Real Price and Wage Rigidities in a Model with Matching Frictions*

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Abstract

I reconcile macro- and micro-evidence on price setting in a search and matching framework. Search frictions lead price-setting firms to negotiate wage rates with their employees. The increase in strategic complementarity of price-setting leads to substantial real price rigidities which in turn reduce implied price durations. At the same time this mechanism dampens the reaction of real wage rates to aggregate fluctuations which is necessary to explain the highly volatile response of vacancies in the data. A further interesting finding is that inflation via the Phillips curve is not only driven by an output gap but also by an employment gap – a feature usually neglected in empirical research. I demonstrate that the modified model can be parameterized such that it can replicate impulse responses to monetary policy shocks obtained from a structural VAR for post Volcker-disinflation U.S. data.

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1 Introduction

The microfoundations paradigm, which nowadays is at the forefront of macroeconomic thinking, aims at bringing macroeconomics in line with microeconomic theory and evidence. In this respect, one apparent failure of recent estimates of plain Calvo-type Phillips curves for the U.S. is that these imply that firms change their prices only every six quarters – or even less often (see Gali and Gertler, 1999, Eichenbaum and Fisher, 2004). Micro-level evidence, however, shows that U.S. firms on average adjust much more often: at least every second quarter (see Bils and Klenow, 2004, and Klenow and Kryvtsov, 2005).[1]

Real price rigidities help to reconcile micro- and macro-evidence (see e.g. Ball and Romer, 1990, Altig, Christiano, Eichenbaum, and Linde, 2005, and Woodford, 2003, chapter 3). If average price changes are small, price changes can be frequent while still being consistent with a smooth inflation series. This paper stresses that the search and matching model (e.g. Pissarides, 1985) is a natural candidate to generate these real price rigidities.[2]

In the search and matching model labor is a temporarily firm-specific factor of production, i.e. the firm cannot hire labor in a competitive market. To the contrary, frictions when searching for a new worker lead a firm to share rents with its employee via wage bargaining. Considering a firm that contemplates raising its price, lower demand due to a higher sales price translates into less hours worked and hence a fall in the worker's marginal disutility of work. The standard Calvo model features constant marginal costs of production. In the search and matching framework, in contrast, the associated decrease in the worker's subjective wage rate (his marginal rate of substitution between leisure and consumption) translates into lower marginal costs for the firm. This fall in marginal costs in turn depresses the incentive to raise the price in the first place. Compared to the standard Calvo model with constant marginal costs, in the framework advocated in this paper firms will therefore opt for smaller price changes.

The technical contribution of the current paper is to directly integrate the wage bargaining into a sector which produces differentiated goods and hence has a margin for setting its price but

[1] This contradiction qualitatively is not confined to the U.S.. For the Euro area as a whole, Dhyne, Álvarez, Bihan, Veronese, Dias, Hoffman, Jonker, Lünnemann, Rumler, and Vilmunen (2005) examine consumer price data. They stress that price spells last on average between 4 and 5 quarters and that the median duration is 3 to 4 quarters. While this micro-level duration is larger than for the US it is still in stark constrast to the macro-level estimates in Smets and Wouters (2003), say, which imply that prices change every 9-10 quarters only. Similar evidence can be foud in Gali, Gertler, and López-Salido (2001) when one abstracts from features which make marginal cost responsive to own output. Interestingly, previous stylized facts for the U.S. concluded that prices were substantially more sticky. The survey by Taylor, 1999, e.g., concluded they were constant for slightly less than a year.

[2] Christiano, Eichenbaum, and Evans (2005) emphasize three other channels which tend to induce a small inflation response: variable capital utilisation, sticky wages and working capital. The latter channel works in the event of a monetary easing. If firms have to borrow their wage bill, a fall in the nominal interest rate will reduce their interest burden and thus marginal cost. This has a dampening effect on inflation or can even lead to an initial fall.

to retain *ex-ante* worker homogeneity (as a counterexample, see *e.g.* Trigari, 2004 and Braun, 2005, for the "standard" new Keynesian implementation of the search and matching model with *constant* marginal cost).[3]

Pointing to the importance of firm-specific factors in reconciling the macro and micro-evidence on price setting has some tradition in the literature. While firm-specific labor has been explored to a lesser extent, the potential importance of firm-specificity of capital has recently been met by considerable interest; see Sbordone (2002), Woodford (2003, 2004), Sveen and Weinke (2004), Christiano (2004), Eichenbaum and Fisher (2004) and Altig, Christiano, Eichenbaum, and Linde (2005). Another way to reconcile Phillips curve estimates with micro-evidence is to assume decreasing returns to factors of production, see *e.g.* Gali, Gertler, and López-Salido (2001), or to assume a non-constant elasticity of demand (a slightly kinked demand curve), which makes it easier to loose customers by raising a firm's price than to gain customers by lowering it, i.e. the elasticity of demand is falling sharply with a firm's market share (hence rising sharply in a firm's price) see Kimball (1995).[4]

Closest to the current paper is Woodford (2003, ch. 3). He has explored real rigidities originating from the labor choice. In his model there are different types of labor. Each type of labor is used to produce a specific variety of a differentiated good. The marginal cost of production increases in output due to an increase in the marginal rate of substitution between leisure and labor on the worker side, similar to the mechanism in my paper. Woodford needs to make the strong assumption that labor is completetely firm-specific and worthless outside of the specific firm.[5]

In my model, in contrast, the firm-specific factor is only firm-specific as long as the match is not severed, i.e. there is an outside market value to the worker. Costly search and matching creates a quasi-rent for existing jobs that can be shared between firm and worker via a wage payment. Wage rates in turn determine the magnitude of the response of firms' profits to aggregate shocks and hence vacancy posting and the creation of employment relationships.[6] Hall (2005) and Shimer (2004) argue that the Mortensen and Pissarides (1994) model's shortcomings in accounting for the sizeable reaction of vacancies (and thus market tightness, the Beveridge curve) to reasonably sized shocks can be attributed to the standard assumption of wage determination

[3] An exception to the standard modeling scheme is Krause and Lubik (2006) who assume that wage bargaining and price-setting takes place in the same sector (they assume quadratic price adjustment costs). Krause und Lubik, however, assume that utility is *linear* in hours worked. With this assumption, the marginal rate of substitution does not change in hours worked and thus, there are no real price rigidities. In addition, they do not derive a model-consistent wage rigidity.

[4] Similar effects arise when consumption habits are product specific. This also leads to pro-cyclical own price elasticities of demand; see Ravn, Schmitt-Grohé, and Uribe (2006).

[5] A similar assumption in a firm-specific capital environment is found in Altig, Christiano, Eichenbaum, and Linde (2005).

[6] Note that in contrast to Hall (2005) wage rates are allocational even for existing matches since hours worked are an endogenous variable in my model.

via Nash-Bargaining. For a critical appraisal of this literature see Mortensen and Nagypal (2005). Besides reconciling micro- and macro-evidence on price setting, my model provides for significant real wage rigidity, a fact Hall (2005) and Shimer (2004) argue is important to match labor market fluctuations. In particular, an increase in strategic complementarity in price-setting translates into more rigid real wages.[7]

As to the results, I find that the raised degree of strategic complementarity in price-setting not only dampens the response of inflation to aggregate shocks but also induces the real wage rate to be less volatile. The smooth wage rate series implied by the model in turn helps to replicate the fluctuation of vacancies found in U.S. data. An interesting finding of my paper is furthermore that the Phillips curve once accounting for variations on the extensive margin of employment is not only driven by the output gap, as is commonly assumed in the empirical literature, but also by an "employment gap". Omitting the latter (as most of the literature does) is likely to bias implied price-durations inferred from Phillips curve estimates upwards – and thus is likely to bias estimates for the price duration against the micro-evidence.

The next section lays out the model. Section 3 discusses some of the (linearized) equilibrium conditions. Special emphasis is on the implied reduced form Phillips curve. The fit of the Phillips curve hinges critically on the value of the own-prive elasticity of demand. A change in the elasticity, however, also directly affects the transmission in the labor market. In section 4 I therefore illustrate that the entire model can replicate the impulse responses to monetary policy shocks taken from a small structural vector autoregression. A final section wraps up and concludes. Some technical material and a thorough description of the data is deferred to the Appendix.[8]

2 The Model

According to Hall (2005) the separation rate does not vary much over the U.S. business cycle. Cyclical fluctuations in employment are mainly due to fluctuations in vacancy posting – I therefore do not model endogenous separation in this paper but assume that each period a constant fraction of firm-worker relationships splits up for reasons exogenous to the state of the economy. As is common in the literature, I focus on a cashless limit economy; cp. Smets and Wouters (2003) and large parts of Woodford (2003).

[7] The mechanism therefore differs from Gertler and Trigari (2005) who use staggered Calvo wage-setting in a real-business cycle model. Since in their setup, it is not clear how, if wages are left unchanged, hours are determined, they have to shut-down the intensive margin completely. In my model, the assumption of wage and pricing setting being conducted in the same sector, leads hours worked to be (demand-)determined. Also, Gertler and Trigari (2005) lack the amplification mechanism for wage rigidity, which I discussed above.

[8] A further technical appendix which derives the model equations in linearized form is available from the author upon request.

2.1 Consumers

The model economy consists of a large number of identical families. Each family has a continuum of members of two types: unemployed workers with mass u_t and employed workers with mass n_t. The total mass of workers and families each is normalized to one. Families earn real income from the real wages of their employed members, $n_t w_t h_t$, where w_t is the real wage rate per hour worked, h_t. They, in addition, obtain income from real unemployment benefits, b, which unemployed members receive ($u_t b$ in total) and from holding pure discount bonds. Families also hold shares in a mutual fund that redistributes profits in the economy. Family members, indexed by i, are infinitely lived and seek to maximize expected lifetime utility by deciding on the level (and intertemporal distribution) of consumption of a bundle of consumption goods, c_t^i, and by deciding on the real expenditure, d_t^i, for riskless one-period bonds:

$$\max_{\{c_t^i, d_t^i\}} E_t \left\{ \sum_{j=0}^{\infty} \beta^j \left\{ U(c_{t+j}^i, c_{t+j-1}) - g(h_{t+j}^i) \right\} \right\}, \ \beta \in (0,1). \tag{1}$$

Household members pool their income – there is thus perfect consumption risk sharing. We assume that households take the labor supply decision for their members in order to prevent free-riding. The family member's budget constraint is given by:

$$u_t b + n_t w_t h_t + \frac{d_{t-1}^i}{\Pi_t} R_{t-1} + \int_0^{n_t} \psi_t^j dj \quad = c_t^i + d_t^i + t_t + v_t \kappa_t. \tag{2}$$

Here R_t denotes the nominal gross return on the bond from t to $t+1$ and Π_t is the gross consumer price inflation rate. The wholesale sector firms' profits, ψ_t^j, accrue to the households, $\int_0^{n_t} \psi_t^j dj$. v_t are the number of vacancies, κ_t are real costs of posting a vacancy. Vacancy posting costs are assumed to be lump-sum tax costs. They thus enter the household's budget constraint but not the aggregate ressource constraint. The household pays lump-sum taxes t_t.

Let c_{t-1} be the aggregate level of consumption in period $t-1$. I assume that an individual's consumption is subject to external habit persistence, indexed by parameter $h_c \in [0,1)$,

$$U(c_t^i, c_{t-1}) = \frac{(c_t^i - h_c c_{t-1})^{1-\sigma}}{1-\sigma}, \ \sigma > 0. \tag{3}$$

As in Abel (1990) households therefore are concerned with "catching up with the Joneses".

