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In 2007 all ECB publications feature a motif taken from the €20 banknote.

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Abstract

This paper incorporates search and matching frictions in the labor market into a New Keynesian model. In contrast to the literature, the labor market activity takes place in the (Calvo-staggered) price-setting sector. Matching frictions lead price-setting firms to negotiate wage rates with their employees. The negotiation of wages substantially increases strategic complementarity in price-setting among suppliers of differentiated goods. This leads to an increase in real rigidities as in Woodford (2003), which reduces the size of price changes optimally chosen by re-optimizing firms. The same factors which induce smooth inflation also dampen the adjustment of wages in response to shocks. In the search and matching framework this is key for explaining the highly responsive nature of vacancies in the data. Another interesting finding for the Phillips curve is that inflation is not only driven by an output gap but also by an employment gap – a feature usually neglected in empirical research. The modified model matches impulse responses of an SVAR for post Volcker-disinflation US data very well.

JEL Classification System: E31,E24,E32,J63,J64

Keywords: firm-specific labor, real rigidities, Phillips curve, wage rigidity, bargaining.

Non-technical Summary

This paper highlights that the labor market may have a potentially strong effect on the joint behavior of inflation and real wages over the business cycle. In particular, even if wage rates are reset as frequently as prices are (on average every second quarter in the paper's calibration for the US), the resulting real wage series does not respond much to a sudden monetary easing and to the associated increase in aggregate demand and labor market tightness. The intuition rests on the assumption that wages are not set independently of the demand situation which the firm is facing. Especially if demand is relatively price-elastic, as might reasonably be argued is the case for many industries in times of increasing globalisation, the model predicts both smooth wages and smooth inflation.

The model is set up in a plain-vanilla New Keynesian environment with search and matching frictions in the labor market à la Mortensen and Pissarides (1994). These frictions mean that firms which seek to recruit may not find a suitable worker to instantly fill the vacancy. On the worker side, these frictions also mean that workers who are unemployed might not immediately find a new job. Since opening vacancies is costly and neither the firm can easily substitute a worker for another nor a worker can easily change jobs, a firm-worker match entails economic rents. These rents are distributed between the firm and the worker through wage bargaining.

The model highlights that labor naturally arises as a temporarily firm-specific factor within a New Keynesian framework with search and matching frictions in the labor market. The existing literature assumes that bargaining and hiring occur in a different industry than the production of final consumption goods. The setting of the price of these final goods is therefore not directly linked to the bargaining situation within the firm. As *e.g.* Krause and Lubik (2005), Trigari (2006) and Christoffel and Linzert (2005) have shown, in such a setting, including the labor market into the New Keynesian benchmark model does not have much of an effect on inflation inertia unless one assumes that the wage bargaining deviates from efficient bargaining. Consequently, this paper merges these two sectors: workers are employed in firms which directly produce a differentiated final output good. While this appears to be a minor change, it turns that it has repercussions on both inflation and wage rigidity. Intuitively, with both sectors merged, at the stage of the wage bargaining both workers and firms are well aware of the effect which the wage has for the (marginal) costs of the firm and therefore for the firm's demand conditions.

The mechanism which is at work is the following. Due to the matching frictions, in the short-run a worker constitutes a firmspecific factor of production for the firm. He is associated with the firm, is not himself able to walk away and work at a different firm and, on the other hand, the firm also cannot easily replace him. Now consider a worker who contemplates asking for a wage increase. All else equal an increase in the wage rate for the worker would lead to an increase in marginal production costs for the firm. Since the firm is a monopolist for its variety of the good[1], it would immediately pass part of the cost increase on to consumers through an increase in the product price. So the worker knows that a higher wage demand will lead to a higher product price. This higher product price, however, would make the variety of the good which the firm produces relatively more expensive than that of competitors. Demand would fall. In turn, the worker will be employed for fewer hours in order to satisfy this demand. Assuming that workers have an increasing marginal disutility of work, this leads to a fall in the worker's

[1] In technical terms, the firm operates in monopolistically competitive product markets.

marginal disutility of work. In other words, the subjective price that the worker assigns to his work-load has fallen. Any putative increase in the wage demanded by the worker therefore triggers a counteracting force, reducing a worker's incentive to ask for a wage increase in the first place. Wages are therefore smoother than in the absence of this channel.

For the argument to go through three ingredients are of importance: a) demand needs to be relatively price-elastic (so demand drops by enough when wages increase), b) marginal disutility of work needs to be sufficiently increasing (so the subjective price of work reacts enough to a change in the work-load) and c) there need to be matching frictions in the labor market (without matching frictions, the firm would simply immediately replace a worker who is asking for a wage increase by another worker).

Exactly the same mechanism is at work to generate smooth price adjustments.[2] The same factors that drive the real (*price*) rigidity thus translate into significant real *wage* rigidity. The current paper therefore contends the irrelevance of the labor market for the inflation process found in the recent labor market literature.

The resulting smooth hourly wage series implied by the model allows to replicate the fluctuation of vacancies and unemployment found in US data (cp. Hall, 2005, Shimer, 2005). The current paper illustrates this using a structural VAR analysis with an identified monetary policy shock.

[2] A firm that would like to increase its price would face a fall in demand. The ensuing fall in the worker's shadow price of work would reduce the workers wage demand and thus marginal costs. With marginal costs fallen the firm would face less pressure to incresase the price in the first place. For prices and in the absence of equilibrium unemployment, this mechanism has already been highlighted in the discussion about real rigidities in Woodford (2003).

1 Introduction

The New Keynesian model can achieve a smooth inflation series while preserving the assumption of reasonable nominal rigidity[3] once the model structure induces firms to voluntarily opt for small price changes through so called real (price) rigidities, see *e.g.* Ball and Romer (1990) and Eichenbaum and Fisher (2004). One strand of the literature states that the labor market is at the heart of understanding the inflation process. Here, wage rigidity can be used to induce inflation inertia, see *e.g.* Christiano, Eichenbaum, and Evans (2005). A full-fledged labor market and especially equilibrium unemployment is, however, suspiciously absent from these models. The other strand of literature adds an explicit labor market with search and matching frictions and equilibrium unemployment to the New Keynesian model. Astonishingly, this strand of literature arives at the contrary conclusion: litte real rigidity remains, see *e.g.* Krause and Lubik (2005) and Trigari (2006). The current paper contends the irrelevance of the labor market for the inflation process found in the latter strand of literature.

Labor market frictions, on the one hand, can help to account for a smooth inflation series once they induce reasonably smooth aggregate marginal cost. In Christiano, Eichenbaum, and Evans (2005) price-setting firms hire labor in a perfectly competitive market. Wage rigidity then achieves smooth marginal cost. The presence of equilibrium unemployment can further curb aggregate marginal cost as there are slack resources into which firms can tap once shocks increase aggregate demand. The literature, however, has found that the effect from adding an extensive margin of employment is rather limited, see Krause and Lubik (2005) and Trigari (2006). A different mechanism which induces firms to change prices in small increments works *via* strongly responsive marginal cost at the individual firm level.[4] In Woodford (2003, Ch. 3), *e.g.*, workers are permanently assigned to a specific firm which produces a differentiated good. A firm which contemplates increasing its price then anticipates that the ensuing fall in demand causes a reduction in hours worked. In his framework this triggers a fall in the marginal rate of substitution of the worker which leads to lower wage demand and consequently lower marginal cost. This in turn reduces the incentive to increase the price in the first place. Woodford needs to make the assumption that labor is completetely firm-specific and worthless outside of the specific firm.[5]

My paper, in contrast, stresses that labor as a firm-specific factor arises naturally within a New

[3] US firms adjust prices on average twice a quarter (see Bils and Klenow, 2004, and Klenow and Kryvtsov, 2005).

[4] 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.* Galí, 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). 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 (2005).

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

Keynesian framework with search and matching frictions in the labor market. In my model, all workers are *ex-ante* homogenous and only differentiate themselves by being currently (but not permanently) matched to a specific firm (or are unemployed otherwise). The firm-specific factor is thus only firm-specific as long as the match is not severed so that there always remains an outside market value to the worker. Costly search and matching creates a quasi-rent for existing jobs, which firm and worker distribute by wage bargaining. I assume, realistically, that hiring and wage negotation take place within the same firms which produce differentiated goods. The assumption that wage bargaining takes place in the differentiating industry considerably improves the New Keynesian model in terms of inflation persistence. The current paper thus highlights that the search and matching model (e.g. Pissarides, 1985) *is* a natural candidate to generate real rigidities.

At first glance, this assertion runs counter to the results of Trigari (2006) and Krause and Lubik (2005) who also introduce search and matching mechanism into the New Keynesian model but with little effect on inflation inertia. The reasons for the differing results are as follows: In my model, there is a direct link from the labor market to price-setting at the individual firm level. In Trigari (2006), in contrast, the labor market matters for inflation only through aggregate states like labor market tightness.[6] Closer to my framework are Krause and Lubik (2005), who also assign price setting and vacancy posting decisions to the same sector. For analytical tractability they assume, however, that marginal disutility of work is constant.[7] The current paper, in contrast, emphasizes that real rigidity arises precisely from the fact that disutility of work is increasing in work-load. Higher output of a firm then means higher wage demand by its worker and thus a curbing effect on price changes.

