(Un)Employment Dynamics: The Case of Monetary Policy Shocks*

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Abstract

This paper estimates an identified VAR on US data to gauge the dynamic response of the job finding rate, the worker separation rate, and vacancies to monetary policy shocks. I develop a general equilibrium model that can account for the large and persistent responses of vacancies, the job finding rate, the smaller but distinct response of the separation rate, and the inertial response of inflation. The model incorporates labor market frictions, capital accumulation, and nominal price rigidities. Special attention is paid to the role of different propagation mechanisms and the impact of search frictions on marginal costs. Estimates of selected parameters of the model show that wage rigidity, moderate recruiting costs, and a high value of the opportunity costs of employment are important in explaining the dynamic response of the economy. The analysis extends to a broader set of aggregate shocks and can be used to understand and design monetary, labor market, and other policies in the presence of labor market frictions.

1 Introduction

Empirical research shows that a key to understanding business cycle fluctuations lies in labor market frictions (Hall (1997), Galí, Gertler, and Lopez-Salido (2002), Christiano, Eichenbaum, and Evans (2005)). Knowledge of the exact nature of these frictions is necessary to design, for example, labor market and monetary policies (Levin, Onatski, Williams, and Williams (2005)). Candidate labor market frictions are contractual frictions and the time and resource costs associated with searching for suitable employment relationships. Although the integration of search frictions held promise for the performance of business cycle models (Merz (1995), Andolfatto (1996)), the ability of the canonical Mortensen and Pissarides (1994) model to account for the strong cyclicality and persistence of vacancies, unemployment, and worker flows into and out of unemployment has recently been questioned (Shimer (2005a), Pries (2004), Fujita (2004)).

I develop and estimate a dynamic stochastic general equilibrium (DSGE) model that incorporates search frictions and wage rigidity. The model is consistent with the magnitude and persistence of the responses of key macroeconomic variables, including inflation, vacancies, and the inflows and outflows of unemployment, to a monetary policy shock. I use the model to assess the contribution of propagation mechanisms that are able to reconcile the Mortensen and Pissarides (1994) (MP) model with the data. I analyze the role of search frictions and wage rigidity in explaining the inertial response of inflation.

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I find that the mechanisms which are consistent with the amplitude and persistence of the responses of vacancies, unemployment, the job finding rate, the separation rate, and the inertial response of inflation are (i) *wage rigidity*, (ii) *large fixed opportunity costs of employment relationships,* (iii) *moderate recruiting costs*, and (iv) *adjustment costs in vacancy creation*. The analysis is relevant not just for monetary policy shocks, because unemployment, vacancies, and the job finding and separation rate respond similarly to other aggregate shocks (Fujita (2004), Fujita and Ramey (2005), Braun, De Bock, and DiCecio (2005)).

This paper contributes to the recent literature on the evaluation and reconciliation of the Mortensen and Pissarides (1994) model of search frictions and unemployment with worker flows and vacancy data that the model seeks to explain (see Mortensen and Nagypal (2005) for a summary). I develop new features and integrate ones already proposed in this literature. I formulate wage rigidity in a tractable way that nests the standard Nash-Bargaining solution used in the literature. I model vacancy adjustment costs that generate persistent, hump-shaped responses of vacancies and the job finding rate. Furthermore I analyze the role of overhead and turnover costs. I include capital accumulation and model worker separations into unemployment.

The bulk of the literature has ignored the separation margin of employment adjustment and framed the analysis in partial equilibrium. Even though the hiring margin is quantitatively more important, separations are not acyclical and clearly react to monetary policy and other shocks. The separation decision is an economic one and should be part of any attempt to model worker flows. I find that ignoring the behavior of worker separations into unemployment is not only inconsistent with the data but may lead to erroneous conclusions about the mechanisms at work. In addition, explicitly modelling capital costs as part of the surplus value of firms and workers clears up some misconceptions about the role of 'capital overhead' costs.

Another contribution of this paper lies in the extension of the analyses of search frictions in New-Keynesian models.[1] Closely related is the estimated DSGE model of Trigari (2004), who studies job flows data. Job flows data point to a more volatile separation margin of employment adjustment.[2] Adjustment on this margin can be relatively cheap and an evaluation of the role of search frictions based on job flows may lead to different conclusions. Instead, I focus on the nature of the propagation mechanisms that can account for inflation inertia in conjunction with the observed responses of worker flows data and vacancies. Capital and investment are included in the analysis because – in addition to recruiting costs, the costliness of separations, and the wage – capital utilization costs are a key determinant of marginal costs and hence the response of inflation.

