Finding Rates:				
Baseline Calibration	0.682 (0.124)	0.007 (0.0040)	0.416 (0.045)	6.72 (0.044)
Alternative Calibration	0.704 (0.129)	0.007 (0.0039)	0.414 (0.044)	6.87 (0.044)
Using Tightness:				
Baseline Calibration	0.698 (0.124)	0.007 (0.0041)	0.416 (0.045)	7.68 (0.044)
Alternative Calibration	0.692 (0.124)	0.007 (0.0041)	0.417 (0.046)	6.70 (0.044)

Note: In all cases the dependent variable is quarterly inflation measured using the GDP Deflator. The sample period is 1985:I-2004:IV. Standard errors are shown in brackets. The instrument set includes two lags of detrended output, and one lag of real marginal costs. The hazard rates are from Shimer (2005b). The results are unchanged under alternative hazard rates.

Table 4. Prior Distributions

Definition	Parameter	Density	Mean	Std.
Relative Risk Aversion	σ	*Gamma*	1.00	0.10
Habits	ς	*Beta*	0.50	0.20
Inverse of Labor Supply Elasticity	μ	*Gamma*	1.00	0.50
Elasticity of Output to Labor Input	α	*Beta*	0.67	0.02
Elasticity of Matching to Unemployment	ξ	*Beta*	0.70	0.05
Match Efficiency	$\overline{m}$	*Gamma*	0.70	0.10
Elasticity of Vacancy Creation	ϵ_c	*Gamma*	1.00	0.50
Scaling Factor on Vacancy Creation	c_c	*Gamma*	0.05	0.02
Bargaining Power of the Worker	η	$Uniform$	0.50	0.25
Unemployment Benefit	b	*Beta*	0.40	0.10
Separation Rate	ρ	*Beta*	0.10	0.02
Indexation	γ	*Beta*	0.50	0.20
Price Adjustment Costs	ψ	*Gamma*	20.00	5.00
Elasticity of Demand	ϵ	*Gamma*	11.00	1.00
Interest Rate Smoothing	ρ_r	*Beta*	0.70	0.02
Interest Rate Response to Inflation	γ_π	*Gamma*	1.50	0.10
Interest Rate Response to Output	γ_Y	*Gamma*	0.25	0.05
AR-Coefficients of Shocks	$\rho' s$	*Beta*	0.90	0.05
Std. Deviation of Shocks	$\sigma' s$	*Inv. Gamma*	0.01	1.00

Table 5. Posterior Estimates: Baseline Model

		Prior	Posterior	
		Mean	Mean	90% Interval
Relative Risk Aversion	σ	1.00	0.92	[0.75, 1.08]
Habits	ς	0.50	0.03	[0.00, 0.05]
Input Elasticity	α	0.67	0.65	[0.61, 0.68]
Labor Supply Elasticity	μ	1.00	5.06	[3.42, 6.75]
Elast. of Matching	ξ	0.70	0.68	[0.62, 0.74]
Scaling Factor Matching Function	$\overline{m}$	0.70	0.72	[0.57, 0.86]
Elast. of Vacancy Cost	ϵ_c	1.00	3.35	[2.35, 4.35]
Bargaining Power	η	0.50	0.67	[0.38, 0.97]
Worker Outside Option	b	0.40	0.42	[0.38, 0.46]
Separation Rate	ρ	0.10	0.06	[0.04, 0.08]
Indexation	γ	0.50	0.29	[0.04, 0.55]
Price Adjustment Costs	ψ	20.00	9.06	[5.27, 12.73]
Elasticity of Demand	ϵ	10.00	10.71	[9.09, 12.41]
Interest Rate Smoothing	ρ_γ	0.70	0.61	[0.58, 0.68]
Inflation Response	γ_π	1.50	2.24	[2.05, 2.43]
Output Response	γ_y	0.25	0.14	[0.10, 0.19]

Table 6. Robustness: Labor Share

Parameter Estimates

	Mean	90% Interval		Mean	90% Interval
σ	0.93	[0.75, 1.10]	η	0.29	[0.00, 0.83]
ς	0.03	[0.00, 0.05]	b	0.34	[0.17, 0.53]
μ	1.96	[0.79, 2.83]	γ	0.21	[0.03, 0.41]
ξ	0.72	[0.64, 0.80]	ψ	2.08	[1.08, 2.98]
ϵ_c	1.22	[0.87, 1.57]			