Another feature differentiates this paper from the literature: I derive wage rigidity from a mechanism in the model, and highlight that rigidity mainly arises as a result of strategic behavior of firms and workers. The intuition for this is as follows: all else equal an increase in the negotiated firm-worker-specific hourly wage would lead to an increase of marginal cost at the firm level and thus to an increase of the product price. With elastic demand for goods the amount of the good supplied falls. In order to satisfy the now reduced demand, the worker needs to work less hours. The marginal disutility of work in turn falls which, all else equal, dampens the worker's demanded wage per hour.

The resulting smooth hourly wage series implied by the model allows to replicate the fluctuation of vacancies and unemployment found in US data (cp. Hall, 2005, Shimer, 2005).[8] A structural

[6] Trigari (2006) assumes that there are two sectors in the economy. In her model, a Mortensen and Pissarides (1994) type labor sector produces an intermediate "labor" input. This is the only input to production of differentiated goods. The market for "labor" input is competitive. All that matters for the pricing decision in the differentiation sector is thus the price level for "labor" goods and hence aggregate states. This seems to be the standard approach in the literature, see e.g. Braun (2005).

[7] Their model features endogenous separation. The fact that all firms face the same marginal cost simplifies their computations considerably.

[8] Hagedorn and Manovskii (2005) calibrate the model in Hall (2005) to a low bargaining power of workers. This also induces unresponsive wages. Jung (2005) illustrates that a key assumption is that the utility difference between employment and unemployment is small in order to explain the large amplitude of unemployment in the data. In his framework with capital, however, this does not necessarily require as large a replacement rate as in Hagedorn and Manovskii.

VAR analysis illustrates this for a monetary policy shock. Contributing to the work of Shimer (2004) and Hall (2005), who right-away assume real wage rigidity from the outset, the current paper provides an economic mechanism which translates minor nominal rigidity into substantial real wage rigidity. It therefore links the real rigidities debate to labor market fluctuations in that it provides for sufficient real wage rigidity to match the degree of vacancy fluctuations observed in the data.[9]

An interesting third finding of the paper (besides the induction of inflation and wage inertia) is that it also has implications for single equation estimates of New Keynesian Phillips curves taken for themselves. The model implies (a) that future inflation in the Phillips curve is more heavily discounted than by the consumers' time-discount factor 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. Output and employment are strongly positively correlated in the data. If the model posited here is the data-generating process omitting the employment gap is likely to bias implied price-durations inferred from Phillips curve estimates upwards. In turn this would imply an upward bias for the implied price duration.

The remainder of the paper is structured as follows: 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 and the wage equation. Section 4 illustrates that the entire model can replicate the impulse responses to monetary policy shocks taken from a small structural vector autoregression for post Volcker disinflation US data. A final section concludes. Some technical material and a thorough description of the data is deferred to the Appendix.[10]

2 The Model

According to Hall (2005) cyclical fluctuations in employment are mainly due to fluctuations in vacancy posting. I therefore assume a constant separation rate. In each period a constant fraction, δ, of firm-worker relationships splits up for an exogenous reason. The backbone of the model discussed here is therefore similar to Trigari (2006). As is common in the literature, I focus on a cashless limit economy; cp. Smets and Wouters (2003) and large parts of Woodford (2003).

Inflation inertia has been well documented in monetary policy structural vector autoregressions (SVARs). Section 4 will match the DSGE model's impulse-responses as closely as possible to the responses obtained in a monetary SVAR. This exercise is partial in the sense that I abstract from identifying any aggregate shocks in the economy apart from monetary policy shocks. To ease

[9] The mechanism stressed in this paper 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) seem to lack the amplification mechanism for wage rigidity, which I discussed above.

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

notational burden, throughout the paper I refrain from mentioning other sources of fluctuations but for a shock to monetary policy.

There are information lags. When making decisions in period t, firms and workers know everything pertaining to them individually and all period $t-1$ shocks. They do not, however, know the contemporaneous value of the only aggregate shock, the monetary policy shock. The timing in the model is as follows: firms and workers first observe whether a match is separated or not. In the Calvo-staggered framework which I apply, they are, next, informed whether they can update their price and wage. Based on this information but otherwise only information available in $t-1$, worker and firm, respectively, take non-state contingent consumption, price- and wage-setting and vacancy posting decisions for period t. The monetary policy shock materializes thereafter and the family takes its portfolio (equity) choice with full information. Due to these information lags on behalf of the private sector, monetary policy innovations have a contemporaneous bearing only on the monetary policy instrument (the nominal interest rate) as in Christiano, Eichenbaum, and Evans (2005), and on the share prices of firms.

2.1 Consumers

The model economy is populated by a large number of identical, representative, families with unit mass. Each family has a continuum of members of two types: unemployed workers with mass u_t and employed workers with mass $n_t = 1 - u_t$. Each family pools the labor incomes of their members. The representative family earns real income from the wages of their employed members, $\int_0^{n_t} w_t^i h_t^i di$, where w_t^i is the real wage per hour worked by member i, h_t^i. In addition, a family obtains income from real unemployment benefits, b, ($u_t b$ in total). Families also hold shares in a mutual fund that redistributes profits in the economy. Individual members of the representative family, indexed by $i \in [0, 1]$, are infinitely lived and seek to maximize expected lifetime utility by deciding on the level (and intertemporal distribution) of consumption of a bundle, c_t^i, of consumption goods and by deciding on the real expenditure, d_t^i, for riskless one-period bonds. These decisions are taken before the monetary policy shock becomes known. In the following, endogenous variables pertaining to individual consumers carry superscript index i. Endogenous variables pertaining to an individual firm (its product, price or profit) carry subscript j. Variables without index refer to aggregates.

$$\max_{\{c_t^i, d_t^i\}} E_{t-1} \left\{ \sum_{k=0}^{\infty} \beta^k \left\{ \frac{(c_{t+k}^i - \varrho c_{t+k-1})^{1-\sigma}}{1-\sigma} - g(h_{t+k}^i) \right\} \right\}, \ \beta \in (0,1), \sigma > 0. \tag{1}$$

Here c_{t-1} is the aggregate level of consumption in period $t-1$. I assume that an individual family member's consumption is subject to external habit persistence, indexed by parameter $\varrho \in [0, 1)$. As in Abel (1990) households therefore are concerned with "catching up with the Joneses". Family members pool their income – there is thus perfect consumption risk sharing. I assume that family takes the labor supply decision for its members in order to prevent free-riding.[11]

[11] This assumption and the pooling assumption follow den Haan, Ramey, and Watson (2000). Both assumptions are standard in the literature, see *e.g.* Braun (2005), Trigari (2006).

The family member's budget constraint is given by:

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

Here R_t denotes the nominal gross return on the risk-free bond from t to $t+1$ and Π_t is the gross inflation rate. In period t, a measure of n_t one-worker firms produce goods. $n_t \in (0,1)$ thus also is the level of employment in t. Firm j of these makes real profit $\psi_{j,t}$, total profits accruing to the consumer are $\int_0^{n_t} \psi_{j,t} dj$. The consumer pays lump-sum taxes t_t. 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 consumers's budget constraint but not the aggregate ressource constraint.

A total mass of n_t varieties $y_{j,t}$, $j \in [0, n_t]$, of wholesale goods is produced in a given period. Let $c_{j,t}^i$ be the amount of each of these goods consumed by family member i. The final bundle of consumption goods consumed by family member i, c_t^i, is "produced" according to

$$c_t^i = n_t \left[\frac{1}{n_t} \int_0^{n_t} \left(c_{j,t}^i\right)^{\frac{\epsilon-1}{\epsilon}} dj \right]^{\frac{\epsilon}{\epsilon-1}}, \tag{3}$$

where $\epsilon > 1$ denotes the own-price elasticity of demand. By assumption therefore, more product diversity leads to more output in terms of the consumption basket, i.e. consumers value product diversity.[12] Due to consumption insurance and separability of consumption and leisure in the utility function, all households in equilibrium will have the same consumption levels of each good. I therefore suppress index i in the following. The cost-minimizing demand for wholesale goods of type j is

$$c_{j,t} = \left(\frac{P_{j,t}}{P_t} \right)^{-\epsilon} y_t^a, \tag{4}$$

where y_t^a marks average output of the consumption basket per *employed* worker, $y_t^a = \frac{1}{n_t} c_t$. The aggregate price index for the consumption basket, P_t, is given by

$$P_t = \left[\frac{1}{n_t} \int_0^{n_t} P_{j,t}^{1-\epsilon} dj \right]^{\frac{1}{1-\epsilon}}. \tag{5}$$

The first-order conditions for consumption versus saving (taken subject to a no-Ponzi condition) can be summarized by the Euler equation

$$E_{t-1} \{\lambda_t\} = \beta E_{t-1} \left\{ \lambda_{t+1} \frac{R_t}{\Pi_{t+1}} \right\}, \tag{6}$$

where $\lambda_t = (c_t - \varrho c_{t-1})^{-\sigma}$ marks marginal utility of consumption, and by the transversality condition

$$\lim_{s \to \infty} E_{t-1} \{\beta^s \lambda_{t+s} d_{t+s}\} \leq 0. \tag{7}$$

[12] The results of this paper regarding real price and wage rigidity would equally well be obtained when the final consumption good work homogenous of degree zero in degree of product variety. Only the final result of this paper, that inflation in the Phillips curve may be driven also by an employment gap hinges on this assumption.