The first-order conditions for consumption versus saving can be summarized by the Euler equation

$$\lambda_t = \beta E_t \left\{ \lambda_{t+1} \frac{R_t}{\Pi_{t+1}} \right\}, \tag{4}$$

where $\lambda_t = (c_t - h_c\, c_{t-1})^{-\sigma}$ marks marginal utility of consumption.[9] The optimal consumption

[9] Due to consumption insurance and separability of consumption and leisure in the utility function, all households

plan in equilibrium also satisfies the merged transversality and no-Ponzi condition

$$\lim_{s\to\infty} E_t \left\{ \beta^s \frac{\lambda_{t+s}}{\lambda_t} d_{t+s} \right\} = 0. \tag{5}$$

Completing the description of preferences, disutility of work is characterized by

$$g_t(h_t^i) = \kappa_h \frac{h_t(i)^{1+\phi}}{1+\phi}, \ \phi > 0, \ \kappa_h > 0. \tag{6}$$

Here, κ_h denotes a scaling parameter for the disutility of work. Importantly for the argument below, the marginal disutility of work, $\frac{\partial g(h)}{\partial h}$, is *increasing* in individual hours worked, h_t^i. It is this fact which leads a worker to seek increasing compensation per hour on the margin (due to an increase in his subjective price of work). This in turn induces firms to adjust prices (and, implicitly, their demand-driven output) by less than in the standard model.

2.2 Production

The existing macro-labor market literature assumes that firms which are free to set prices face constant marginal cost; e.g. Trigari (2004), Braun (2005) and Christoffel, Kuester, and Linzert (2005) assume that labor is used only as an input into an intermediate good. This in turn is sold to a differentiating sector in perfectly competitive markets. The major contribution of the current paper is to integrate the labor market activity into the price setting sector, *i.e.* to let firms which are free to set their price also negotiate wages. Again, it is this change combined with the increasing marginal disutility of work that allows to bring about the real price (and ultimately wage) rigidity.

There are two types of firms. Firms in the wholesale sector need one worker to produce. Wholesale firms which have a worker produce differentiated goods which they sell under monopolistic competition. They are subjected to time-dependent price (and wage) setting impediments à la Calvo (1983).[10] Firms and workers, if they are allowed to update, decide jointly how to split the rents of their employment relationship. Hours worked are demand-driven (hence dependent on the firm's sales price) and have a first-order effect on individual utility. I therefore assume that a firm and a worker not only decide about the nominal hourly wage rate, W_t^j, but that they simultaneously also bilaterally agree on the product price, P_t^j – again, since the price determines

in equilibrium will have the same consumption levels. I therefore suppress index i here.

[10] Klenow and Kryvtsov (2005) summarize that individual price data obtained from the U.S. Bureau of Labor Statistics reveal that (a) price changes are largely non-synchronized, (b) variation in the *magnitude* of price changes contributes much more to the variation in aggregate inflation (90+%) than variation in the *number* of price changes and (c) the size of absolute price changes is large, over 8%. Overall they conclude that the Dotsey, King, and Wolman (1999) state-dependent pricing model, once calibrated to match the micro-price data, very much resembles the Calvo-model in so far as pricing behavior is concerned. Modeling pricing as time-dependent may thus not be an overly stringent assumption.

hours worked via the firm's demand function.A greatly simplifying assumption is that wages and prices have the same duration: whenever a firm resets its price it renegotiates its wage and *vice versa*.[11] Retailers bundle the differentiated goods and sell the homogenous consumption basket y_t at price P_t.

2.2.1 Retail Firms

Let $n_t \in (0,1)$ be employment in t. Since workers are employed in one-worker wholesale firms this means that n_t wholesale firms engage in production. Thus a total mass of n_t varieties y_t^j, $j \in [0, n_t]$, of wholesale goods is produced in a given period. Retail firms in turn operate in perfectly competitive product markets. They buy differentiated wholesale goods, $y_t(j)$, and produce y_t units of the consumption good according to

$$y_t = n_t \left[\frac{1}{n_t} \int_0^{n_t} y_t(j)^{\frac{\epsilon-1}{\epsilon}} dj \right]^{\frac{\epsilon}{\epsilon-1}}. \tag{7}$$

The cost-minimizing demand for wholesale goods of type j is

$$y_t^j = \left(\frac{P_t^j}{P_t} \right)^{-\epsilon} y_t^a, \tag{8}$$

where y_t^a marks average output per employed worker, $y_t^a = \frac{1}{n_t} y_t$, and $\epsilon > 1$ is the own-price elasticity of demand. The consumption good price index P_t is given by

$$P_t = \left[\frac{1}{n_t} \int_0^{n_t} P_t(j)^{1-\epsilon} dj \right]^{\frac{1}{1-\epsilon}}. \tag{9}$$

2.2.2 Wholesale Firms

There is an infinite number of potential one-worker wholesale good producers. Wholesale firms engage in vacancy posting. Once having recruited a worker, they produce a differentiated good and engage in wage bargaining. I describe each decision in turn.

[11] After all, this assumption may not be as stringent as it seems: In their benchmark version estimated on aggregate U.S. data, Christiano, Eichenbaum, and Evans (2005) find that prices and wages roughly have the same duration, 2.5 and 2.8 quarters, respectively. Crucial for their estimates in line with micro-evidence is the assumption of working capital and variable capital utilization, features which I do not have in my model. Also on aggregate data, in contrast, Altig, Christiano, Eichenbaum, and Linde (2005) find that wages are changed less frequently: every 3.6 quarters. Direct evidence for wage rigidity is scarcer: there is no systematic direct evidence on the frequency of wage negotiations. In a survey Taylor (1999) argues that wages are typically adjusted once per year. Based on micro-level data on wages per hour, Gottschalk (2004) concludes similarly. Yet this evidence applies mainly to base pay. Other wage components like bonuses or perks will likely adjust more frequently.

Vacancy Posting. Firms without a worker have to incur a real vacancy posting cost, $\kappa_t > 0$, in order to stand a chance of recruiting a worker. The model allows for fluctuations in vacancy posting costs, e.g. since there are vacancy adjustment costs as in Braun (2005) or because vacancy costs are posted in nominal terms.[12] V_t is the market value of a prototypical firm that posts a vacancy in period t. $J_t(P_t^j, W_t^j)$ is the value of a wholesale firm in period t that has a worker, charges P_t^j for its good and pays W_t^j for each hour worked. Due to nominal rigidities, each period workers and firms can renegotiate prices and wages only with probability $1-\varphi$. Otherwise they partially update (but do not reoptimize) their price and wage by the realized gross inflation rate ($\Pi_{t-1}^{\gamma_p}$ and $\Pi_{t-1}^{\gamma_w}$, respectively, $\gamma_p, \gamma_w \in [0,1]$).[13] For analytical tractability, I keep the heterogeneity to a minimum by assuming that firms which just found a worker, i.e. enter the market, have the same pricing pattern as existing firm-worker relationships:[14] They can choose their optimal price, P_t^*, and their optimal wage rate, W_t^*, (both to be defined below) with probability $1-\varphi$. With probability φ, however, they have to set previous period's average price and wage (suitably indexed). A firm which posts a vacancy finds a new employee with probability q_t. With probability ρ this new match is severed for an exogenous reason prior to production in t. Firms which loose their worker cease to exist and are therefore worthless. The value of a firm which opened a vacancy consequently is given by

$$V_t = -\kappa_t + q_t(1-\rho)E_t\left\{\beta_{t,t+1}\left[\varphi J_{t+1}(P_t\,\Pi_t^{\gamma_p}, W_t\,\Pi_t^{\gamma_w}) + (1-\varphi)J_{t+1}(P_{t+1}^*, W_{t+1}^*)\right]\right\}. \quad (10)$$

Here $\beta_{t,t+1} := \beta\frac{\lambda_{t+1}}{\lambda_t}$ is the equilibrium pricing kernel. There is free entry into production apart from the sunk vacancy posting cost. This drives the value of a vacancy to zero in equilibrium: $V_t \stackrel{!}{=} 0$.

Production. Each wholesale firm has the same linear production technology

$$y_t^j = z_t h_t^j. \quad (11)$$

z_t marks the economy-wide level of labor productivity.
A firm in production makes a real profit ψ_t in period t, which depends on the wage rate paid to

[12] The empirical exercise in Section 4 shows that constant vacancy posting costs, i.e. $\kappa_t = \kappa\ \forall\, t$, are sufficient to fit the vacancy series .

[13] The partial updating follows Christiano, Eichenbaum, and Evans (2005) and Smets and Wouters (2003).

[14] In addition, to achieve sufficient fluctuation in vacancies, Shimer (2004) argues that real wages of *newly* formed matches must be sticky in order to induce sufficient fluctuation in vacancies and unemployment – a fact, that is achieved by my formulation.

its employee and the price charged for its product:

$$\psi_t\left(P_t^j, W_t^j\right) = \frac{P_t^j}{P_t} y_t^j - \frac{W_t^j}{P_t} h_t^j. \tag{12}$$

With probability $1-\rho$ the current match will not be severed at the beginning of the next period. Conditional on survival, with probability φ the firm has to retain its current price and wage. With probability $1-\varphi$, however, it can set the new optimal price-wage pair, P_{t+1}^*, W_{t+1}^*. Whence the value of one of the n_t firms which produce in t is

$$\begin{aligned} J_t\left(P_t^j, W_t^j\right) &= \psi_t(P_t^j, W_t^j) \\ &+(1-\rho)E_t\left\{\beta_{t,t+1}\left[\varphi J_{t+1}\left(P_t^j \Pi_t^{\gamma_p}, W_t^j \Pi_t^{\gamma_w}\right) + (1-\varphi) J_{t+1}\left(P_{t+1}^*, W_{t+1}^*\right)\right]\right\}. \end{aligned} \tag{13}$$

Matching. I assume a constant-returns to scale matching function, linking new matches, m_t, to unemployment, u_t, and vacancies, v_t:

$$m_t = \sigma_m u_t^\alpha v_t^{1-\alpha},\ \sigma_m > 0,\ \alpha \in [0,1]. \tag{14}$$

σ_m governs the rate at which new matches arrive, the efficiency of matching. α governs the relative weight the pool of searching workers and firms, respectively, receive in the matching process. Define labor market tightness (from the view point of a firm) as $\theta_t := v_t/u_t$. The probability that a vacant job will be filled is $q_t = m_t/v_t$. The probability that an unemployed worker finds employment is $s_t = m_t/u_t$. Workers which are matched to a firm in t will not start working before $t+1$. Employment therefore evolves according to

$$n_t = (1-\rho)(n_{t-1} + m_{t-1}). \tag{15}$$

Unemployment is

$$u_t = 1 - n_t. \tag{16}$$

Worker Surplus. An employed worker receives his real wage bill and suffers disutility of work, $\frac{g(h_t^j)}{\lambda_t}$, where λ_t is the marginal utility of consumption. Next period he remains employed with probability $1-\rho$ or will be unemployed otherwise (ρ). The value of employment, $\Gamma_t(\cdot)$, to the worker who is employed in a firm with price P_t^j and wage rate W_t^j is

$$\begin{aligned}\Gamma_t(P_t^j, W_t^j) =& \frac{W_t^j}{P_t} h_t(P_t^j) - \frac{g_t\left(h_t(P_t^j)\right)}{\lambda_t} \\ &+ (1-\rho)\varphi E_t\left\{\beta_{t,t+1}\Gamma_{t+1}(P_t^j\Pi_t^{\gamma_p}, W_t^j\Pi_t^{\gamma_w})\right\} \\ &+ (1-\rho)(1-\varphi)E_t\left\{\beta_{t,t+1}\Gamma_{t+1}(P_{t+1}^*, W_{t+1}^*)\right\} \\ &+ \rho E_t\left\{\beta_{t,t+1}U_{t+1}\right\}.\end{aligned} \tag{17}$$