To estimate parameters of the model and identify the dynamic response of the economy to a monetary policy shock, I follow the limited information strategy in Christiano, Eichenbaum, and Evans (2005) (CEE). I identify monetary policy shocks in a vector autoregression (VAR) representation of postwar US aggregate, worker flow, and vacancy data. The identification strategy assumes that the nominal interest rate reacts contemporaneously to monetary policy shocks while the variables ordered before the interest rate do not. The VAR includes output, the price level, hours, wages, the nominal interest rate, investment, consumption, measures of job finding and worker separation rates constructed by Shimer (2005b), and a measure of vacancy posting.

The estimated responses of inflation and other aggregate variables are consistent with those reported in CEE and consistent with estimates using alternative specifications and identifying assumptions (Christiano, Eichenbaum, and Evans (1999), Uhlig (2005)). The estimated responses of the job finding rate, unemployment, and vacancies are hump shaped, large, and persistent. The response of the worker separation rate is distinct but less persistent, and contributes up to one third of changes in unemployment. These results are consistent with

[1] See Cooley and Quadrini (1999), Cheron and Langot (2000), Krause and Lubik (2003), Walsh (2005), Trigari (2004) and Christoffel, Kuester, and Linzert (2005), who estimate Trigari (2004)'s model using a Bayesian approach on German data. For an analysis in the absence of nominal price stickiness see Nason and Slotsve (2004).

[2] For a comparison of the cyclical properties of job and worker flows data see Braun, De Bock, and DiCecio (2005). The finding that job destruction contributes more to employment changes is not necessarily at odds with the findings from worker flow data, as job destruction pertains to employment losses at contracting establishments and does not imply that the main margin of adjustment is an increase in worker separations.

the responses to embodied technology, neutral technology, demand, and monetary shocks identified using sign restrictions in Braun, De Bock, and DiCecio (2005) and the responses to an aggregate shock estimated in Fujita (2004) and Fujita and Ramey (2005). A key feature of worker flows is the strong cyclicality and persistence of the job finding rate of unemployed workers and vacancy posting activity by firms. Stated differently, aggregate shocks entail large and persistent movements along the Beveridge curve.

The dynamic general equilibrium model used to understand these responses incorporates a frictional labor market based on Mortensen and Pissarides (1994) in a New-Keynesian model along the lines of CEE. Search and matching frictions, endogenous worker separations, wage and price rigidities, variable capital utilization, and investment and vacancy adjustment costs are key features of the model. Monetary policy follows a Taylor rule.

I estimate the model parameters that govern the dynamic response of the economy using a limited information minimum distance estimator. The parameters are chosen such that the model impulse responses match the empirical impulse responses as closely as possible, where more weight is attributed to the responses which are estimated more precisely. The estimated model impulse response functions are able to match their empirical counterparts reasonably well.

The sectoral structure of the model is similar to Trigari (2004). A monopolistically competitive intermediate good sector with nominal price rigidities in its output market uses homogenous goods produced by matched firm-worker pairs ('jobs') as an input. In the job sector, firms post vacancies in order to hire unemployed workers in a frictional labor market. The job finding probability of unemployed workers is increasing in the number of vacancies relative to the size of the pool of unemployed and searching workers. Endogenous worker separations into unemployment are due to idiosyncratic shocks to the match value.

Costly search and matching creates a quasi-rent for existing jobs that can be shared between firm and worker via a wage payment. This rent creates the scope for wage rigidity that is consistent with the participation constraints of firms and workers. Although the wage does not have allocational consequences for existing matches, it determines the magnitude of the response of firms' profits to aggregate shocks and hence vacancy posting and the creation of employment relationships. Hall (2005) and Shimer (2004) argue that the MP model's shortcomings in accounting for the large reaction of vacancies and the job finding rate to reasonably sized shocks can be attributed to the standard assumption of wage determination via Nash-Bargaining. Along the lines suggested in Hall (2005), I model wage rigidity in a tractable way that nests the Nash-Bargaining solution.