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

$$g(h_t^i) = \kappa_h \frac{\left(h_t^i\right)^{1+\phi}}{1+\phi},\ \phi > 0,\ \kappa_h > 0. \quad (8)$$

Here κ_h denotes a scaling parameter for the disutility of work. Importantly for the argument below, the marginal disutility of work, $\frac{\partial g(h_t^i)}{\partial h_t^i}$, is *increasing* in individual hours worked, h_t^i. It is this fact which leads a worker to seek increasing compensation per hour at the margin. For a firm this means that marginal costs increase in the production level which in turn induces them to adjust prices by less than in the standard New Keynesian model. Also this leads to less volatile negotiated wages.

2.2 Production

The existing macro-labor market literature assumes that firms which are free to set their price face marginal costs which are independent of own decisions; e.g. Krause and Lubik (2005) directly assume that marginal disutility of work is constant, and Trigari (2006), Braun (2005) and Christoffel, Kuester, and Linzert (2006) 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 contribution of the current paper is to integrate the labor market activity into the price setting sector and allow for firmspecific marginal costs. This brings about the real rigidity which induces both rigid prices and wages.

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) and Yun (1996).[13] Firms and workers, if they are allowed to update, decide jointly how to split the rents of their employment relationship. Hours worked have a first-order effect on individual utility. In this model, they are demand-driven and thus depend directly on the firm's sales price. I therefore assume that a firm and a worker not only decide about the nominal hourly wage rate, $W_{j,t}$, but that they simultaneously also agree on the product price, $P_{j,t}$. This is a reasonable assumption in the current framework since the price determines hours worked via the firm's demand function. A simplifying assumption is that wages and prices have the same duration: whenever a firm can reset its price it can renegotiate its wage rate and *vice versa*.[14]

[13] Klenow and Kryvtsov (2005) summarize that individual price data obtained from the US 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.

[14] This assumption may not be restrictive: In their benchmark version estimated on aggregate US data, Christiano, Eichenbaum, and Evans (2005) find that prices and wages roughly have the same duration, 2.5 and 2.8 quarters, respectively. In a survey, Taylor (1999) argues that wages are typically adjusted once per year. Based on micro-level data on wages per hour, Gottschalk (2005) concludes similarly. Yet this evidence applies mainly to base pay. Other wage components like bonuses or perks will adjust much more frequently.

2.2.1 Firms

There is an infinite number of potential one-worker firms. These may post vacancies. Once having recruited a worker, they produce a differentiated good and engage in wage bargaining. I describe each decision in turn.

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.[15] V_t is the market value of a prototypical firm that posts a vacancy in period t. $J_t(P_{j,t}, W_{j,t})$ is the real value of a wholesale firm in period t that has a worker, charges $P_{j,t}$ for its good and pays a nominal wage $W_{j,t}$ for each hour worked. Due to nominal rigidities, in 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, $\gamma_p, \gamma_w \in [0,1]$). The partial updating follows Smets and Wouters (2003). For analytical tractability, I keep the heterogeneity to a minimum.
Firms which just found a worker, i.e. entered the market, have the same price and wage setting pattern as existing firm-worker relationships.[16] 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). Intuitively this captures the notion that a share of firms which just set up their business is so busy with getting in place their business proper, like setting up a distribution channel or administrative tasks, they they take the prevailing prices and wages in their neighborhood as a first approximation. Only later on, when time permits, will they engage in re-optimizing their price and wage. A firm which posts a vacancy finds a new employee with probability q_t. With probability δ 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. As of period t, the value of a firm which opens a vacancy consequently is given by

$$V_t = -\kappa_t + q_t(1-\delta)E_t\left\{\beta_{t,t+1}\left[\varphi J_{t+1}(P_t\,\Pi_t^{\gamma_p}, W_t\,\Pi_t^{\gamma_w}) + (1-\varphi)J_{t+1}(P_{t+1}^*, W_{t+1}^*)\right]\right\}. \quad (9)$$

Here $\beta_{t,t+1} := \beta\frac{\lambda_{t+1}}{\lambda_t}$ is the equilibrium pricing kernel. Due to information lags, vacancies need to be posted a period in advance, i.e. on the basis of $t-1$ information. There is free entry into production apart from the sunk vacancy posting cost. This drives the expected value of a vacancy to zero in equilibrium: $E_{t-1}\{V_t\} = 0$.

[15] In priciple, the model allows for fluctuations in real vacancy posting costs, *e.g.* since there are vacancy adjustment costs as in Braun (2005) or because vacancy costs are posted in nominal terms. The empirical exercise in Section 4 shows that constant real vacancy posting costs, i.e. $\kappa_t = \kappa\ \forall\, t$, are, however, sufficient to fit the vacancy series.

[16] To achieve sufficient fluctuation in vacancies, real wages of *newly* formed matches must be sticky in order to induce sufficient fluctuation in vacancies and unemployment (see Shimer, 2004). This is a by-product achieved by my formulation. Note that the real rigidities mechanism employed in the current paper features spill-overs from existing prices and wages to newly set ones. The curbing effect on newly set prices and wages would thus presumably also remain present if all entering firms were to optimize their price and wage in their first period of production.

Production. Each firm has the same constant returns to scale production technology

$$y_{j,t} = zh_{j,t}. \tag{10}$$

z 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 its employee and the price charged for its product:

$$\psi_t \left(P_{j,t}, W_{j,t}\right) = \frac{P_{j,t}}{P_t} y_{j,t} - \frac{W_{j,t}}{P_t} h_{j,t}. \tag{11}$$

With probability $1 - \delta$ the current match will not be severed at the beginning of next period. Conditional on "surviving", 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}. Hence the value of, say, firm j of the n_t firms which produce in t is

$$\begin{aligned} J_t \left(P_{j,t}, W_{j,t}\right) &= \psi_t(P_{j,t}, W_{j,t}) \\ &+(1-\delta)E_t \left\{\beta_{t,t+1}\left[\varphi J_{t+1}\left(P_{j,t}\Pi_t^{\gamma_p}, W_{j,t}\Pi_t^{\gamma_w}\right) + (1-\varphi)J_{t+1}\left(P^*_{t+1}, W^*_{t+1}\right)\right]\right\}. \end{aligned} \tag{12}$$

Matching. A constant-returns-to-scale matching function links new matches, m_t, to unemployment, u_t, and vacancies, v_t:

$$m_t = \sigma_m u_t^{\alpha} v_t^{1-\alpha}, \ \sigma_m > 0, \ \alpha \in [0,1]. \tag{13}$$

σ_m governs the rate at which new matches arrive, the efficiency of matching. α governs the relative weight which the pool of searching workers and firms, respectively, receive in the matching process. Labor market tightness from the firm's point of view is measured by $\theta_t := v_t/u_t$. 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 coming from unemployment are matched to a firm during t do not take up productive work until period $t+1$. New matches can also be separated prior to production. Employment thus evolves according to

$$n_t = (1-\delta)(n_{t-1} + m_{t-1}). \tag{14}$$

Unemployment is given by

$$u_t = 1 - n_t. \tag{15}$$

Worker Surplus. As noted earlier, unemployed workers receive real unemployment benefits b. The worker's surplus from being in employment, i.e. the increase of family welfare through an additional family member in employment in t is $\Delta_t(P_{j,t}, W_{j,t}) := \Gamma_t(P_{j,t}, W_{j,t}) - U_t$.[17] Hence

$$\begin{aligned}\Delta_t(P_{j,t}, W_{j,t}) = &\frac{W_{j,t}}{P_t} h_t(P_{j,t}) - \frac{g\left(h_t(P_{j,t})\right)}{\lambda_t} - b \\ &+ (1-\delta)\varphi E_{t-1}\left\{\beta_{t,t+1}(\Delta_{t+1}(P_{j,t}\Pi_t^{\gamma_p}, W_{j,t}\Pi_t^{\gamma_w}) - \Delta_{t+1}^*)\right\} \\ &- (1-\delta)\varphi s_t E_{t-1}\left\{\beta_{t,t+1}(\Delta_{t+1}(P_t\Pi_t^{\gamma_p}, W_t\Pi_t^{\gamma_w}) - \Delta_{t+1}^*)\right\} \\ &+ (1-\delta)(1-s_t)E_{t-1}\left\{\beta_{t,t+1}\Delta_{t+1}^*\right\},\end{aligned} \tag{16}$$

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

Intuitively, this expression can be split in two parts: An employed worker receives his real wage bill and suffers disutility of work, $\frac{g(h_{j,t})}{\lambda_t}$, where λ_t is the marginal utility of consumption. Next period the worker remains employed with probability $1-\delta$ or will be unemployed otherwise (δ). Based on the family's and worker's information when prices and wages are set, the value of employment to the family, $\Gamma_t(\cdot)$, of an employed worker matched to a firm with price $P_{j,t}$ and wage rate $W_{j,t}$ is

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

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

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

Bargaining. Firm-worker pairs which are allowed to update their price and wage face the problem of maximizing expected joint surplus by choosing the sales price and by simultaneously negotiating the nominal wage rate on the basis of $t-1$ information. While wages and prices may be fixed, hours worked can freely adjust to satisfy demand. I stick to the Nash-bargaining assumption: Firms and workers solve

$$\max_{W_{j,t}, P_{j,t}} E_{t-1}\left\{[\Delta_t(P_{j,t}, W_{j,t})]^\eta \; [J_t(P_{j,t}, W_{j,t})]^{1-\eta}\right\}, \tag{19}$$

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

[17] 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 (2006).