Note that the value of employment next period again depends on the price-wage stickiness. Similarly the value of a worker who is unemployed during t is

$$\begin{aligned}U_t =\ & b \\ &+ s_t(1-\rho)\varphi E_t\left\{\beta_{t,t+1}\Gamma_{t+1}(P_t\Pi_t^{\gamma_p}, W_t\Pi_t^{\gamma_w})\right\} \\ &+ s_t(1-\rho)(1-\varphi)E_t\left\{\beta_{t,t+1}\Gamma_{t+1}(P_{t+1}^*, W_{t+1}^*)\right\} \\ &+ (1-s_t+s_t\rho)E_t\left\{\beta_{t,t+1}U_{t+1}\right\}.\end{aligned} \tag{18}$$

Above, b are real unemployment benefits. The worker's surplus from being in employment, i.e. the increase of family utility through an additional family member in employment in t is $\Delta_t(P_t^j, W_t^j) := \Gamma_t(P_t^j, W_t^j) - U_t$.[15] Hence

$$\begin{aligned}\Delta_t(P_t^j, W_t^j) =& \frac{W_t^j}{P_t} h_t(P_t^j) - \frac{g_t\left(h_t(P_t^j)\right)}{\lambda_t} - b \\ &+ (1-\rho)\varphi E_t\left\{\beta_{t,t+1}(\Delta_{t+1}(P_t^j\Pi_t^{\gamma_p}, W_t^j\Pi_t^{\gamma_w}) - \Delta_{t+1}^*)\right\} \\ &- (1-\rho)\varphi s_t E_t\left\{\beta_{t,t+1}(\Delta_{t+1}(P_t\Pi_t^{\gamma_p}, W_t\Pi_t^{\gamma_w}) - \Delta_{t+1}^*)\right\} \\ &+ (1-\rho)(1-s_t)E_t\left\{\beta_{t,t+1}\Delta_{t+1}^*\right\},\end{aligned} \tag{19}$$

where $\Delta_{t+1}^* = \Delta_{t+1}(P_{t+1}^*, W_{t+1}^*)$.

Bargaining. Wholesale firm-worker pairs which are allowed to update their price and wage in period t face the problem of maximizing joint surplus by choosing the sales price and by simultaneously negotiating the nominal wage rate. This specification has the advantage that while wages and prices may be fixed, hours worked can freely adjust to satisfy demand. I stick

[15] This can be derived from first principles by assuming that workers value their labor-market actions in terms of the contribution these actions give to the utility of the family to which they belong and with which they pool their income; see Trigari (2004).

to the Nash-bargaining assumption: Firms and workers solve

$$\max_{W_t^j, P_t^j} \left[\Delta_t(P_t^j, W_t^j)\right]^{\eta} \left[J_t(P_t^j, W_t^j)\right]^{1-\eta}, \tag{20}$$

where $\eta \in (0,1)$ is the worker's bargaining power.

While not born out by the simple notation, the bargaining problem is not a trivial one: the firm and the worker need to take into account the effect of their decision today on all periods in which they may have to keep prices and wages fixed.[16] Let P_t^* and W_t^* denote the optimal price and wage, respectively. Define $J_t^* := J_t(P_t^*, W_t^*)$. The first-order condition for price setting is

$$\left.\frac{\partial \Delta_t(P_t^j, W_t^j)}{\partial P_t^j}\right|_{(P_t^j, W_t^j)=(P_t^*, W_t^*)} \eta J_t^* = - \left.\frac{\partial J_t(P_t^j, W_t^j)}{\partial P_t^j}\right|_{P_t^*, W_t^*} (1-\eta)\Delta_t^*. \tag{21}$$

The first-order condition for optimal wage setting is

$$\left.\frac{\partial \Delta_t(P_t^j, W_t^j)}{\partial W_t^j}\right|_{P_t^*, W_t^*} \eta J_t^* = - \left.\frac{\partial J_t(P_t^j, W_t^j)}{\partial W_t^j}\right|_{P_t^*, W_t^*} (1-\eta)\Delta_t^*. \tag{22}$$

The fact that wages and prices are always set at the same time greatly simplifies the derivation of a linearized version of the model since it keeps heterogeneity among firms and workers, respectively, within manageable bounds.

2.3 Government

2.3.1 Monetary Policy

The monetary authority is assumed to control the nominal one-period risk-free interest rate, R_t. In the following, let hats over variables denote percentage deviations of these variables from steady state. The empirical literature (see, e.g. Clarida, Gali, and Gertler, 1998) finds that simple linearized generalized Taylor-type rules of the form

$$\widehat{R}_t = \rho_m \widehat{R}_{t-1} + (1-\rho_m)\gamma_\pi E_t \widehat{\pi}^a_{t+3} + (1-\rho_m)\gamma_y \widehat{y}_t + \widehat{\epsilon}_t^{money} \tag{23}$$

are a good representation of monetary policy. Here $\rho \in [0,1)$, $\gamma_\pi > 1$, $\gamma_y \geq 0$ and ϵ_t^{money} is an iid shock. The use of specific inflation rate concept differs in these rules. I assume that the policymaker targets average annual inflation, $\widehat{\pi}^a_{t+3} := \frac{1}{4}\left(\widehat{\pi}_t + \widehat{\pi}_{t+1} + \widehat{\pi}_{t+2} + \widehat{\pi}_{t+3}\right)$.[17]

[16] A technical appendix which goes more in depth with the derivations is available from the author.

[17] Such a policy rule can be rationalized by the following rule in levels:

$$R_t = (\overline{\Pi}/\beta)^{1-\rho} R_{t-1}^{\rho} E_t \left(\frac{\Pi^a_{t+3}}{\overline{\Pi}}\right)^{(1-\rho)\gamma_\pi} \left(\frac{y_t}{y}\right)^{(1-\rho)\gamma_y} \epsilon_t^{money}. \tag{24}$$

2.3.2 Fiscal Policy

I assume that fiscal policy is Ricardian. The government does not engage in any government spending. It redistributes any income from debt issues and vacancy posting taxes to the private agents via lump-sum transfers ($-t_t$) and unemployment benefits. The government's budget constraint is:

$$u_t b + \frac{d_{t-1}}{\Pi_t} R_{t-1} = d_t + t_t + v_t \kappa_t. \tag{25}$$

Since the path of debt is not the focus of the current paper, an arbitrary debt-stabilizing rule will close the government sector.

2.4 Market Clearing

Market clearing in the market for wholesale and final retail goods requires

$$y_t = c_t, \tag{26}$$

where

$$y_t = n_t \left[\frac{1}{n_t} \int_0^{n_t} y_t(j)^{\frac{\epsilon-1}{\epsilon}} dj \right]^{\frac{\epsilon}{\epsilon-1}}, \ \epsilon > 1. \tag{27}$$

Here $y_t^j = \left(\frac{P_t^j}{P_t} \right)^{-\epsilon} y_t^a = z_t h_t^j$. In addition, the market for government bonds needs to clear.

3 Intuition from the Linearized Model

To repeat the focus of the paper: the New-Keynesian labor-market literature so far parts wage bargaining from price setting. This assumption causes marginal cost in the monopolistically competitive sector to be independent of own production, see *e.g.* Trigari (2004). I call this the "standard" world. The contribution of the current paper is to bring the firm-specifity of labor in the bargaining world to the forefront. I show that this specification is simple enough (once linearized) to be amenable to empirical research and derive implications for estimates of new Keynesian Phillips curves.

In passing, I provide a means to incorporate real wage rigidity, a fact that Hall (2005) and Shimer (2004) argue might be necessary to fit the fluctuations of vacancies. The degree of real wage rigidity in my model itself intensifies when the degree of strategic complementarity in price-setting increase.[18] Below, I present part of the model after linearizing around the zero-inflation steady state laid out in Appendix A.[19] After some manipulation, the Phillips curve ($\widehat{\pi}_t$ is the

Here $\overline{\Pi}$ is the target for the quarterly gross inflation rate in steady state (which equals steady state inflation) and y is steady state potential output.

[18] This amplification mechanism is absent in the work of Gertler and Trigari (2005).

deviation of the inflation rate from its steady state) can be reduced to

$$\widehat{\pi}_t = \frac{\gamma_p}{1+\gamma_p\,\breve{\beta}}\,\widehat{\pi}_{t-1} + \frac{\breve{\beta}}{1+\gamma_p\,\breve{\beta}}\,E_t\widehat{\pi}_{t+1} + \frac{1-\varphi}{\varphi}\,\frac{1-\breve{\beta}\,\varphi}{1+\gamma_p\,\breve{\beta}}\,\widehat{d}_t, \tag{28}$$

where

$$\widehat{d}_t = \frac{1}{1+\phi\epsilon}\left\{\widehat{mrs}_t - \widehat{z}_t\right\}.$$

Here $\breve{\beta} = \beta(1-\rho)$ and mrs_t is the average marginal rate of substitution between leisure and consumption of employed workers.

Define the natural rate of average output under flexible prices as $y_t^{a,n}$ and the natural marginal utility of consumption under flexible prices as λ_t^n. With these definitions the term $\widehat{d}_t$ in the Phillips curve (28) can be written as:

$$\widehat{d}_t = \frac{1}{1+\phi\epsilon}\left\{\phi\,(\widehat{y}_t^a - \widehat{y}_t^{a,n}) - (\widehat{\lambda}_t - \widehat{\lambda}_t^n)\right\}. \tag{29}$$

The marginal utility of consumption, $\widehat{\lambda}_t$, in turn depends on *total* output, not on *average* output. This means that once substituting for marginal utility of consumption, an employment gap enters the Phillips curve:

$$\begin{aligned} \widehat{d}_t = &\ \frac{1}{1+\phi\epsilon}\left\{\phi\left[\widehat{y}_t - \widehat{y}_t^n - (\widehat{n}_t - \widehat{n}_t^n)\right] + \frac{\sigma}{1-h_c}\left[\widehat{y}_t - \widehat{y}_t^n - h_c\left(\widehat{y}_{t-1} - \widehat{y}_{t-1}^n\right)\right]\right\} \\ = &\ \frac{1}{1+\phi\epsilon}\left\{\phi\left[\widehat{y}_t^{gap} - \widehat{n}_t^{gap}\right] + \frac{\sigma}{1-h_c}\left[\widehat{y}_t^{gap} - h_c\widehat{y}_{t-1}^{gap}\right]\right\}. \end{aligned} \tag{30}$$

The Phillips curve looks very similar to Woodford (2003, p. 187) and Boivin and Giannoni (2006) – without the need to assume any *ex ante* worker heterogeneity. Instead, the matching model naturally lends itself to an increase of the strategic complementarity of price-setting decisions due to firm-specific labor. Comparing (28) and (30) to the standard New Keynesian Phillips curve (e.g. Gali and Gertler, 1999), which is obtained as the special case $\phi = 0, \rho = 0$, three differences stand out. First, in the matching model the firm implicitly discounts the future more intensively owing to its lower survival probability. And indeed, estimates of new Keynesian Phillips curves for the US and other economies consistently show that the reduced form discount factor is estimated to be significantly well below unity, see *e.g.* Gali and Gertler (1999), Gali, Gertler, and López-Salido (2001) and Gagnon and Khan (2005). Second, for reasonable parameter values the factor $\frac{\phi+\frac{\sigma}{1-h_c}}{1+\phi\epsilon}$ is smaller than unity, implying more strategic complementarity in price setting. The degree of strategic complementarity rises as the elasticity of demand increases which substantially dampens the effect of aggregate shocks on inflation

[19] The derivation is explained in detail in a technical appendix available from the author upon request.

as illustrated in Woodford (2003).[20] Similar multiplicative factors are found in the existing real rigidities literature (e.g. Altig *et al.,* 2005; Eichenbaum and Fisher, 2004). Third, the employment gap enters as an additional regressor. Since output is positively correlated with employment in the data, according to this model even reduced form estimates of the slope of the Phillips curve, when they omit the employment gap, may be biased downwards (implying price durations which are biased upwards).[21]

In my model, also two other optimality conditions are altered. Vacancy posting is affected by the gap between the optimal wage and the average wage rate.[22] In addition the law of motion for aggregate wages is changed, to which I turn next.