Variance Decomposition

	Technology	Mark-Up	Matching	Lab. Supply	Preferences	Policy
y	0.80	0.03	0.06	0.10	0.00	0.00
u	0.01	0.45	0.53	0.00	0.01	0.00
v	0.11	0.05	0.81	0.02	0.00	0.00
ls	0.21	0.66	0.08	0.02	0.00	0.03

Table 7. Variance Decomposition: Baseline Model

	Technology	Mark-up	Matching	Lab.Supply	Preferences	Policy
y	0.67	0.27	0.00	0.05	0.00	0.00
π	0.05	0.02	0.00	0.00	0.19	0.74
R	0.07	0.02	0.00	0.00	0.90	0.00
u	0.03	0.60	0.37	0.00	0.00	0.00
v	0.05	0.94	0.01	0.00	0.00	0.00

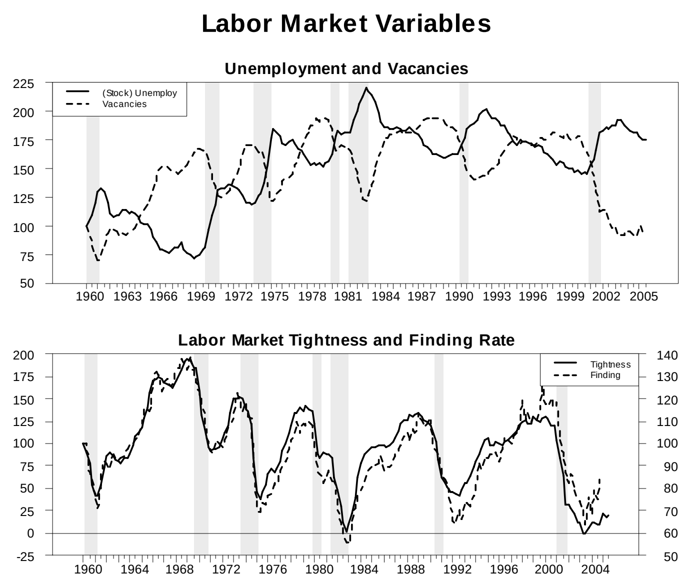

Figure 1: Some labor market variables. Top panel: unemployment rate (solid line) and vacancies (dotted line). Bottom panel: tightness ratio (solid line) and finding rate (dotted line). The shadowed areas correspond to the NBER recession dates.

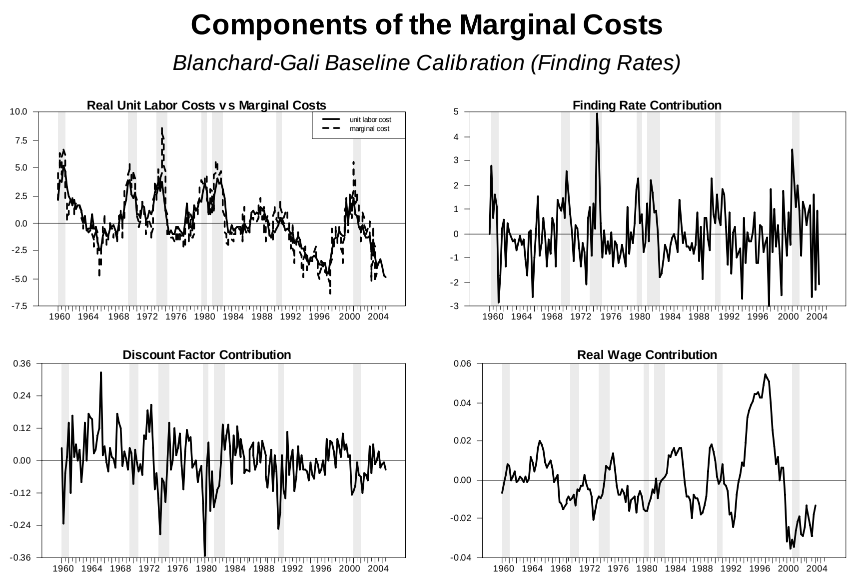

Figure 2: Real marginal costs and search frictions. In the top panel we plot unit labor costs (solid line) and real marginal costs (dotted line). The shadowed areas correspond to the NBER recession dates.