When bargaining, the firm and the worker need to take into account the effect which their decision today continues to have for all periods in which they may have to keep prices and wages fixed. 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

$$E_{t-1}\left\{ \left.\frac{\partial \Delta_t(P_{j,t}, W_{j,t})}{\partial P_{j,t}}\right|_* \eta \Delta_t^{*\eta-1} J_t^{*1-\eta} \right\} = -E_{t-1}\left\{ \left.\frac{\partial J_t(P_{j,t}, W_{j,t})}{\partial P_{j,t}}\right|_* (1-\eta)\Delta_t^{*\eta} J_t^{*-\eta} \right\}, \quad (20)$$

where $|_*$ means that the expression is evaluated at the optimal reset-price, P_t^*, and the reset-wage, W_t^*. The first-order condition for optimal wage setting is

$$E_{t-1}\left\{ \left.\frac{\partial \Delta_t(P_{j,t}, W_{j,t})}{\partial W_{j,t}}\right|_* \eta \Delta_t^{*\eta-1} J_t^{*1-\eta} \right\} = -E_{t-1}\left\{ \left.\frac{\partial J_t(P_{j,t}, W_{j,t})}{\partial W_{j,t}}\right|_* (1-\eta)\Delta_t^{*\eta} J_t^{*-\eta} \right\}. \quad (21)$$

The fact that wages and prices are always set at the same time 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

The model is closed by a standard Taylor rule for the nominal interest rate and by a rule for Ricardian fiscal policy.

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, hats over variables denote percentage deviations of these variables from steady state. The empirical literature (see, e.g. Clarida, Galí, and Gertler, 2000) finds that simple linearized Taylor-type rules of the form

$$\widehat{R}_t = \rho_m \widehat{R}_{t-1} + (1-\rho_m)\gamma_\pi E_t \widehat{\pi}^a_{t+3} + \widehat{\epsilon}_t^{money} \quad (22)$$

quantitatively are a good representation of monetary policy. Here $\rho_m \in [0,1)$, $\gamma_\pi > 1$ and ϵ_t^{money} is an iid monetary shock. The use of specific inflation rate concept differs in these rules. I assume that the policymaker targets average annual inflation, $\widehat{\pi}^a_{t+3} := \frac{1}{4}\left(\widehat{\pi}_t + \widehat{\pi}_{t+1} + \widehat{\pi}_{t+2} + \widehat{\pi}_{t+3}\right)$. This specification of the rule is chosen on empirical grounds: feedback to average inflation helps to obtain reasonable estimates for the coefficient γ_π.[18]

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

$$R_t = (\overline{\Pi}/\beta)^{1-\rho_m} R_{t-1}^{\rho_m} E_t \left(\frac{\Pi^a_{t+3}}{\overline{\Pi}}\right)^{(1-\rho_m)\gamma_\pi} \epsilon_t^{money}. \quad (23)$$

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

2.3.2 Fiscal Policy

I assume that fiscal policy is globally and locally Ricardian. The government does not engage in any government spending. It redistributes revenue 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:

$$u_t b + \frac{d_{t-1}}{\Pi_t} R_{t-1} = d_t + t_t + v_t \kappa_t. \tag{24}$$

Since the path of debt is not the focus of the current paper, an arbitrary debt-stabilizing rule which ensures that the government is passive in the sense of Leeper (1991) can be used to close the government sector. Without loss of generality, I assume that lump-sum taxes adjust so as to ensure a balanced budget in each period, $d_t = 0$ for all t.

2.4 Market Clearing

Goods market clearing requires

$$c_t = n_t \left[\frac{1}{n_t} \int_0^{n_t} y_{j,t}^{\frac{\epsilon-1}{\epsilon}} dj \right]^{\frac{\epsilon}{\epsilon-1}}, \tag{25}$$

where $y_{j,t} = \left(\frac{P_{j,t}}{P_t}\right)^{-\epsilon} y_t^a = z h_{j,t}$. In addition, bonds need to be in zero net supply.

3 Wage and Price Stickiness

The New-Keynesian labor-market literature so far assumes that marginal costs in the price setting sector are independent of an individual firm's production level. Krause and Lubik (2005) implement this by means of a constant marginal disutility of work of the firm's employees. Trigari (2006) separates wage bargaining from price setting altogether by means of a two-sector structure. I call her framework the "benchmark" modeling strategy since it is employed in other studies as well (see e.g. Braun, 2005 and Christoffel and Linzert, 2005).

The contribution of the current paper is to bring to the forefront that labor in the bargaining world is firm-specific. In the model the price-setting sector is merged with the wage-bargaining sector. In addition, workers have an increasing marginal disutility of work. This modification leads to both an increase in price rigidity and an increase in wage rigidity compared to the standard model. Both price and wage rigidity will be the more pronounced, the more elastic demand is and the more convex is the disutility of work. The degree of observed real wage rigidity in my model therefore intensifies when the degree of strategic complementarity in price-setting increases. This amplification mechanism is absent in other bargaining models with sticky wages, e.g. in Gertler and Trigari (2005). The current section highlights these results by closely examining the Phillips curve and the wage equation after having linearized around the zero-inflation steady state laid out in Appendix A.

Let $\widehat{\pi}_t$ be the log deviation of the gross inflation rate from its steady state. The Phillips curve can be written as:

$$\widehat{\pi}_t = \frac{\gamma_p}{1+\gamma_p\,\breve{\beta}}\,\widehat{\pi}_{t-1} + \frac{\breve{\beta}}{1+\gamma_p\,\breve{\beta}}\,E_{t-1}\widehat{\pi}_{t+1} + \frac{1-\varphi}{\varphi}\,\frac{1-\breve{\beta}\,\varphi}{1+\gamma_p\,\breve{\beta}}\,\widehat{\Lambda}_t, \tag{26}$$

where

$$\widehat{\Lambda}_t = \frac{1}{1+\phi\epsilon}\,\widehat{mrs}_t.$$

Here $\breve{\beta} := \beta(1-\delta)$ 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 $\widehat{\Lambda}_t$ in Phillips curve (26) can be written as:

$$\widehat{\Lambda}_t = \frac{1}{1+\phi\epsilon}\left\{\phi\,(\widehat{y}_t^a - \widehat{y}_t^{a,n}) - (\widehat{\lambda}_t - \widehat{\lambda}_t^n)\right\}. \tag{27}$$

The marginal utility of consumption, $\widehat{\lambda}_t$, in turn depends on consumption per capita (employed plus unemployed workers), $\widehat{c}_t$. In equilibrium this equals *total* output, $\widehat{y}_t$ – and not only on output per employee, $\widehat{y}_t^a$ (compare page 11). This means that once substituting for marginal utility of consumption, an employment gap enters the Phillips curve:

$$\begin{aligned}\widehat{\Lambda}_t =&\ \frac{1}{1+\phi\epsilon}\left\{\phi\,[\widehat{y}_t - \widehat{y}_t^n - (\widehat{n}_t - \widehat{n}_t^n)] + \frac{\sigma}{1-\varrho}\left[\widehat{y}_t - \widehat{y}_t^n - \varrho\left(\widehat{y}_{t-1} - \widehat{y}_{t-1}^n\right)\right]\right\} \\ =&\ \frac{1}{1+\phi\epsilon}\left\{\phi\,[\widehat{y}_t^{gap} - \widehat{n}_t^{gap}] + \frac{\sigma}{1-\varrho}\left[\widehat{y}_t^{gap} - \varrho\widehat{y}_{t-1}^{gap}\right]\right\}.\end{aligned} \tag{28}$$

The Phillips curve has the same structure as in Woodford (2003, p. 187) and Boivin and Giannoni (2005) except for the employment gap.[19] The matching model naturally lends itself to an increase in the strategic complementarity of price-setting decisions due to temporarily firm-specific labor. The plain Calvo-type New Keynesian Phillips curve (e.g. Galí and Gertler, 1999) is obtained as a special case of (26) and (28) when $\phi = 0$ and $\delta = 0$. Parameter ϕ governs the curvature of the disutility of work, see equation (8). When $\phi = 0$, disutility of work is linear in hours worked. The marginal disutility of work, as in Krause and Lubik (2005), then is constant and the firm's unit wage costs do not increase in its own production level. Consequently, the strategic complementarity channel by which wage increases limit the incentives to cut prices is absent if $\phi = 0$.

Parameter δ stands for the probability that a match is separated prior to production in which case a firm ceases to exist. The probability of separation leads firms to implicitly discount the future more intensively than consumers owing to the firms' lower survival probability.[20]

[19] The presence of the employment gap originates from the assumption that consumers explicitly value product diversity, cp. equation (3). The remaining findings of the paper do in no way rest on this assumption.

[20] Indeed, estimates of new Keynesian Phillips curves for the US and other economies consistently find reduced form discount factors significantly well below standard calibrations (of 0.99 on a quarterly basis, say), see *e.g.* Galí and Gertler (1999), Galí, Gertler, and López-Salido (2001) and Gagnon and Khan (2005). The

It is reasonable to assume a curved disutility of work, $\phi \in [1, 10]$ say, identified on the basis of low Frisch elasticities, and a not too small interest elasticity of demand, $\frac{1-\varrho}{\sigma}$. In addition, a value of $\epsilon = 5$ seems a lower bound for the price elasticities found in the literature.[21] In this case the factor $\frac{\phi + \frac{\sigma}{1-\varrho}}{1+\phi\epsilon}$ is smaller than unity, reflecting an increase in strategic complementarity in price setting relative to the "benchmark model", exactly as in Woodford (2003, Chapter 3). The degree of strategic complementarity rises as the elasticity of demand increases which substantially dampens the effect of aggregate shocks on inflation. Similar multiplicative factors, albeit clearly with other parametric forms, are found also in the remaining real rigidities literature (see e.g. Eichenbaum and Fisher, 2004).