While the wage equation looks somewhat inaccessible in general, intution can be gained by restricting the analysis to the case $w = mrs$ in steady state.[23]

[20] Usually, the elasticity of demand, ϵ is calibrated to be much larger than unity. Woodford (2003) uses a value of 7.6, Altig, Christiano, Eichenbaum, and Linde (2005) use a value of 101.

[21] Preliminary examination showed that this will, however, not solve the problems in Gali and Gertler (1999) when using conventional output gap measures to estimate the Phillips curve.

[22] The vacancy posting equation can be expressed as

$$\begin{aligned}\widehat{q}_t = \widehat{\kappa}_t + \widehat{\lambda}_t &- [1-(1-\rho)\beta]E_t\widehat{\lambda}_{t+1} - (1-\rho)\beta E_t\{\widehat{\kappa}_{t+1} + \widehat{\lambda}_{t+1} - \widehat{q}_{t+1}\} \\ &- [1-(1-\rho)\beta]E_t\widehat{\psi}^*_{t+1} \\ &- \frac{\varphi}{J}\frac{1}{1-\breve{\beta}}y^a\left[\epsilon\left(1-\frac{w\,e}{z}\right)-1\right]E_t\left\{(1-(1-\rho)\beta)\widehat{p}^*_{t+1} + \widehat{\pi}_{t+1} - \gamma_p\widehat{\pi}_t\right\} \\ &- \frac{\varphi}{J}\frac{1}{1-\breve{\beta}}y^a\frac{w\,e}{z}E_t\left\{\widehat{w}_{t+1} - \widehat{w}_t + \widehat{\pi}_{t+1} - \gamma_w\widehat{\pi}_t - \{1-(1-\rho)\beta\}\left[\widehat{w}_{t+1} - \widehat{w}^*_{t+1}\right]\right\}.\end{aligned} \tag{31}$$

and simplified further to yield

$$\begin{aligned}\widehat{q}_t =& \widehat{\kappa}_t + \widehat{\lambda}_t - [1-(1-\rho)\beta]\,E_t\widehat{\lambda}_{t+1} - (1-\rho)\beta E_t\{\widehat{\kappa}_{t+1} + \widehat{\lambda}_{t+1} - \widehat{q}_{t+1}\} \\ &- [1-(1-\rho)\beta]\,E_t\left\{\widehat{y}^a_{t+1} - \frac{e\,w}{z-e\,w}(\widehat{w}_{t+1} - \widehat{z}_{t+1})\right\}.\end{aligned}$$

[23] This exercise is meant to build intuition. Neither do any other relations presented so far depend on this assumption nor is this condition imposed in the empirical analysis in Section 4.

Let $\widehat{w}_t$ be the linearized aggregate real wage index. This evolves according to[24]

$$\begin{aligned}\alpha_1\widehat{w}_t = \; & \alpha_2\left(\widehat{w}_{t-1}-\widehat{\pi}_t+\gamma_w\widehat{\pi}_{t-1}\right)\\ & +\alpha_3 E_t\left(\widehat{w}_{t+1}+\widehat{\pi}_{t+1}-\gamma_w\widehat{\pi}_t\right)\\ & +\alpha_4\left(\widehat{\theta}_t+\widehat{\kappa}_t\right)\\ & +\alpha_5\left(-\widehat{\lambda}_t\right)\\ & +\widehat{y}_t^a\\ & +(\epsilon-1)\widehat{z}_t\end{aligned} \tag{32}$$

The qualitative features of the wage equation are similar to the standard model: real wages increase in aggregate output, technology and the marginal rate of substitution. Furthermore, real wages increase in market tightness and vacancy posting costs.

An additional mechanism in this equation is that real wages are subject to smoothing. Once one accepts the staggering of the wage and price-setting decisions, this was derived in a completely model-consistent manner without resorting to social norms or the like. On top, equation (32) shows a further advantage of this setup a usually free parameter in the Phillips curve has to obey cross-equation restrictions: the elasticity of demand, ϵ. In fact, the same elasticity of demand, ϵ, that governs the degree of strategic complementarity in price-setting also has a strong bearing on the wage-setting process. In general, the larger ϵ the more important the smoothing terms α_2 and α_3 in the linearized wage equation (32) become relative to the impact of average output, market tightness and technology shocks, i.e. the more rigid will be the real wage rate.

4 Empirical Exercise

As mentioned in Section 3 the mechanism of firm-specific labor does not only feature in the Phillips curve but also elsewhere in the model. I therefore turn to conducting an empirical exercise to examine the fit of the modified model as a whole. In doing so, I match the DSGE model's impulse-responses to monetary policy shocks as closely as possible to the responses obtained in a structural vector-autoregression (SVAR). This exercise is partial in the sense that I abstract from identifying any aggregate shocks in the economy apart from monetary policy shocks. The identification assumption in the VAR is standard: apart from $\widehat{R}_t$ non of the observable variables ($\widehat{y}_t$, $\widehat{\pi}_t$, $\widehat{h}_t+\widehat{n}_t$,$\widehat{v}_t$, $\widehat{u}_t$ and $\widehat{w}_t$) react to a monetary policy shock in the same quarter.

Modified Timing Assumptions. The model presented above needs to be slightly modified in

[24] All the coefficients are strictly positive. $\alpha_2=\frac{1}{\eta}\frac{\epsilon-1}{1-\varphi}\frac{\varphi}{1-\beta(1-\rho)\varphi}$, $\alpha_1=\alpha_2\frac{1+\beta(1-\rho)\varphi(\varphi-\overline{s})}{\varphi}$, $\alpha_3=\alpha_2\beta(1-\rho)(1-\overline{s})$, $\alpha_4=\frac{\beta(1-\rho)\overline{s}}{1-\beta(1-\rho)}$, $\alpha_5=\frac{1-\eta}{\eta}\frac{\epsilon-1}{1+\phi}$.

order to reflect the identification assumption in the SVAR. The timing assumption is as follows: first firms and workers happen to see whether a match is separated. They also see whether they are allowed to update their price and wage. With this knowledge in mind they take consumption, price- and wage-setting and vacancy posting decisions. All this information is contained in the $t-1$ information set. The monetary policy shock materializes thereafter at the beginning of period t. The savings decision is taken with full information. These assumptions leave the Euler equation (4) unchanged, but consumption is now predetermined:

$$E_{t-1}\lambda_t = (c_t - h_c\, c_{t-1})^{-\sigma}. \tag{33}$$

Vacancy posting is also predetermined, so in equilibrium

$$E_{t-1}V_t = 0. \tag{34}$$

The price and wage-setting problem alters to

$$\max_{W_t^j, P_t^j} E_{t-1}\left\{\left[\Delta_t(P_t^j, W_t^j)\right]^{\eta}\left[J_t(P_t^j, W_t^j)\right]^{1-\eta}\right\}. \tag{35}$$

The corresponding first-order condition for price setting consequently is

$$E_{t-1}\left\{\left.\frac{\partial\Delta_t(P_t^j, W_t^j)}{\partial P_t^j}\right|_* \eta\Delta_t^{*\eta-1}J_t^{*1-\eta}\right\} = -E_{t-1}\left\{\left.\frac{\partial J_t(P_t^j, W_t^j)}{\partial P_t^j}\right|_* (1-\eta)\Delta_t^{*\eta}J_t^{*-\eta}\right\}, \tag{36}$$

while the first-order condition for wage-setting as a consequence changes to

$$E_{t-1}\left\{\left.\frac{\partial\Delta_t(P_t^j, W_t^j)}{\partial W_t^j}\right|_* \eta\Delta_t^{*\eta-1}J_t^{*1-\eta}\right\} = -E_{t-1}\left\{\left.\frac{\partial J_t(P_t^j, W_t^j)}{\partial W_t^j}\right|_* (1-\eta)\Delta_t^{*\eta}J_t^{*-\eta}\right\}. \tag{37}$$

The remainder of the model stays unchanged. I turn to describe the estimation procedure.

The Estimation Procedure. The limited-information procedure I use has been intensively employed in the literature; see Rotemberg and Woodford (1997), Amato and Laubach (2003), Boivin and Giannoni (2006), Christiano, Eichenbaum, and Evans (2005) and Meier and Mueller (2006). For a recent theoretical treatment of "semi-parametric indirect inference" see Dridi, Guay, and Renault (2006). The econometric methodology consists of selecting the structural parameters that minimize the distance between the impulse responses of an SVAR to a monetary policy shock and those implied by the model. I thus focus on a subset of the data's properties which has been extensively studied and the characteristics of which are relatively well-established. This simplifies comparability with the literature and – to the extent that the small model is unable to explain all the features of the data – robustifies the analysis. Formally, let $\widehat{\mathbf{\Psi}}$ be the stacked impulse responses obtained from the SVAR and let $\mathbf{\Psi}(\theta)$ be the impulse responses of the model evaluated at structural parameters θ which belong to parameter space Θ. The estimator of the structural parameters is

$$\widehat{\theta} = \arg\min_{\theta \in \Theta} \left(\widehat{\mathbf{\Psi}} - \mathbf{\Psi}(\theta) \right)' W_T \left(\widehat{\mathbf{\Psi}} - \mathbf{\Psi}(\theta) \right), \tag{38}$$

where W_T is a diagonal weighting matrix involving the inverse of each impulse response's variance on the main diagonal as in Christiano, Eichenbaum, and Evans (2005).[25] So more weight is attributed to the responses which are estimated precisely.

Implementation. I estimate a VAR from 1984q1, which marks the end of the non-borrowed reserves targeting period by the Federal Reserve Board and the Volcker disinflation, to 2005q3.[26] The time-series I use are log output per member of the labor force, quarterly inflation rates, log total hours worked per member of the labor force, log vacancies (measured by the helpwanted index) per member of the labor force, the log unemployment rate, the log real hourly wage rate and the federal funds rate in quarterly terms.[27] As a measure of the labor force, I take the civilian labor force of age 16 and over.[28] Table 4 in the Appendix provides the data sources. Let $\mathbf{x}_t$ be the vector of observable variables. I estimate the VAR

$$\mathbf{x}_t = \mu + \mathbf{a}\, t + \sum_{j=1}^{4} A_j\, \mathbf{x}_{t-j} + \mathbf{u}_t. \tag{39}$$

Here μ is a vector of constants, t is a time-trend and $\mathbf{u}_t$ is a vector of white noise shocks.[29] Based on the quarterly frequency of the data, the lag length in the VAR is set to $p = 4$. No evidence for residual serial correlation can be found.