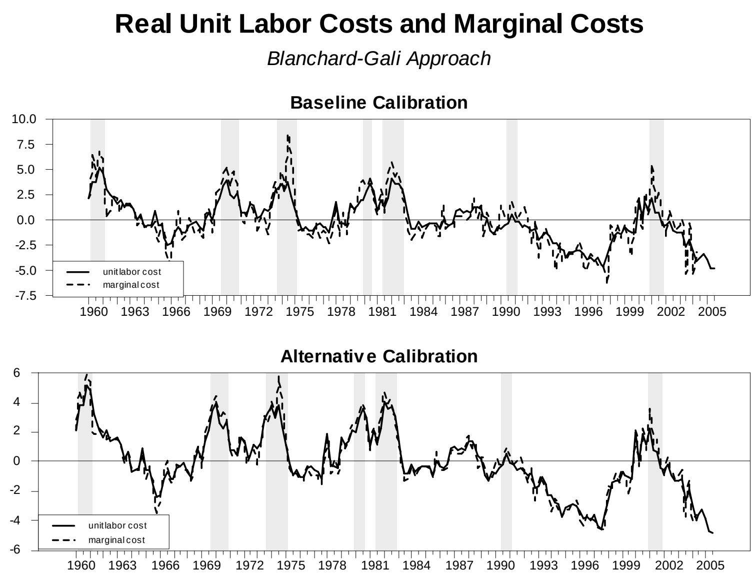

Figure 3: Real marginal costs under alternative calibrations. The solid line represents unit labor costs and the dotted line real marginal costs. The shadowed areas correspond to the NBER recession dates.

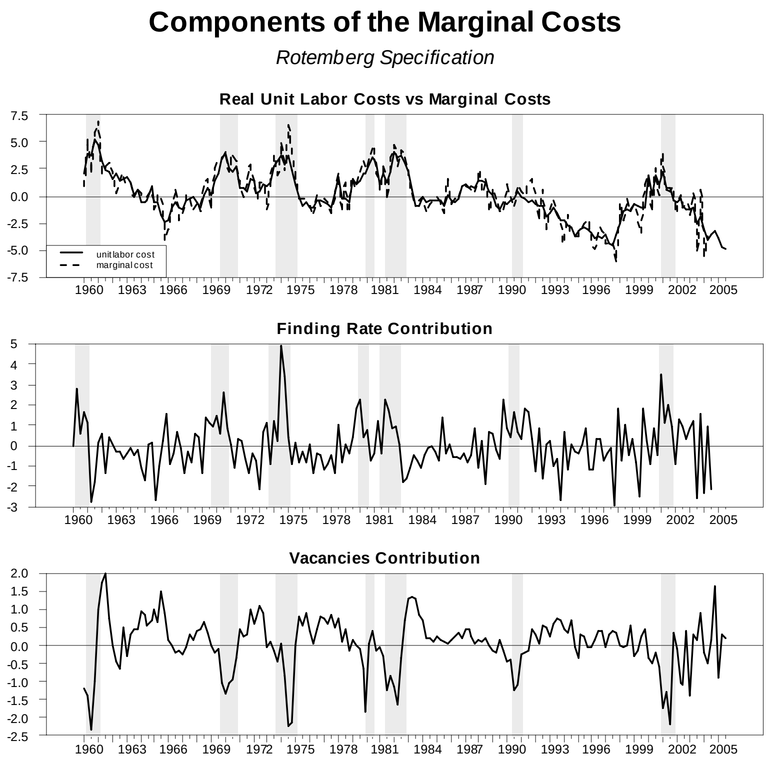

Figure 4: Real marginal costs in the Rotemberg model. In the top panel the solid line represents unit labor costs and the dotted line real marginal costs. The shadowed areas correspond to the NBER recession dates.