Altig, Christiano, Eichenbaum, and Linde (2005) find that, in reduced form, their model with firm-specific capital is observationally equivalent to the same model with perfectly competitive factor markets. From an econometric point of view, these two models are therefore not identifiable from macro-data alone. An advantage of the setup in the current paper is that the factors driving the degree of strategic complementarity in price-setting do not only appear in the Phillips curve but also elsewhere in the model. Most notably the elasticity of demand, ϵ, and the curvature of the disutility of work, ϕ, also figures in the wage equation, and the risk aversion and habit persistence parameters, σ and ϱ, are prominent in the IS equation (the consumption Euler equation). Cross-equation restrictions therefore identify these parameters.

Recalling that

$$\widehat{\Lambda}_t = \frac{1}{1+\phi\epsilon}\left\{\phi\,[\widehat{y}_t^{gap} - \widehat{n}_t^{gap}] + \frac{\sigma}{1-\varrho}\,[\widehat{y}_t^{gap} - \varrho\widehat{y}_{t-1}^{gap}]\right\},$$

a novel feature in this paper is that an "employment gap" enters as an additional explanatory variable for inflation in the Phillips curve. 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).[22]

In the model, two further optimality conditions are altered relative to the benchmark in Trigari (2006). Vacancy posting is affected by the gap between the optimal wage and the average wage rate.[23] As emphasized earlier, an increase in strategic complementarity in price-setting has a bearing on the law of motion for aggregate wages, too. Merging the price-setting and wage bargaining sectors induces real wage rigidity over and above the nominal rigidity which exists by assumption.

This contrasts with both Krause and Lubik (2005) and Trigari (2006) find that Mortensen and Pissarides (1994) type matching frictions add little real rigidity to the New Keynesian model.

current model provides a reason for this: as the separation rate, δ, increases so does the "excess discounting".

[21] Usually, the elasticity of demand, ϵ is calibrated to be much larger than 5. Woodford (2003) uses a value of 7.6, Altig, Christiano, Eichenbaum, and Linde (2005) use a value of 101.

[22] Galí and Gertler (1999) find that using conventional output gap measures, the slope of the Phillips curve is negative, implying $\varphi > 1$, which violates the constraint imposed by theory. Whether the bias by omitting the employment gap is so severe, that the inclusion of the employment gap solves this problem, is an issue for future research.

This is due to the separation of sectors in Trigari and the linearity of disutility of work in Krause and Lubik. The advantage of my formulation of the model is that it links the real rigidities debate to labor-market fluctuations. The next paragraph higlights the cross-equation restrictions that arise.

In general, the wage equation looks somewhat inaccessible. Intuition can be gained by restricting the analysis to the case where the real hourly wage equals the workers' marginal rate of substitution in steady state, "$w = mrs$".[24] The linearized aggregate real wage index, $\widehat{w}_t$, evolves according to

$$\begin{aligned}\widehat{w}_t = & \frac{1}{\alpha_1} E_{t-1} \left\{ \alpha_2 \left(\widehat{w}_{t-1} - \widehat{\pi}_t + \gamma_w \widehat{\pi}_{t-1} \right) + \alpha_3 (\widehat{w}_{t+1} + \widehat{\pi}_{t+1} - \gamma_w \widehat{\pi}_t) \right\} \\ & + \frac{1}{\alpha_1} E_{t-1} \left\{ \alpha_4 \left(\widehat{\theta}_t + \widehat{\kappa}_t \right) - \alpha_5 \widehat{\lambda}_t + \widehat{y}^a_t \right\}.\end{aligned} \tag{30}$$

All the coefficients are strictly positive.[25] The qualitative features of wage equation (30) are similar to the benchmark model: real wages increase in output per worker, $\widehat{y}^a_t$, and vacancy posting costs, $\widehat{\kappa}_t$. Real wages also rise in consumption per capita (*i.e.* they fall with the marginal utility of consumption, $\widehat{\lambda}_t$). Furthermore, real wages increase in market tightness, $\widehat{\theta}_t$.

An additional mechanism of the model is that real wages are subject to smoothing. For one thing real wage smoothing is represented by the positive parameters α_2 and α_3. The degree of real wage smoothing, not surprisingly, increases as wages and prices are updated less often: α_2/α_1 and α_3/α_1 increases when the average duration of prices and wages, $\frac{1}{1-\varphi}$, rises. At the same time the influence of market tightness, vacancy posting, marginal utility of consumption and production per worker all decrease.

More novel, equation (30) reveals a further cause for wage stickiness: The larger the elasticity of demand, ϵ, the more does the influence of market tightness fall, and the less important are fluctuations in vacancy costs and in output per worker (as the elasticity of demand ϵ increases,

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[23] The vacancy posting equation can be expressed as

$$\begin{aligned}\widehat{q}_t = E_{t-1} \left\{ \widehat{\kappa}_t + \widehat{\lambda}_t \right\} & - [1-(1-\delta)\beta] E_{t-1} \left\{ \widehat{\lambda}_{t+1} \right\} - (1-\delta)\beta E_{t-1} \{ \widehat{\kappa}_{t+1} + \widehat{\lambda}_{t+1} - \widehat{q}_{t+1} \} \\ & - [1-(1-\delta)\beta] E_{t-1} \left\{ \widehat{\psi}^*_{t+1} \right\} \\ & - \frac{\varphi}{J} \frac{1}{1-\tilde{\beta}} y^a \left[\epsilon \left(1 - \frac{w}{z} \right) - 1 \right] E_{t-1} \{ (1-(1-\delta)\beta) \widehat{p}^*_{t+1} + \widehat{\pi}_{t+1} - \gamma_p \widehat{\pi}_t \} \\ & - \frac{\varphi}{J} \frac{1}{1-\tilde{\beta}} y^a \frac{w}{z} E_{t-1} \{ \widehat{w}_{t+1} - \widehat{w}_t + \widehat{\pi}_{t+1} - \gamma_w \widehat{\pi}_t - \{1-(1-\delta)\beta\} [\widehat{w}_{t+1} - \widehat{w}^*_{t+1}] \}.\end{aligned} \tag{29}$$

and simplified further to yield

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

[24] This exercise is meant to build intuition only. Neither do any other relations presented so far depend on the assumption that in steady state $w = mrs$ nor is this condition imposed in the empirical analysis in Section 4.

[25] $\alpha_2 = \frac{1}{\eta} \frac{\epsilon-1}{1-\varphi} \frac{\varphi}{1-\beta(1-\delta)\varphi}$, $\alpha_1 = \alpha_2 \frac{1+\beta(1-\delta)\varphi(\varphi-\bar{s})}{\varphi}$, $\alpha_3 = \alpha_2 \beta (1-\delta)(1-\bar{s})$, $\alpha_4 = \frac{\beta(1-\delta)\bar{s}}{1-\beta(1-\delta)}$, $\alpha_5 = \frac{1-\eta}{\eta} \frac{\epsilon-1}{1+\phi}$.

α_4/α_1 and $1/\alpha_1$ fall while all other ratios are not affected). Similarly, an increase of the curvature of the disutility of work, ϕ, reduces the influence of marginal utility (α_5/α_1 falls) while not affecting any of the other ratios. The same two parameters which are instrumental in increasing strategic complementarity in price-setting and thus real rigidity therefore also induce a smooth wage rate, i.e. curb the response of wages to its aggregate driving forces like market tightness and aggregate output.

This is the main point of the current paper: when integrating the wage and price-setting into one and the same sector, real rigidities result which lead to both smooth prices,[26] and smooth wage rates. The same parameters which cause inflation to react less to aggregate shocks cause wage rates to react by less. The smoother wage rate in my model causes aggregate fluctuations to translate into larger amplitudes of a firm's period profits. Fluctuating profits, in turn, mean fluctuating incentives to post vacancies and thus mean volatile vacancy and unemployment series; see also Shimer (2004) among others. The next section assesses the fit of this mechanism econometrically.

4 Evaluating the Model

The inert and mild response of inflation has been well documented in a rich literature concerned with monetary policy structural vector autoregressions (SVARs), see e.g. Rotemberg and Woodford (1997), Christiano, Eichenbaum, and Evans (2005), Amato and Laubach (2003), Boivin and Giannoni (2005) and Meier and Mueller (2005). These results therefore provide a natural benchmark against which to frame the assessment. My measure of fit of the model is whether it can to a reasonable extent match the impulse responses to a monetary policy shock identified in a monetary SVAR. This exercise is partial in the sense that I abstract from identifying any aggregate shocks in the economy apart from monetary policy shocks, $\widehat{\epsilon}_t^{\text{money}}$. Yet the exercise is general equilibrium in that it brings the entire model structure to bear on this partial aspect of the data.

As highlighted in Section 3 in contrast to real rigidities arising from firm-specific capital (see Altig, Christiano, Eichenbaum, and Linde, 2005), in the setup with temporarily firm-specific labor, the parameters which raise the degree of strategic complementarity in price-setting do not only feature in the Phillips curve but also in the wage equation. In addition, my setup also alters the vacancy posting equation relative to, e.g., Trigari (2006). A partial equilibrium analysis examining only some equations of the model, say the Phillips curve as in Eichenbaum and Fisher (2004), would not be adequate for analyzing the mechanism. The entire model structure needs to be taken into account even when focussing on just one conditional correlation in the data.