[25] The variances are based on 10,000 bootstrap estimates from the SVAR.

[26] Overall, volatility of aggregate real variables has decreased since the early 1980s; Kim and Nelson (1999) locate the break date in the amplitude of U.S. GDP growth rates and the volatility of shocks to U.S. GDP growth rates at 1984q1 (their posterior mode). The same break date is found in McConnell and Perez-Quiros (2000). Stock and Watson (2002) document that this evidence is not limited to real GDP growth but can be found in a great number of U.S. macroeconomic time series. My sample start should safeguard against structural breaks. In order not to restrict the sample too much, I include lags prior to 1984q1.

[27] The response of output and hours worked is identical in my model yet not in the data. The impulse responses presented below appeared to be robust to leaving out hours worked.

[28] The use of the labor force series of Francis and Ramey (2005) would have reduced the sample by 4 observations. I conduct sensitivity analysis using also the Francis and Ramey (2005) labor force measure (see Appendix C). The results are qualitatively unchanged. The (low frequency) demographic movements, over the postwar period, that are features of the civilian labor force 16+ measure which these authors correct for seem more important for responses to technology shocks than for responses to monetary shocks, which are the focus of my paper. I would like to thank Francis and Ramey for providing me with their labor force series.

[29] The inclusion of the time-trend turned out not to have any qualitative bearing on the impulse-responses reported below.

Table 1: Forecast Error Variance Decomposition

Variable	4 quarters		8 quarters		12 quarters	
$\widehat{y}_t$	5.28	[0.55, 13.88]	10.20	[1.07, 20.27]	10.47	[1.26, 18.25]
$\widehat{\pi}_t$	0.36	[0.29, 6.95]	3.97	[1.90, 11.93]	6.06	[2.53, 12.97]
$\widehat{v}_t$	1.37	[0.16, 7.57]	10.71	[1.02, 20.40]	9.76	[1.10, 16.85]
$\widehat{u}_t$	0.87	[0.19, 6.60]	9.86	[1.13, 21.56]	13.94	[1.39, 21.83]
$\widehat{h}_t+\widehat{n}_t$	0.53	[0.15, 5.98]	4.24	[0.51, 13.47]	6.14	[0.69, 13.70]
$\widehat{w}_t$	1.59	[0.19, 8.21]	0.95	[0.56, 10.89]	1.31	[0.55, 14.64]
$\widehat{R}_t$	26.15	[11.50, 36.69]	15.53	[7.21, 28.47]	18.07	[7.02, 28.17]

Notes: For each variable in the first column and three different forecast horizons, the table reports the share of the forecast error variance which is accounted for by the identified monetary policy shock. The values in parentheses are lower and upper bounds of 90% confidence intervals obtained from 10,000 bootstraps of the estimated SVAR. From top to bottom the variables are output, inflation, vacancies, the unemployment rate, total hours worked per capita, the real wage rate and the nominal interest rate. The data used is as described in Table 6.

Table 1 shows forecast error decompositions for the variables featuring in the VAR and the monetary policy shock. As can be inferred, a sizeable share of the fluctuation in these variables is accounted for by the monetary policy shock.

Only a small subset of parameters will be estimated: of those pertaining to monetary policy I the smoothing coefficient ρ_m and the response to inflation γ_π. I also estimate the degree of habit persistence h_c, the elasticity of demand ϵ, wage indexation γ_w and worker bargaining power η as well as the weight of unemployment in matching α. The majority of parameters are calibrated following the literature, see Table 2. I restrict myself to determinate equilibria.

Impulse Responses. Figure 1 compares the impulse reponses of the estimated DSGE model (red and dotted) to the impulse responses obtained from the SVAR (black and solid). Shaded areas are 90% confidence intervals.

Overall, the model fits the data along the examined dimensions very well, in line with the results presented by Trigari (2004) and Braun (2005). The response of output to a monetary policy shock is hump-shaped and fairly persistent. Inflation shows a mild and persistent response to the monetary policy shock. In fact, the calibrated and estimated parameter values imply that the strategic complementarity term, $\frac{\phi+\frac{\sigma}{1-h_c}}{1+\phi\epsilon}=0.06$, in the Phillips curve (28) substantially dampens the inflation response. Both vacancies and the unemployment rate show a strong reaction to the shock. Vacancy rates increase by over 20% and the unemployment rate shows a similar fall in the data.[30] The DSGE model matches the timing of the peak responses as well as the

[30] To be very clear: the unemployment rate falls by roughly 20 *percent not* by 20 *percentage points*. Using the 10% steady state unemployment rate in my calibration, this means that the unemployment rate falls to 8% in

Table 2: Calibrated Parameters

Parameter	Description	Value	Source
	Monetary Policy Rule		
γ_y	response to output gap	0.00	Estimates by Boivin and Giannoni (2006).
	Preferences		
ϕ	inverse of labor supply elasticity	10.0	Trigari (2004).
β	time-discount factor	0.99	$\sim$ average real rate of 4% p.a. in the data.
	Labor Market		
ρ	separation rate	0.08	Hall (1999), Trigari (2004).
u	steady state unemployment rate	0.10	matches employment rate of 94%$^{*)}$.
q	steady state vacancy filling rate	0.70	den Haan, Ramey, and Watson (2000).
$\frac{b}{wh}$	steady state replacement rate (including home-production)	0.90	similar to Braun (2005), Hagedorn and Manovskii (2005).
	Price and Wage Setting		
γ_p	inflation indexation of prices	1.00	Christiano, Eichenbaum, and Evans (2005).
φ	price stickiness	0.50	Bils and Klenow (2004).

Notes: *) The employment rate of 94% in the data translates into an unemployment rate of 6% when interpreted as representing post-separation employment or 13.5% when interpreted as pre-separation employment. The unemployment rate of 10% in above calibration ranges in between these two bounds. The value of u is large in comparison with the official unemployment rate. In the model, however, u is the pool of searching workers and should encompass workers who are not included in the official unemployment rate but searching for work (e.g., discouraged workers). For a thorough discussion see Yashiv (2005).

magnitude of the responses very closely. Most notably, vacancies show strong persistence in response to a monetary policy shock even without introducing vacancy adjustment costs as in Braun (2005) or convex hiring costs as in Yashiv (2005), and in contrast to the results using productivity shocks in Fujita and Ramey (2005).[31] In my model, partial wage indexation goes a long way in inducing the correct response of vacancies.[32] Similarly, the interest rate response is well-matched.

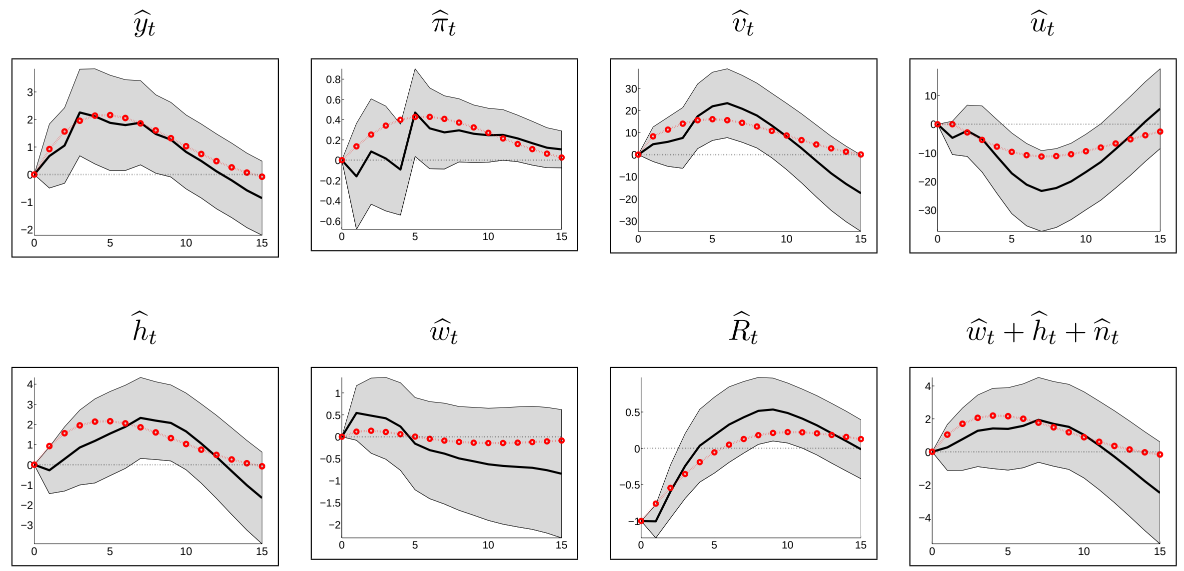
The recent labor market literature, e.g. Hall (2005) and Shimer (2004), points to the fact that wages tend to correlate only weakly with the business cycle. In so far as monetary policy shocks as a business cycle driving force are concerned, this finding is corroborated by the wage rate

response to a monetary policy shock – which I would still qualify as a sizeable response.

[31] Fujita and Ramey (2005) argue that the real business cycle matching model lacks persistence in response to a technology shock. They add a job creation cost (a fixed cost payable once which is not the same for each job) as opposed to a vacancy posting cost (a cost payable each period the vacancy is open) to the model – in each period there is thus only a limited number of profitable job opportunities for new entrants to the vacancy pool. Once a job is created, posting a vacancy is costless. This makes vacancies a state variable. Since shocks are persistent there will be new profitable job opportunities in the next period. Thus vacancies continue to build up, leading to a more sluggish (and hump-shaped) adjustment.

[32] When estimating both wage indexation γ_w and a quadratic adjustment cost for vacancies, both estimates are insignificant – and the fit of the model is not improved.

Figure 1: Impulse Responses of Estimated SVAR and DSGE Model



Notes: The plots show impulse responses to a unit monetary policy shock. All variables are plotted in percentage deviation from their respective steady state values. The solid black line corresponds to the empirical impulse response estimated in a VAR(4) from 1984q1 to 2005q3 (including lags up to 1983q1). The red dotted line marks the impulse response from the estimated DSGE model. Shaded areas pertain to 90% bootstrapped symmetric confidence intervals from 10,000 draws (computed as ± 1.645 the bootstrapped standard deviation). From top left to bottom right the graphs show the responses of: the output gap, the inflation rate, vacancies, the unemployment rate, total hours worked, the real wage rate and the gross nominal interest rate. The bottom right plot reports the implied response of total wages. This last response was not used in the estimation exercise but is reported for completeness. The data used is as described in Table 6.

panel in Figure 1: the response of the real wage rate to a monetary policy shock is insignificant across the board – and the wage response is small; similar to Christiano, Eichenbaum, and Evans (2005) and Amato and Laubach (2003).

The mild response of real wage rates to monetary policy shocks found in above-cited literature, however, is not as robust as responses by the other variables. Like Amato and Laubach (2003), for example, Giannoni and Woodford (2005) estimate an SVAR on the Volcker-disinflation sample. They obtain that the percentage response of real wage rates is about half as strong as the response for output – in stark contrast to Amato and Laubach (2003) whose real wage response is an order of magnitude smaller and even smaller than the response that I find. My estimates range in between these two results in the literature.