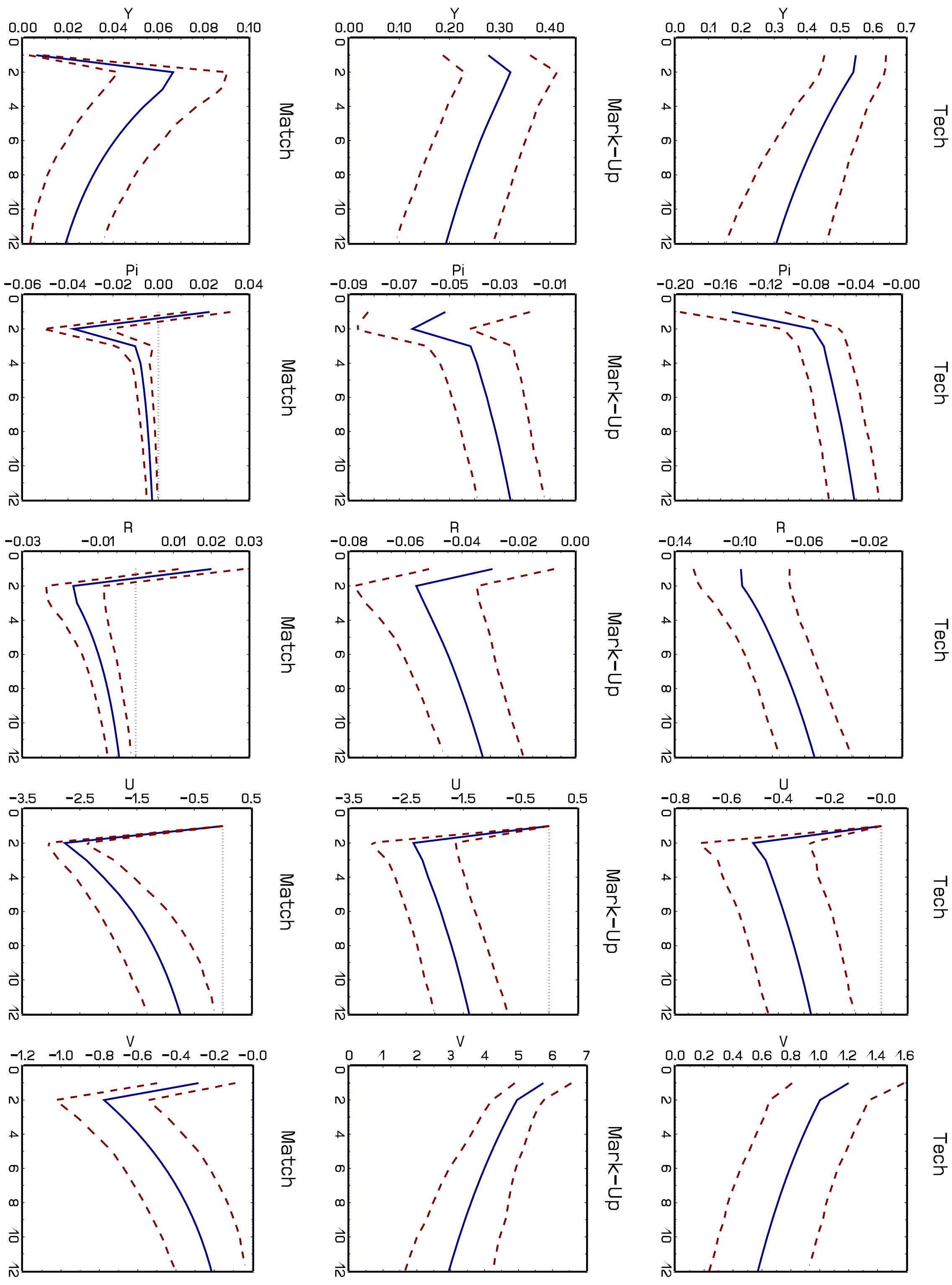

Figure 5: Impulse Response Functions: Baseline

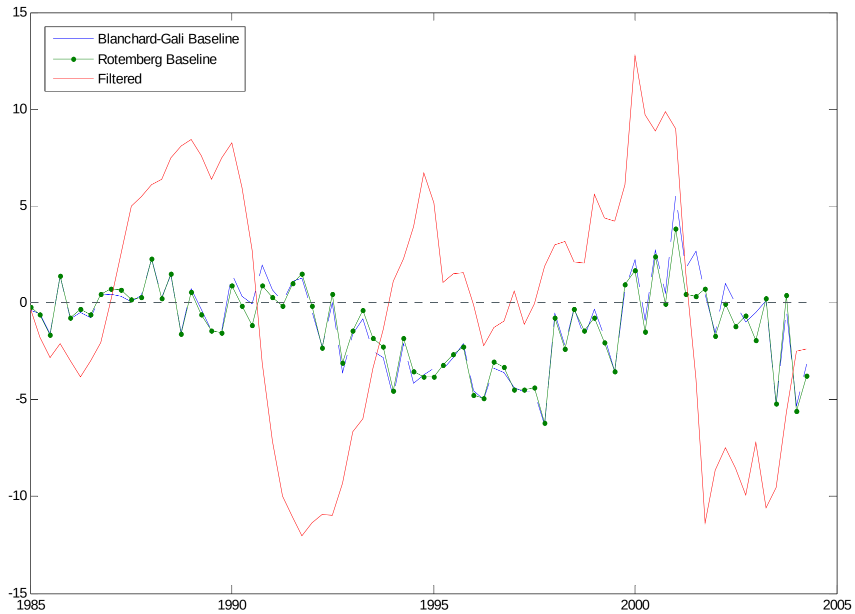

Figure 6: Marginal Cost Series