The identification assumption in the VAR is standard and in line with the model presented above: apart from the interest rate, $\widehat{R}_t$, non of the observable variables (output $\widehat{y}_t$, inflation $\widehat{\pi}_t$, total hours worked $\widehat{h}_t + \widehat{n}_t$, vacancies $\widehat{v}_t$, the unemployment rate $\widehat{u}_t$ and the real wage rate $\widehat{w}_t$) react to a monetary policy shock in the same quarter.

[26] The impact on price-setting has been emphasized by Woodford, 2003 in a different but related setup, see the introduction.

The Estimation Procedure. The econometric methodology consists of selecting the structural parameters which minimize the distance between the impulse responses of an SVAR to a monetary policy shock and those implied by the model. Focussing only on a subset of the data's properties which has been extensively studied 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 $\mathbf{\Psi}(\boldsymbol{\theta})$ be the impulse responses of the model evaluated at structural parameter vector $\boldsymbol{\theta}$ which belong to parameter space Θ. The estimator of the structural parameters is

$$\widehat{\boldsymbol{\theta}} = \arg\min_{\boldsymbol{\theta}\in\Theta} \left(\widehat{\mathbf{\Psi}} - \mathbf{\Psi}(\boldsymbol{\theta})\right)' W_T \left(\widehat{\mathbf{\Psi}} - \mathbf{\Psi}(\boldsymbol{\theta})\right), \tag{31}$$

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). The variances are based on 10,000 bootstrap estimates from the SVAR.

Implementation. I estimate a VAR from 1984q1, which marks the end of the non-borrowed reserves targeting episode and the Volcker disinflation, through 2005q3.[27] 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.[28] I take the civilian labor force of age 16 and over.[29] Table 4 in the Appendix provides the data sources.

Let $\mathbf{x}_t$ be the vector of observable variables. I estimate the VAR

$$\mathbf{x}_t = \mu + \mathbf{a}\,t + \sum_{j=1}^{4} A_j\,\mathbf{x}_{t-j} + \mathbf{u}_t. \tag{32}$$

Here μ is a vector of constants, $\mathbf{a}$ is a vector of coefficients, t is a time-trend, A_j are coefficient matrices and $\mathbf{u}_t$ is a vector of white noise shocks. The inclusion of the time-trend turned out not

[27] The volatility of aggregate real variables has decreased since the early 1980s; Kim and Nelson (1999) locate the break date in the amplitude of US GDP growth rates and the volatility of shocks to US 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 US macroeconomic time series. My sample start should safeguard against these structural breaks. In order not to restrict the sample too much, I include lags prior to 1984q1.

[28] 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.

[29] Francis and Ramey (2005) construct a labor force measure which corrects for (low frequency) demographic movements over the postwar period, which can be features of the civilian labor force 16+ measure. The use of their labor force series would have reduced the sample by 4 observations. Yet, as the sensitivity analysis in Appendix C shows, the results would be qualitatively unchanged. The low frequency movements seem to be more important for responses to technology shocks than for responses to monetary shocks, which are the focus of my paper. I thank Francis and Ramey for providing me with their labor force series.

to have any qualitative bearing on the impulse-responses reported below. 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.

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 (member of the labor force), the real wage rate and the nominal interest rate. The data used is as described in Table 6 in the Appendix.

Table 1 shows forecast error variance decompositions. For each variable featuring in the VAR each entry gives the percentage of forecast error variance that is attributable to the identified monetary policy shock. As can be inferred, the monetary policy shock accounts for a sizeable share of the fluctuation in these variables.

The model is calibrated to match independent evidence in the literature; see Table 2. Labor supply is not very elastic, $\phi = 10$ as in Trigari (2006). The value of $\sigma = 0.1$ is lower than the degree of risk aversion conventionally used. It is, however, close to the value of Boivin and Giannoni (2005). The current model equates a theoretical concept, non-durable consumption, with data on GDP. It therefore does not take into account other much more interest sensitive categories of consumption and GDP (like durable consumption and investment spending). A low σ corrects for this omission. See also the discussion on page 21. The calibration for the labor market is standard. The replacement rate, $\frac{b}{wh}$ is meant to include the value of home production similar to Hagedorn and Manovskii (2005). A key feature of my paper is that I assume price-setting frictions in line with microevidence (see Bils and Klenow, 2004): prices are reset on average twice a year, $\varphi = 0.5$. The weak response of inflation to a monetary shock is therefore left to be explained by real rigidities.

Only a small subset of parameters will be estimated: the smoothing coefficient ρ_m and the response to inflation γ_π, the degree of habit persistence ϱ, the elasticity of demand ϵ, wage indexation γ_w and worker bargaining power η as well as the weight of unemployment in matching α. I restrict the estimation 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

Table 2: Fixed Parameters and Calibration Targets

Parameter	Description	Value	Source
	Preferences		
ϕ	inverse of labor supply elasticity	10.0	Evidence collected in Card (1994); also used by Trigari (2006).
β	time-discount factor	0.99	$\sim$ average real rate of 4% p.a. in the data.
σ	degree of risk aversion	0.10	close to estimate in Boivin and Giannoni (2005).
	Labor Market		
δ	separation rate	0.08	Hall (1999), Trigari (2006).
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 (2006).

areas are 90% confidence intervals.

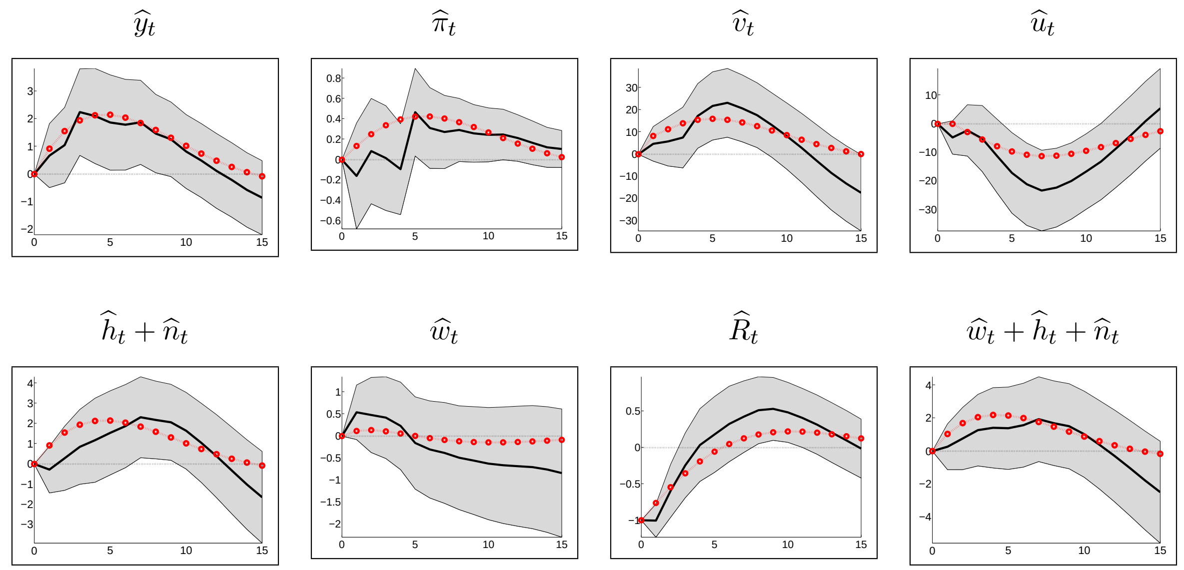
The model fits the data along the examined dimensions very well, in line with the results presented by Trigari (2004) and Braun (2005). The response of output to a monetary policy shock is hump-shaped and persistent. The strategic complementarity term in the Phillips curve (26) is estimated to be substantially smaller than unity: $\frac{\phi+\frac{\sigma}{1-\varrho}}{1+\phi\epsilon}\hat{=}0.06$. Even though prices are adjusted frequently, inflation thus shows a mild but lasting response to the monetary policy shock. 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 by and large matches the timing of the peak responses as well as the magnitude of the responses. 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 (2006), and in contrast to the results using productivity shocks in Fujita and Ramey (2005).[31] In my model, with probability φ firms entering production for the first

[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 response to a monetary policy shock – which 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 their model. In each period then there is 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.

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: output, 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 in the Appendix.

time have to set previous period's nominal wage which is only partially indexed to inflation. In a boom, for some of the new entrants this mechanism curbs the response of wage costs. A larger share of period profits flows to firms inducing more firms to enter in the first place. Partial wage indexation causes these incentives to persist over time and thus 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. Shimer (2004) and Hall (2005), 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 panel in Figure 1: the response of the real wage rate, $\widehat{w}_t$, 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 these two papers, however, is not as robust as responses by the other variables. On a similar sample as Amato and Laubach (2003), for example Giannoni and Woodford (2005) obtain that the percentage

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

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 yet another order of magnitude smaller than the response which I find. My estimates therefore are bracketed by the results in the literature. Appendix C reports impulse responses and implied structural model parameters for SVARs estimated on alternative data sets.[33]

While the response of the real wage rate is subject to some uncertainty when changing the measure used for the hourly wage rate, 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. The model marvellously reproduces the response of implied total wages to a monetary policy shock for all data sets. The responses do not inherit the sensitivity surrounding the choice of measure for the real wage rate; see the bottom right panel in Figure 1 and the same panels in the figures reported in the sensitivity analysis (Appendix C).