I conduct a sensitivity analysis in order to examine this issue further by running the SVAR on alternative data sets (see Appendix C for details).[33] Indeed, the response by the real wage rate turns out to be somewhat sensitive to the data chosen. Confidence bands remain wide but depending on the data used wage rates sometimes show a stronger response than in my benchmark data set and may even turn out to be marginally significantly positive at times. The current form of the model, however, will have a hard time to fit a strong response by the wage rate following a monetary shock. In fact, that wage rates in my model must be flat whenever inflation is smooth can intuitively be inferred from (32). There the smoothing terms α_2, α_3 for almost any parameterization are orders of magnitude larger than responses to market tightness and output with the importance of the smoothing terms increasing with higher elasticities of demand.

In so far yet as, in the light of this sensitivity, one is in unwilling to place much emphasis on the response of the wage rate itself the good news is that the response by aggregate (total) wages, $\widehat{w}_t + \widehat{h}_t + \widehat{n}_t$, and the other aggregates is not at stake. In fact, the fit of the response of implied total wages is marvellous in any case considered and does not inherit much of the sensitivity surrounding the choice of measure for the real wage rate; see the respective bottom right panels in Figure 1 and the figures reported in the sensitivity analysis (Appendix C). Still, if anywhere it with the real wage rate that one might want the DSGE model to be more flexibly adaptable to whatever choice of data for real wage rates one opts for.[34] Bear in mind, however, that a stronger response of wage rates would be hard to bring in line with responsive vacancies. See the discussion in Hall (2005) and Shimer (2004).

Parameter Estimates. Turning to the estimates $\widehat{\theta}$ of the structural parameters, Table 3 confirms that these estimates are in line with the literature. The degree of interest rate smoothing, $\rho_m = 0.83$, and the interest response to inflation, $\gamma_\pi = 1.51$, are in the standard range of values commonly estimated for Taylor-type rules, see e.g. Clarida, Gali, and Gertler (1998). The estimate of the degree of habit persistence, $h_c = 0.97$, is larger than the value of 0.65 estimated in Christiano, Eichenbaum, and Evans (2005) and that of 0.7 in Altig, Christiano, Eichenbaum, and Linde (2005), while our calibrated value of $\sigma = 0.1$ is substantially smaller than the value of unity usually assumed for the intertemporal elasticity of substitution in consumption. Yet, the estimate of habit h_c is by and large in line with Boivin and Giannoni (2006).[35] One simplification

[33] Three additional SVARs are considered (labeled Case 2 through 4 in Table 7). Case 2 is the same as the benchmark SVAR but discounts wage rates by the GDP deflator instead of the consumer price index. Case 3 uses a different wage series (wage and salary disbursements private industry divided by total hours worked in the business sector) than the benchmark SVAR (which uses a ready-made index of average hourly earnings for private industries). Case 4 obtains per capita measures by use of the Francis and Ramey (2005) measure of the labor force. This measure excludes government employment. For consistency, this case therefore takes output and wage data for the business sector only.

[34] More flexibility would likely ask for letting wages be set in a state contingent fashion whenever wages and prices are set – running counter to the intuition that if anything wages tend to be at least as sticky as prices. For a paper that, in a different context but still in a DSGE framework, indeed obtains a duration of wage contracts of just on quarter see Gali and Rabanal (2004).

Table 3: Parameter Estimates

Parameter	Description	Estimate	Standard Error	90% bounds
ρ_m	interest-rate smoothing	0.83	(0.060)	[0.68 , 0.92]
γ_π	response to expected inflation	1.51	(0.542)	[1.01*) 6.83]
h_c	degree of habit persistence	0.97	(0.007)	[0.94 , 1.00]
ϵ	own-price elasticity of demand	22.8	(9.935)	[6.29 , 33.44]
γ_w	indexation wages	0.49	(0.165)	[0.00 , 0.93]
η	bargaining power of workers	0.21	(0.112)	[0.01 , 0.82]
α	elasticity of matches w.r.t. unemployment	0.52	(0.083)	[0.46 , 1.00]

Notes: The standard error number is the asymptotic standard error. Standard errors are based on asymptotic covariance formulae for extremum estimators. For details see Meier and Mueller (2006). The final column shows 5% lower and 95% upper bounds for parameter estimates obtained from 10,000 bootstraps. The data used is as described in Table 6.
*) the lower bound for γ_π in the estimation was set to 1.01.

that the current model shares with theirs is that I consider all expenditure (including investment) as if it were non-durable consumption. Models that account separately for investment and consumption dynamics usually assume investment adjustment costs, see e.g. Christiano, Eichenbaum, and Evans (2005). The "habit persistence", h_c, estimated here can therefore be understood as a mixture of adjustment costs in investment expenditure and true habits in private consumption. Similarly, parameter σ reflects the intertemporal substitution in investment spending as much as the intertemporal elasticity of substitution in consumption. In fact, Woodford (2003, Ch. 5) shows that a fixed-capital model and the more general model featuring adjustment costs for investment can be calibrated so as to generate almost identical and empirically credible impulse responses of inflation, output, interest rates and real marginal costs to a monetary shock. See the discussions in (Woodford, 2003, Ch. 5) and Boivin and Giannoni (2006).

The literature allows for a sizeable range of the own-price elasticity of demand, ϵ. This runs from a value of $\epsilon = 6$ in Christiano, Eichenbaum, and Evans (2005), to the "standard" value of 11 (e.g. Boivin and Giannoni, 2006), to $\epsilon = 101$ in Altig, Christiano, Eichenbaum, and Linde (2005).[36] The estimate of $\epsilon = 22.8$, is thus well in the reasonable range. Due to both, a small markup of roughly 4.6% and non-negligible bargaining power of workers, $\eta = 0.21$, overall estimated period profits are small: period profits of firms matched with a worker in steady state account for only 0.6% of period production.

Turning to the labor market parameters, micro-level estimates for the worker bargaining power,

[35] Their sample ranges from 1979q3 to 2002q2. The estimates in Boivin and Giannoni (2006) in a similarly "small" model as mine are $\sigma = 0.08$ and $h_c = 0.91$.

[36] In the papers just mentioned, these values imply a markup of 20%, 10% and 1%, respectively.

η, are hard to come by. On U.S. macro-data Trigari (2004) estimates $\eta = 0.10$, while Braun (2005) gets $\eta = 0.77$. My estimate of $\eta = 0.21$ is in this range. Finally, for the elasticity of matching with respect to unemployment, α, Petrongolo and Pissarides (2001) survey the literature to find that most estimates for the matching elasticity fall in the range from 0.5 to 0.7.[37] My estimate of $\alpha = 0.52$ is thus reasonable when judged by the micro-evidence.

Sampling Uncertainty of Parameters. The standard errors reported in Table 3 are based on the asymptotic normality of the minimum-distance estimators. Complementary evidence on the finite-sample distribution of the estimators can be obtained by bootstrapping. For each set of impulse-responses obtained in the 10,000 bootstraps of the SVAR the model parameters are re-estimated. Figure 2 shows histograms of the resulting sampling distribution of the parameters and the final column of Table 3 reports 90% confidence intervals based on the sampling distribution. Clearly, the advantage of this measure is that proper account is taken of the sampling errors that result at each stage of the estimation. For about 9% of the estimates the lower bound of 1.01 imposed for the monetary policy feedback to inflation, γ_π, is binding. Most notable are the implications for wage indexation and the bargaining power of workers. More than 40% of the estimates for wage indexation, γ_w, end up at the lower bound of zero – wage indexation does not seem to be a robust feature of my data set and model, in contrast to the case made Christiano, Eichenbaum, and Evans (2005).[38] Finally the bargaining power of workers, η has a mode closer to zero than the point estimate in the benchmark SVAR suggests. Yet overall, and abstracting from the asymmetry of some of the sampling distributions, the standard errors reported in Table 3 give reasonable guidance to the uncertainty surrounding the point estimates in the benchmark SVAR.

5 Conclusions

I have illustrated that with equilibrium unemployment and matching frictions strategic complementarities in price setting naturally increase due to a temporarily firm-specific factor of production: labor. The matching framework thus induces a significant amount of real price rigidity as is needed to reconcile macro-estimates of Calvo-type Phillips curves with micro-evidence. Besides, the same demand-factors that drive the real *price* rigidity translate into significant amplification of real *wage* rigidity. The technical contribution of the paper was to directly integrate the wage bargaining into a sector which has a margin for setting its price but to retain *ex-ante* worker homogeneity.

[37] In some of the studies reviewed therein, which use total hires as dependent variable (not only hires from unemployment), the coefficient is lower ranging from 0.3 to 0.4.

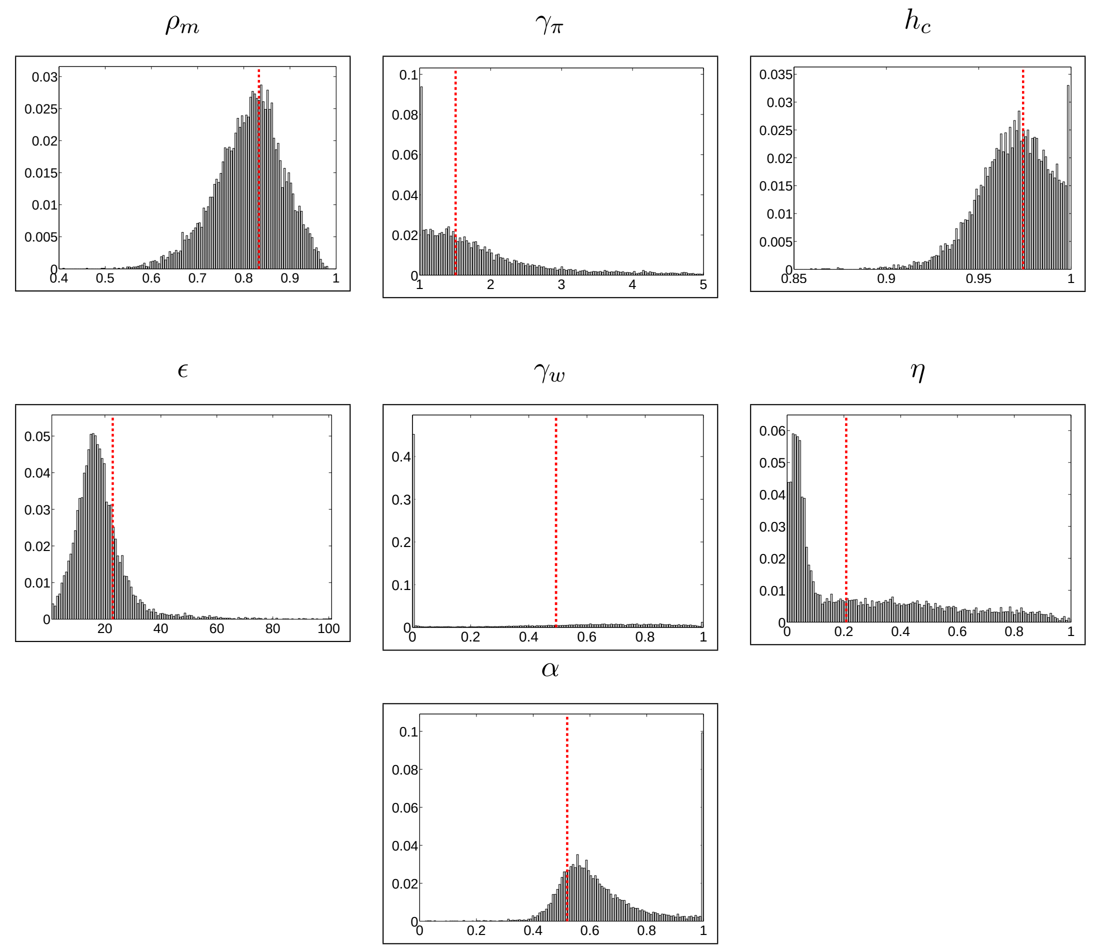
[38] It goes without mentioning that they have a very different model (and data span), of course.

In contrast to firm-specific capital models, say, the modified model implies cross-equation restrictions for a key parameter governing real rigidities (and thus identifies this parameter): the elasticity of demand. For single equation Phillips-curve estimates the model implies (a) a time discount-factor substantially smaller than unity (as is indeed commonly found in single equation estimates of the New-Keynesian Phillips curve) due to the probability of separation of firm and worker, the model implies (b) the presence of an employment gap as an additional (and usually omitted) regressor and (c) small pass-through of aggregate developments to inflation, i.e. price-durations in line with micro-evidence.

I find that the strategic complementarities in price-setting do not only induce inflation to be less volatile than in the benchmark model. Most notably, the strategic complementarities also have a bearing on the wage series. Even if wages are reset as frequently as prices (every second quarter in my calibration), the resulting real wages series does not respond much to a sudden monetary easing and to the associated increase in demand and labor market tightness. The smooth wage series thus helps to replicate the fluctuations of vacancies found in U.S. data, which have been the focus of much recent debate; see, for instance, Hall (2005) and Shimer (2004). A structural VAR application to post Volcker disinflation U.S. data showed that the modified model can very well replicate impulse responses to monetary policy shocks.

Throughout the analysis I have assumed that wages and prices are staggered á la Calvo and have the same durations, i.e. prices are reset whenever wages are and *vice versa*. In this respect it appears worth exploring to which extent the price and wage setting decisions can be uncoupled in a way that still keeps heterogeneity tractable. In particular, real wage rates could be negotiated in a state-contingent fashion. I leave this for future research – as well as an examination of how these more flexible wages will affect vacancy fluctuations implied by the model.

Figure 2: Sampling Distribution of Parameters



Notes: The plots show histograms of the sampling distribution of the estimated parameters. On the set of impulse responses obtained in the 10,000 bootstraps underlying the grey areas of Figure 1 problem (38) is solved. The distribution of estimators $\widehat{\theta}$ is plotted on the support of the respective parameters allowed for in the estimation. Exceptions are the plots for ρ_m,γ_π, and h_c. The estimation of γ_π fixed the upper bound at 60. 7.8% of the estimates were larger than the highest value of 5 plotted here. The estimation of ρ_m allowed for a support between zero and one. However, no estimate was smaller than the lowest value reported in the plot. Similarly h_c was estimated on [0,1) but no value was smaller than the lowest value reported. The vertical dashed red line in each graph marks the point estimate obtained from the SVAR run on actual data (cp. Table 3). From top left to bottom right the graphs show the distribution of estimates of the interest rate response to lagged interest rates and inflation, respectively, of habit persistence, the elasticity of demand, wage indexation, the bargaining power of workers and the elasticity of matching w.r.t. unemployment.

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A Steady State and Calibration

The following sixteen equations (40) to (55) jointly characterize the steady state of the model.

A.1 Household conditions

Real rate: By Euler equation (4)

$$R = \frac{1}{\beta}. \tag{40}$$

Marginal utility of consumption:

$$\lambda = (1 - h_c)^{-\sigma} y^{-\sigma}. \tag{41}$$

Marginal rate of substitution:

$$mrs = \kappa_h \frac{h^{\phi}}{\lambda}. \tag{42}$$

Surplus of the worker: by equation (19)

$$\Delta = \frac{wh - \frac{mrs}{1+\phi} h - b}{1 - \beta(1-\rho)(1-s)}. \tag{43}$$

A.2 Firm conditions

Value of the firm: by equation (13)

$$J = \frac{y^a - wh}{1 - \beta(1-\rho)}. \tag{44}$$

Vacancy posting: by equation (10)

$$J = \frac{\kappa}{\beta q(1-\rho)}. \tag{45}$$

Wage FOC: by equation (22), using the steady state expressions for the partial derivatives involved,

$$\eta J = (1-\eta)\Delta. \tag{46}$$

Price FOC: by equation (21), using the steady state expressions for the partial derivatives involved,

$$mrs = \frac{\epsilon - 1}{\epsilon} z. \tag{47}$$

A.3 Matching Market

Number of employees: by equation (15)

$$\rho n = (1-\rho)m. \tag{48}$$

Number of unemployed: by equation (16)

$$u = 1 - n. \tag{49}$$

Number of matches: by equation (14)

$$m = \sigma_m \, u^{\alpha} v^{1-\alpha}. \tag{50}$$

Probability of finding a job:

$$s = \frac{m}{u}. \tag{51}$$

Probability of finding a worker:

$$q = \frac{m}{v}. \tag{52}$$

A.4 Goods market clearing

Average production:

$$y^a = zh. \tag{53}$$

Final good supply: by equation (27)

$$y = nzh. \tag{54}$$

Final good demand: by equation (26)

$$c = y. \tag{55}$$

A.5 Calibration

The model has four free parameters: the disutility of work scaling factor, κ_h, vacancy posting costs, κ, the efficiency of matching, σ_m, and the unemployment benefit (including the value of home production), b. I normalize z to unity. I fix a steady state unemployment rate as described in Table 2 and choose a value of 1/3 for hours worked as well as the probability of finding a worker, q, and the replacement rate, $\frac{b}{wh}$, as both described in Table 2. Using the other calibrated and estimated parameters in Tables 2 and 3 this implicitly defines the free parameters and the steady state values of all endogenous variables.

B Source of Data

All data are taken from the Federal Reserve Board of St. Louis database FRED except for the adjusted labor force series by Francis and Ramey (2005), which was supplied by these authors and is given mnemonic LABFFR below, and wage and salary disbursements (private industry), which is taken from the Bureau of Economic Analyis NIPA data and carries mnemonic A132RC1 below.

Table 4: Data Description and Sources Benchmark Model

	Mnemonic	Data description
Vacancies	HELPWANT	Index of Help-Wanted Advertising base year 1987=100, seasonally adjusted quarterly average of monthly figures (own).
Interest rate	FEDFUNDS	Effective Federal Funds Rate monthly average, % p.a. quarterly average of monthly figures (own).
Nominal wage rate	AHETPI	Average Hourly Earnings: Total Private Industries monthly, seasonally adjusted, dollars per hour quarterly average of monthly figures (own).
Labor Force	CLF16OV	Civilian Labor Force, 16 years and over monthly, seasonally adjusted, thousands quarterly average of monthly figures (own).
Total hours worked	HOABS	Business Sector: Hours of all Persons quarterly, seasonally adjusted index 1992=100.
Unemployment rate	UNRATE	Civilian Unemployment Rate monthly, seasonally adjusted, quarterly average of monthly figures (own).
Real output	GDPC96	Real Gross Domestic Product quarterly, seasonally adjusted annual rates billions of chained 2000 dollars.
GDP deflator	GDPDEF	Gross Domestic Product: Implicit Price Deflator quarterly, seasonally adjusted index 2000=100.
Consumer price index	PCECTPI	Personal Consumption Expenditures: Chain-Type Price Index quarterly, seasonally adjusted index 2000=100.

Table 5: Description of Additional Data for Sensitivity Analysis

	Mnemonic	Data description
GDP deflator	GDPDEF	Gross Domestic Product: Implicit Price Deflator quarterly, seasonally adjusted Index 2000=100.
Wage and salary disbursements	A132RC1	Wage and Salary Disbursements Private Industry quarterly, seasonally adjusted, Source: Bureau of Economic Analysis.
Adjusted labor force series	LABFFR	Adjusted labor force series quarterly, seasonally adjusted Francis and Ramey (2005).
Real compensation per hour	RCPHBS	Business Sector: Real Compensation Per Hour quarterly, seasonally adjusted index 1992=100.
Price deflator business sector	IPDBS	Business Sector: Implicit Price Deflator quarterly, seasonally adjusted index 1992=100.
Real output business sector	OUTBS	Business Sector: Output quarterly, seasonally adjusted index 1992=100.

Table 6: Data Used in the Benchmark Analysis

Variable	Formula
Output per capita	$= \log(\mathrm{GDPC96}_t/\mathrm{CLF16OV}_t)$
Total hours worked per capita	$= \log(\mathrm{HOABS}_t/\mathrm{CLF16OV}_t)$
Real wage per hour	$= \log(\mathrm{AHETPI}_t/\mathrm{PCECTPI}_t)$
Quarterly federal funds rate	$= \log(1 + \mathrm{FEDFUNDS}_t/400)$
Quarterly inflation rate	$= \mathrm{d}\log(\mathrm{PCECTPI}_t)$
Unemployment rate	$= \log(\mathrm{UNRATE}_t/100)$
Vacancy per capita	$= \log(\mathrm{HELPWANT}_t/\mathrm{CLF16OV}_t)$

Notes: Mnemonics in the formulae refer to the definitions in Table 4.

Table 7: Data Used in the Sensitivity Analysis

Variable	Formula
	Case 2
Output per capita	$= \log(\text{GDPC96}_t/\text{CLF16OV}_t)$
Total hours worked per capita	$= \log(\text{HOABS}_t/\text{CLF16OV}_t)$
Real wage per hour	$= \log(\text{AHETPI.}_t/\text{GDPDEF}_t)$
Quarterly federal funds rate	$= \log(1 + \text{FEDFUNDS}_t/400)$
Quarterly inflation rate	$= \mathrm{d}\log(\text{PCECTPI}_t)$
Unemployment rate	$= \log(\text{UNRATE}_t/100)$
Vacancy per capita	$= \log(\text{HELPWANT}_t/\text{CLF16OV}_t)$
	Case 3
Output per capita	$= \log(\text{GDPC96}_t/\text{CLF16OV}_t)$
Total hours worked per capita	$= \log(\text{HOABS}_t/\text{CLF16OV}_t)$
Real wage per hour	$= \log(\text{A132RC1}_t/\text{PCECTPI}_t/\text{HOABS}_t)$
Quarterly federal funds rate	$= \log(1 + \text{FEDFUNDS}_t/400)$
Quarterly inflation rate	$= \mathrm{d}\log(\text{PCECTPI}_t)$
Unemployment rate	$= \log(\text{UNRATE}_t/100)$
Vacancy per capita	$= \log(\text{HELPWANT}_t/\text{CLF16OV}_t)$
	Case 4
Output per capita	$= \log(\text{OUTBS}_t/\text{LABFFR}_t)$
Total hours worked per capita	$= \log(\text{HOABS}_t/\text{LABFFR}_t)$
Real wage per hour	$= \log(\text{RCPHBS}_t * \text{IPDBS}_t/\text{PCECTPI}_t)$
Quarterly federal funds rate	$= \log(1 + \text{FEDFUNDS}_t/400)$
Quarterly inflation rate	$= \mathrm{d}\log(\text{PCECTPI}_t)$
Unemployment rate	$= \log(\text{UNRATE}_t/100)$
Vacancy per capita	$= \log(\text{HELPWANT}_t/\text{LABFFR}_t)$

Notes: Mnemonics in the formulae refer to the definitions in Tables 4 and 5.