Parameter Estimates. The main point of the current paper is to show that when integrating wage and price-setting setting into one and the same sector, real rigidities result which lead to both smooth prices and smooth wage rates. This is corroborated by the impulse responses in Figure 1. The model manages to reproduce both the small reaction of inflation and of wage rates to a monetary shock. Section 3 highlighted from a theoretical angle that the same parameters which cause inflation to react less to aggregate shocks, most notably the curvature of disutility of work φ and the elasticity of demand ϵ, cause wage rates to react by less. The smooth wage rate in my model causes aggregate fluctuations to translate into fluctuations of a firm's period profits. Fluctuating profits, in turn, mean fluctuating vacancies and thus mean a volatile vacancy series, as desired and evident in Figure 1.

Turning to the estimates $\widehat{\theta}$ of the structural parameters underlying the impulse responses, Table 3 confirms that these estimates are in line with other studies. The literature allows for a sizeable range of the own-price elasticity of demand, ϵ, which is an instrumental parameter for inducing real rigidity in my model. Only if demand is sufficiently elastic, marginal production costs react enough to curb the incentive for price changes. Values proposed in the literature run from $\epsilon = 6$ in Christiano, Eichenbaum, and Evans (2005), to a value of 11 (e.g. Boivin and Giannoni, 2005), to an own-price elasticity of $\epsilon = 101$ in Altig, Christiano, Eichenbaum, and Linde (2005).[34] The estimate of $\epsilon = 22.8$ in my model is reasonable and lies in the range of values just listed. Due to both, the implied 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 are in the order of only 0.6% of period production. Aggregate profits are estimated to be low, in line with Rotemberg and Woodford (1999).

[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 an 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. Confidence bands for the real wage rate response remain wide but depending on the data used wage rates may show a stronger response than in my benchmark data set.

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

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]
ϱ	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 (2005). 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 in the Appendix.
*) the lower bound for γ_π in the estimation was set to 1.01.

Turning to the remaining parameters, 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, Galí, and Gertler (2000).
The estimate of the degree of habit persistence, $\varrho = 0.97$, 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 the calibrated value of $\sigma = 0.1$ is substantially smaller than the value of unity usually assumed for the intertemporal elasticity of substitution in consumption. The estimate is, however, by and large in line with Boivin and Giannoni (2005).[35] One simplification 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", ϱ, 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 elasticity of substitution in investment spending as much as the intertemporal elasticity of substitution in consumption. See the discussions in Woodford (2003, Ch. 5) and Boivin and Giannoni (2005).[36]
Turning to the labor market parameters, micro-level estimates for the worker bargaining power, η, are hard to come by. On US macro-data Trigari (2004) estimates $\eta = 0.10$, while Braun (2005) obtains $\eta = 0.77$. 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 micro-data based estimates for the matching elasticity fall in the range from 0.5 to 0.7, and so does my estimate of $\alpha = 0.52$.

[35] Their sample ranges from 1979q3 to 2002q2. The estimates in Boivin and Giannoni (2005) in a similarly "small" model as mine are $\sigma = 0.08$ and $\varrho = 0.91$.

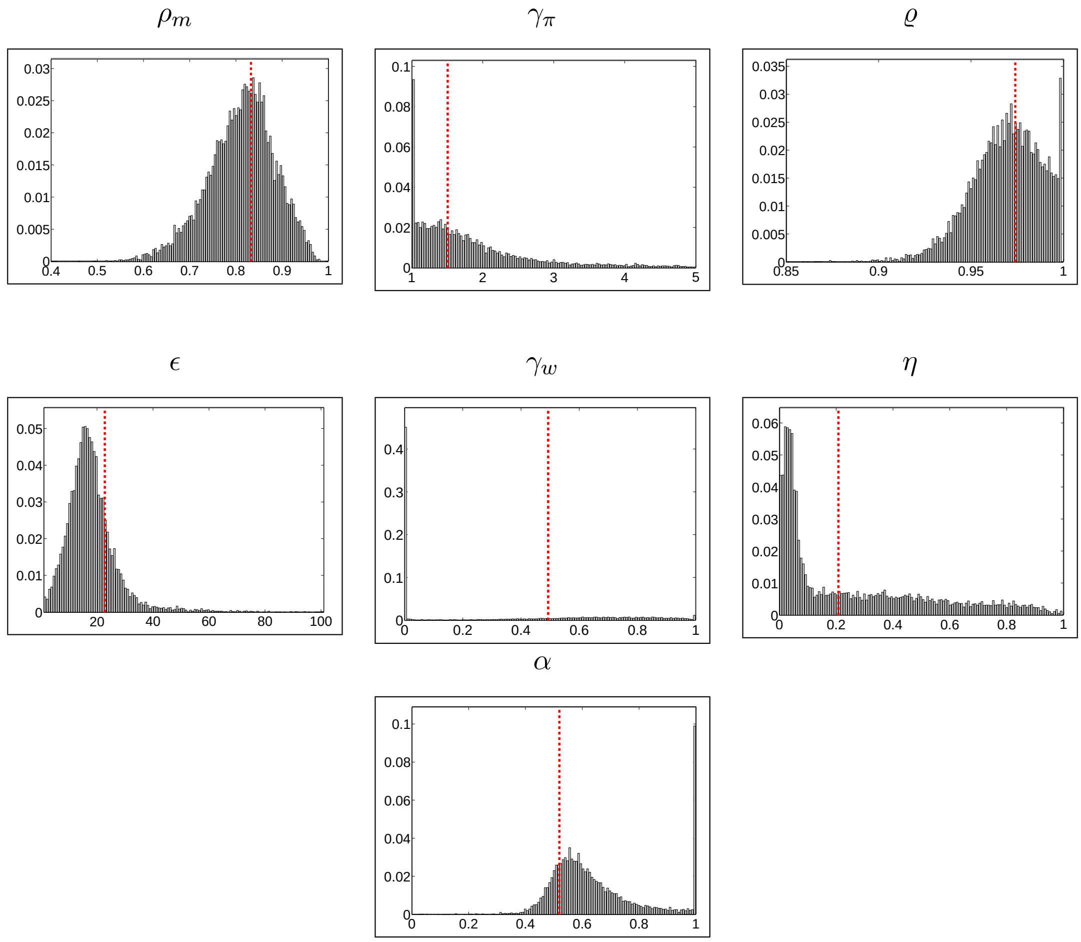
[36] Woodford (2003, Ch. 5) shows that a fixed-capital model and the more general model featuring adjustment costs for investment can be calibrated so as to generate almost identical and empirically credible impulse responses of inflation, output, interest rates and real marginal costs to a monetary shock.

Sampling Uncertainty of Parameters. The standard errors reported in Table 3 are based on the asymptotic normality of 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, so proper account is taken of the sampling errors that result at each stage of the estimation.

For about 9% of the estimates for the monetary policy feedback to inflation, γ_π, the imposed lower bound of 1.01 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).[37] 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.

[37] It goes without saying that they have a structurally different model and use a different sample).

Figure 2: Sampling Distribution of Estimated 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 (31) 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 ϱ, which focus on only part of the support for better readability. 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. No estimate was smaller than the lowest value reported in the plot. Similarly ϱ 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 the 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, ρ_m and γ_π respectively, of habit persistence, ϱ, the elasticity of demand, ϵ, wage indexation, γ_w, the bargaining power of workers, η, and the elasticity of matching w.r.t. unemployment, α.

5 Conclusions

This paper has illustrated that with equilibrium unemployment and matching frictions, strategic complementarities in price-setting naturally arise due to a temporarily firm-specific factor of production: labor. The matching framework thus induces a significant amount of real rigidity as is needed to reconcile macro-estimates of Calvo-type Phillips curves with microevidence. I conclude that leaving out the labor market from New Keynesian models is not necessarily an innocent assumption.

The most important result of this paper, however, is that the strategic complementarities in price-setting do not only induce smooth inflation. Even if wage rates are reset as frequently as prices are (on average every second quarter in my calibration), the resulting real wage series does not respond much to a sudden monetary easing and to the associated increase in aggregate demand and labor market tightness. The intuition rests on the assumption that wages are not set independently of the demand situation which the firm is facing. Especially if demand is relatively elastic, as may reasonably be argued is the case for many industries in times of increasing globalisation, the model predicts that both wages and inflation are smooth at the same time and for the same reasons. For the sake of the argument consider a worker contemplating to ask for a wage increase. All else equal an increase in the wage rate would lead to an increase in marginal production costs for the employer. Consequently the employer would pass part of the cost increase on to consumers by increasing the product price. This would cause a fall in demand and thus in hours worked per employee, which would lead to a smaller marginal disutility of work of the employee. This fall in the subjective price of work in turn would counteract the worker's incentive to ask for a wage increase in the first place. The same factors that drive the real (*price*) rigidity thus translate into significant real *wage* rigidity.

The smooth wage series thus implied helps to replicate the large fluctuations of vacancies found in US data, which have been the focus of much recent debate; see, for instance, Shimer (2004), Hall (2005), Hagedorn and Manovskii (2005) and Jung (2005). The paper has illustrated this fact in a structural VAR analysis. The modified model succeeds in replicating impulse responses to monetary shocks in post Volcker-disinflation US data even with price rigidity in line with micro-evidence.

The technical contribution of the paper was to directly integrate the wage bargaining into a sector which has a margin for price-setting but to retain *ex-ante* worker homogeneity. The modified model implies cross-equation restrictions for the key parameters governing real rigidity. It can thus be used to identify these parameters from macro-data in contrast to some of the firm-specific capital literature.

Throughout the analysis I have assumed that wages and prices are staggered á la Calvo and have the same durations, i.e. in each individual firm prices are reset whenever wages are and *vice versa*. In this respect one could explore to which extent the price and wage setting decisions can be uncoupled in a way that still keeps heterogeneity tractable.