C Sensitivity

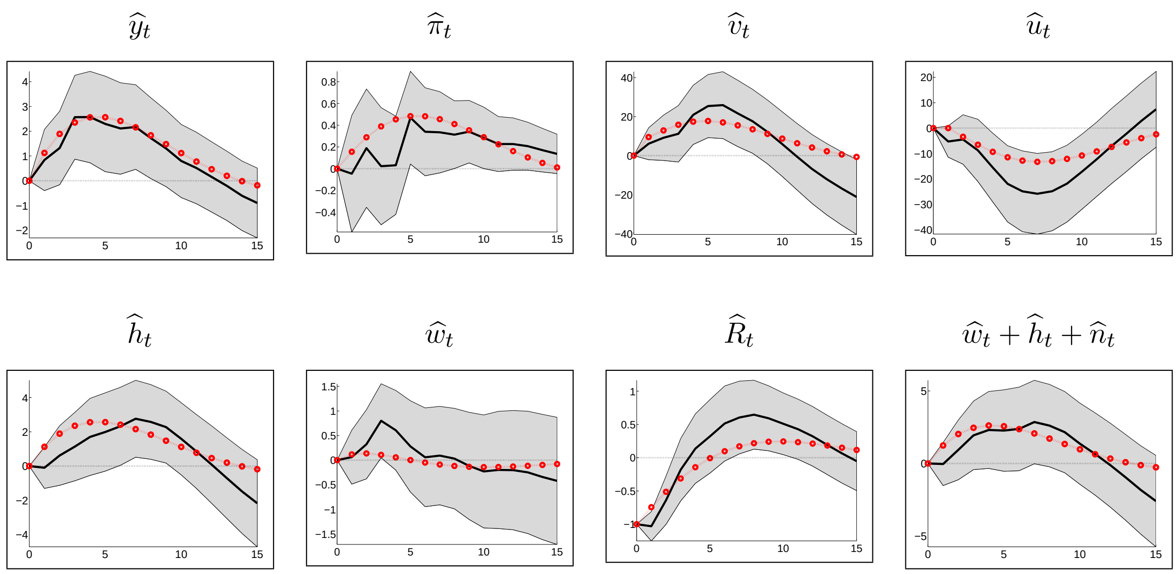
C.1 Case 2

Table 8: Parameter Estimates Sensitivity Case 2

Parameter	Description	Estimate	Standard Error
ρ_m	interest-rate smoothing	0.82	(0.059)
γ_π	response to expected inflation	1.35	(0.414)
h_c	degree of habit persistence	0.97	(0.008)
ϵ	own-price elasticity of demand	22.8	(9.197)
γ_w	indexation wages	0.53	(0.146)
η	bargaining power of workers	0.23	(0.117)
α	elasticity of matches w.r.t. unemployment	0.50	(0.082)

Notes: Parameter Estimates. The weighting matrix is obtained by 1,000 bootstraps from the estimated SVAR. The numbers reported for standard errors are the asymptotic standard errors. Standard errors are based on asymptotic covariance formulae for extremum estimators. For details see Meier and Mueller (2006). The data used is as described in Table 7.

Figure 3: Impulse Responses - Sensitivity Case 2



Notes: The plots show impulse responses to a unit monetary policy shock. All variables are in percentage deviation from their respective steady state values. The solid black line corresponds to the empirical impulse response estimated in a VAR(4) from 1984q1 to 2005q3 (including lags up to 1983q1). The red dotted line marks the impulse response from the estimated DSGE model. Shaded areas pertain to 90% bootstrapped symmetric confidence intervals from 1,000 draws (computed as ± 1.645 the bootstrapped standard deviation). From top left to bottom right the graphs show the responses of: output gap, inflation rate, vacancies, unemployment rate, total hours worked, real wage rate and gross nominal interest rate. The bottom right plot reports the implied response of total wages which was not used in the estimation exercise but is reported for completeness. The data used is as described in Table 7.

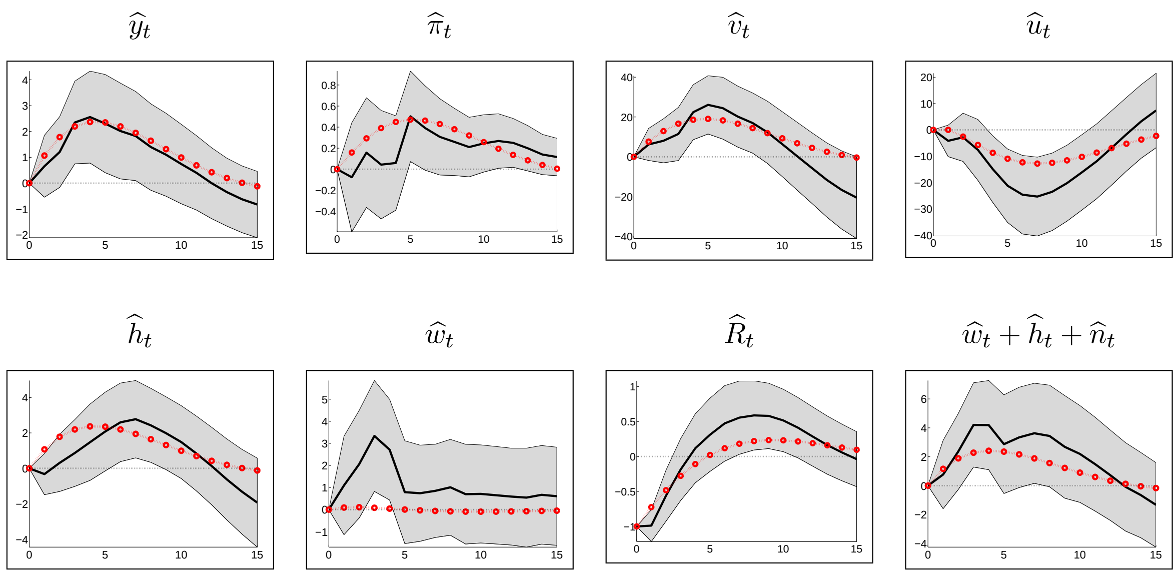
C.2 Case 3

Table 9: Parameter Estimates Sensitivity Case 3

Parameter	Description	Estimate	Standard Error
ρ_m	interest-rate smoothing	0.81	(0.060)
γ_π	response to expected inflation	1.29	(0.354)
h_c	degree of habit persistence	0.97	(0.009)
ϵ	own-price elasticity of demand	20.7	(8.422)
γ_w	indexation wages	0.59	(0.152)
η	bargaining power of workers	0.34	(0.177)
α	elasticity of matches w.r.t. unemployment	0.53	(0.074)

Notes: Parameter Estimates. The weighting matrix is obtained by 1,000 bootstraps from the estimated SVAR. The numbers reported for standard errors are the asymptotic standard errors. Standard errors are based on asymptotic covariance formulae for extremum estimators. For details see Meier and Mueller (2006). The data used is as described in Table 7.

Figure 4: Impulse Responses - Sensitivity Case 3



Notes: The plots show impulse responses to a unit monetary policy shock. All variables are in percentage deviation from their respective steady state values. The solid black line corresponds to the empirical impulse response estimated in a VAR(4) from 1984q1 to 2005q3 (including lags up to 1983q1). The red dotted line marks the impulse response from the estimated DSGE model. Shaded areas pertain to 90% bootstrapped symmetric confidence intervals from 1,000 draws (computed as ± 1.645 the bootstrapped standard deviation). From top left to bottom right the graphs show the responses of: output gap, inflation rate, vacancies, unemployment rate, total hours worked, real wage rate and gross nominal interest rate. The bottom right plot reports the implied response of total wages which was not used in the estimation exercise but is reported for completeness. The data used is as described in Table 7.

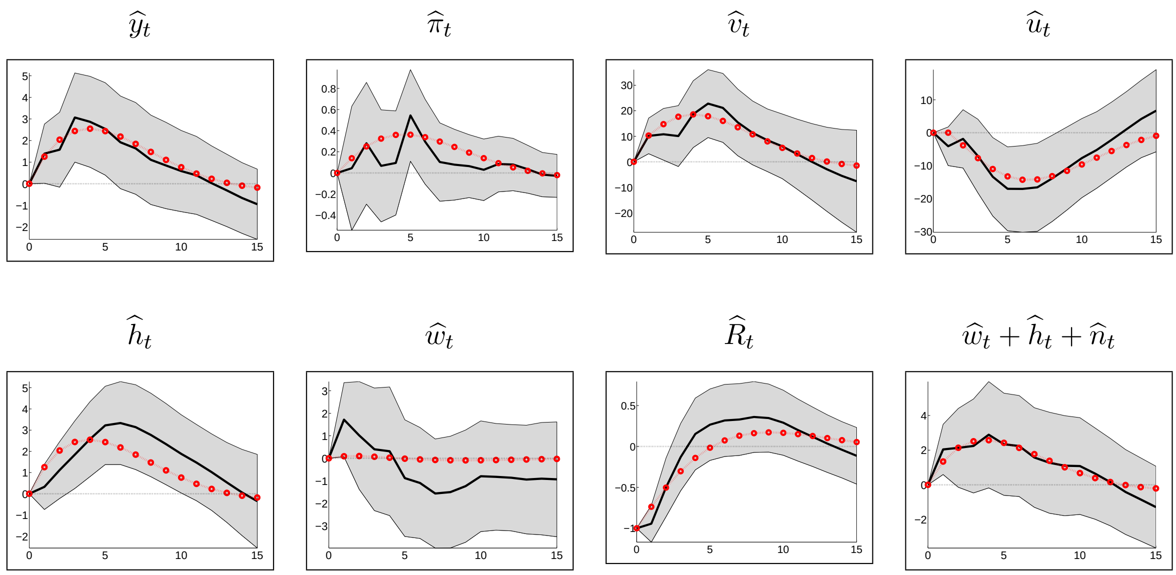
C.3 Case 4

Table 10: Parameter Estimates Sensitivity Case 4

Parameter	Description	Estimate	Standard Error
ρ_m	interest-rate smoothing	0.82	(0.071)
γ_π	response to expected inflation	1.83	(0.884)
h_c	degree of habit persistence	0.96	(0.012)
ϵ	own-price elasticity of demand	22.2	(10.454)
γ_w	indexation wages	0.45	(0.214)
η	bargaining power of workers	0.34	(0.182)
α	elasticity of matches w.r.t. unemployment	0.48	(0.069)

Notes: Parameter Estimates. The weighting matrix is obtained by 1,000 bootstraps from the estimated SVAR. The numbers reported for standard errors are the asymptotic standard errors. Standard errors are based on asymptotic covariance formulae for extremum estimators. For details see Meier and Mueller (2006). The data used is as described in Table 7.

Figure 5: Impulse Responses - Sensitivity Case 4



Notes: The plots show impulse responses to a unit monetary policy shock. All variables are in percentage deviation from their respective steady state values. The solid black line corresponds to the empirical impulse response estimated in a VAR(4) from 1984q1 to 2004q3 (including lags up to 1983q1). The red dotted line marks the impulse response from the estimated DSGE model. Shaded areas pertain to 90% bootstrapped symmetric confidence intervals from 1,000 draws (computed as ± 1.645 the bootstrapped standard deviation). From top left to bottom right the graphs show the responses of: output gap, inflation rate, vacancies, unemployment rate, total hours worked, real wage rate and gross nominal interest rate. The bottom right plot reports the implied response of total wages which was not used in the estimation exercise but is reported for completeness. The data used is as described in Table 7.