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A Steady State and Calibration

The following sixteen equations (33) to (48) jointly characterize the steady state of the model.

A.1 Household conditions

Real rate: By Euler equation (6)

$$R = \frac{1}{\beta}. \tag{33}$$

Marginal utility of consumption:

$$\lambda = (1-\varrho)^{-\sigma} y^{-\sigma}. \tag{34}$$

Marginal rate of substitution:

$$mrs = \kappa_h \frac{h^{\phi}}{\lambda}. \tag{35}$$

Surplus of the worker: by equation (16)

$$\Delta = \frac{wh - \frac{mrs}{1+\phi}h - b}{1-\beta(1-\delta)(1-s)}. \tag{36}$$

A.2 Firm conditions

Value of the firm: by equation (12)

$$J = \frac{y^a - wh}{1-\beta(1-\delta)}. \tag{37}$$

Vacancy posting: by equation (9)

$$J = \frac{\kappa}{\beta q(1-\delta)}. \tag{38}$$

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

$$\eta J = (1-\eta)\Delta. \tag{39}$$

Price FOC: by equation (20), using the steady state expressions for the partial derivatives involved,

$$mrs = \frac{\epsilon - 1}{\epsilon} z. \tag{40}$$

A.3 Matching Market

Number of employees: by equation (14)

$$\delta n = (1-\delta)m. \tag{41}$$

Number of unemployed: by equation (15)

$$u = 1 - n. \tag{42}$$

Number of matches: by equation (13)

$$m = \sigma_m \, u^{\alpha} v^{1-\alpha}. \tag{43}$$

Probability of finding a job:

$$s = \frac{m}{u}. \tag{44}$$

Probability of finding a worker:

$$q = \frac{m}{v}. \tag{45}$$

A.4 Goods market clearing

Average production:

$$y^a = zh. \tag{46}$$

Final good supply: by equation (25)

$$y = nzh. \tag{47}$$

Final good demand:

$$c = y. \tag{48}$$

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 and fix a steady state unemployment rate as described in Table 2. I set 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 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 aggregation).
Interest rate	FEDFUNDS	Effective Federal Funds Rate monthly average, % p.a. quarterly average of monthly figures (own aggregation).
Nominal wage rate	AHETPI	Average Hourly Earnings: Total Private Industries monthly, seasonally adjusted, dollars per hour quarterly average of monthly figures (own aggregation).
Labor Force	CLF16OV	Civilian Labor Force, 16 years and over monthly, seasonally adjusted, thousands quarterly average of monthly figures (own aggregation).
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 aggregation).
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.

Notes: Unless explicitly stated otherwise, all data were obtained form the Federal Reserve Bank of St. Louis database FRED.

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), provided by the authors.
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.

Notes: See table 4.

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

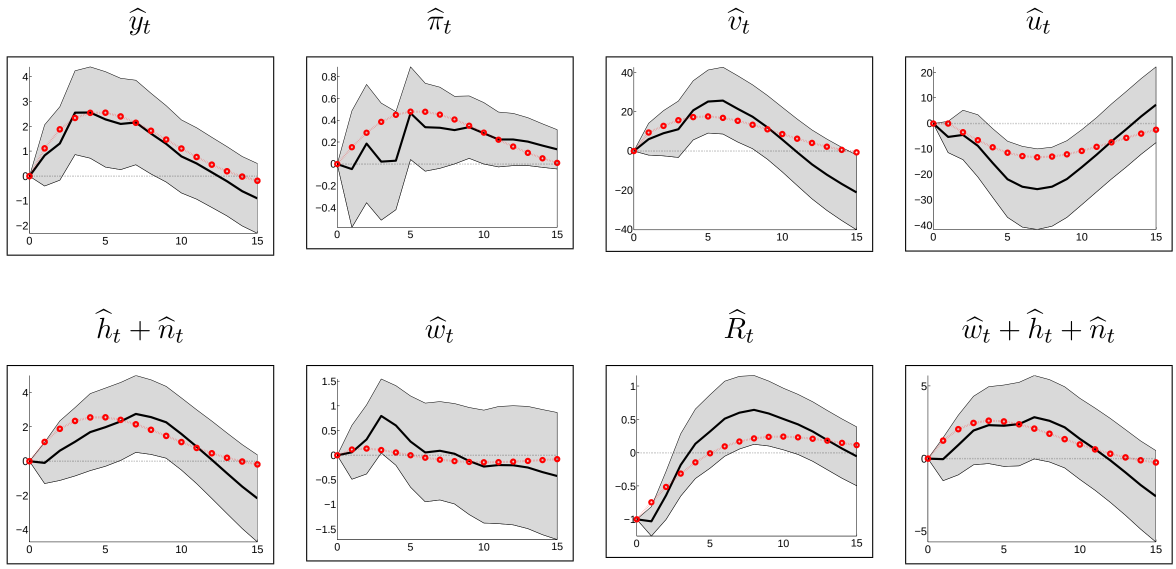
C.1 Case 2

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 (2005). 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.

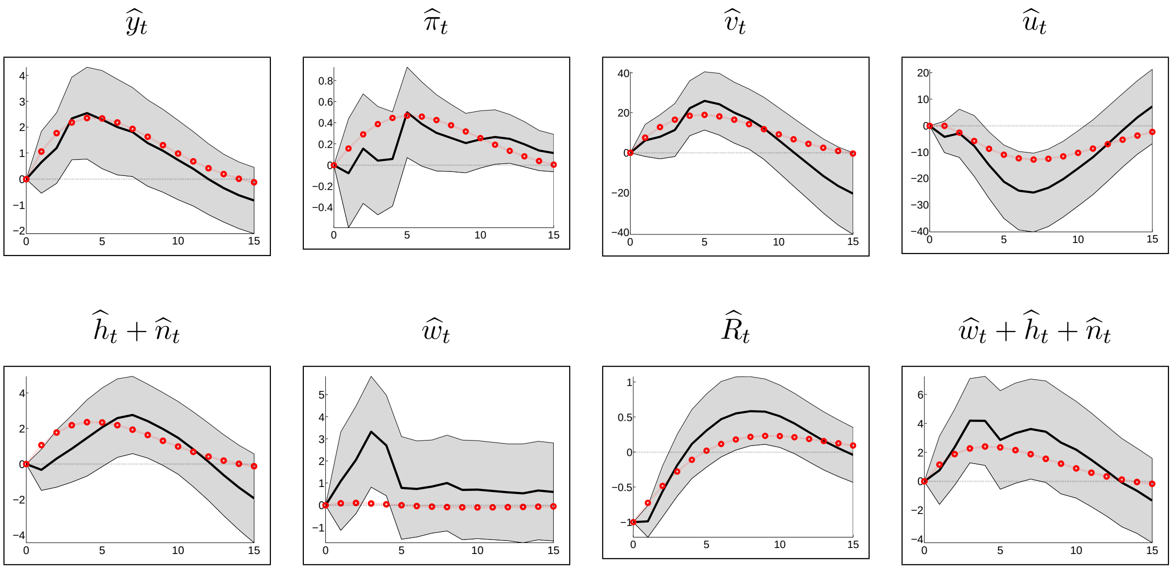
C.2 Case 3

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 (2005). 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.

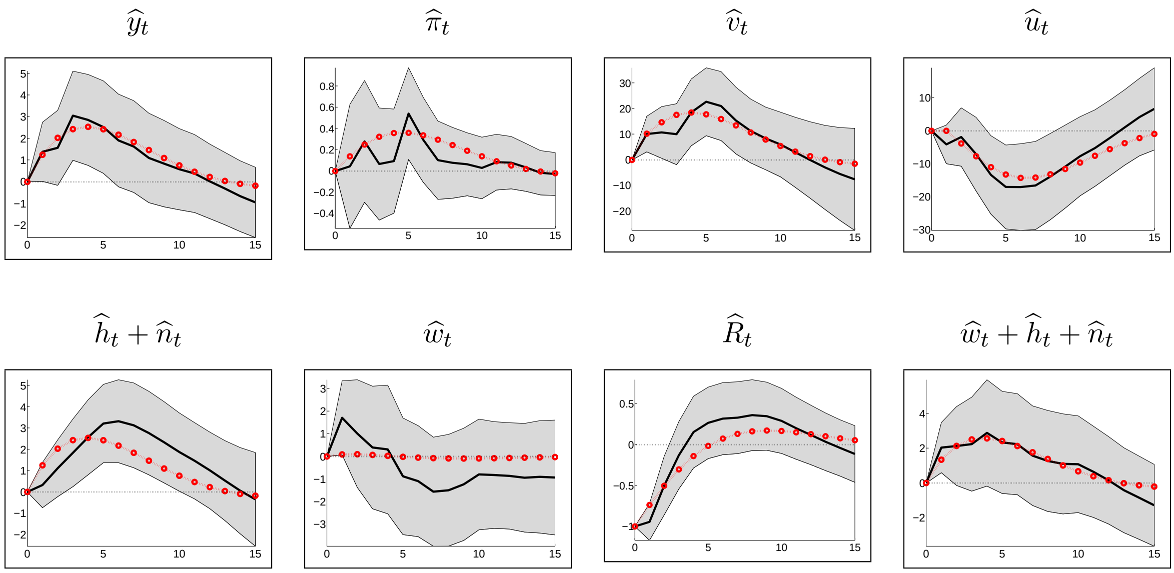
C.3 Case 4

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 (2005). 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.

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