The estimated degree of wage rigidity contributes considerably to the model's ability to match the empirical responses of vacancies and the job finding rate and is consistent with the weak response of wages. However, high wage rigidity alone does not suffice to explain the responses of the labor market variables, including separations. The opportunity costs of employment must also be high. Wage rigidity alone may induce an eventual increase of separations after an expansionary shock. The reason lies in the participation constraint of the worker. If wage rigidity is high, firms' vacancy posting reacts strongly to shocks. This increases the value of workers' outside job-opportunities through an increase in the job finding rate and may *decrease* the worker's surplus value of the match. The effect can be strong enough to *reduce* the joint continuation value of a firm-worker match and hence increase worker separations into unemployment, which is incompatible with the data. The value of the participation constraint of the worker encompasses not only the value of outside job opportunities, but also of the opportunity costs of employment – for example in the form of unemployment benefits, the value of home production, and the disutility of work net of the disutility of search. A high value of non-responsive opportunity costs of employment implies that the response of the participation constraint of the worker is relatively small. Then, the counterfactual effect on separations into unemployment described above is absent. Accordingly, the estimate of the opportunity costs of employment is high relative to standard calibrations of the MP model.

Furthermore, any unresponsive cost components of the match, such as fixed overhead, firing, and training costs in addition to the opportunity costs listed above increase the response of firms' surplus value of a filled job and hence of hiring activity to aggregate shocks. In the form of workers' opportunity costs, this mechanism is stressed by Hagedorn and Manovskii (2005) in a model without endogenous separations. In the form of fixed capital costs, it is employed by Mortensen and Nagypal (2005) and Fujita and Ramey (2005). Training costs appear in the hiring adjustment cost specification of Yashiv (2005).

Another shortcoming of the MP model is its inability to explain the persistence of vacancies and the job finding rate. In response to a positive aggregate shock, the unemployment pool diminishes quickly as unemployed workers find jobs. In the standard calibrations of the MP model, recruiting costs increase and vacancy creation and hiring activity slump. I show that adjustment costs in the growth rate of vacancies generate persistent and hump shaped responses of vacancies and the job finding rate. This formulation can be interpreted as a reduced form of a 'time-to-build' model of vacancy creation as discussed below. Yashiv (2005) also assumes adjustment costs in vacancy creation and hiring activity. Fujita and Ramey (2005) make vacancies a state variable by assuming that vacancy creation is associated with sunk costs and show that – together with large fixed overhead costs and recurrent job loss – the persistence of vacancies and the job finding rate increases.

In Section 2, I discuss the construction of the separation and job finding rates and present the estimated impulse responses of the VAR to a monetary policy shock. Section 3 lays out the model. In Section 4, I present the estimates of parameters of the model that govern the dynamic responses of the variables of interest. Section 5 discusses the results and the mechanisms at work. I change parameter values from the point estimates to understand the contribution of the propagation channels and conduct a sensitivity analysis with respect to the values of calibrated parameters. Section 6 analyzes the role of overhead and training costs as sources of amplification. Section 7 extends and estimates a variant of the model that incorporates an intensive margin of hours adjustment. Section 8 concludes and suggests avenues for further research.

2 Structural VAR Analysis

2.1 Data

The quarterly data of the VAR analysis includes real GDP (Y), the GDP deflator (P), real wages (per capita, w) , hours (H), consumption (C), investment (I), the Fed Funds rate (R), a measure of vacancies (v), and job finding (hir) and separation probabilities (sep). In Section 7 I consider an alternative VAR specification by replacing hours with employment and average hours (per worker) to analyze the extensive and intensive margin of labor adjustment. Because the response of average hours is small, the response of total hours and employment are similar.

The separation and the job finding rate are obtained from Shimer (2005b).[3] The separation rate is constructed from CPS data on the short term unemployment rate. Using this separation rate, the job finding rate is constructed from differences in the unemployment pool across months. Both are adjusted for time-aggregation bias. Since they refer to exit rates from employment to unemployment and out of unemployment, flows between non-participation and the labor force are ignored.

In particular, assume that there are only worker flows between unemployment (U) and employment (E). Assume that the separation and job finding rates are constant within a time period $t, t+1$. Denote these Poisson arrival rates by $\widetilde{sep}_t$ and $\widetilde{hir}_t$ respectively. Consider the evolution of the unemployment pool at a date $\tau \in (0,1)$

[3] For additional details, please see Shimer (2005b) and his webpage http://home.uchicago.edu/~shimer/data/flows/. For the approach, see also Darby, Haltiwanger, and Plant (1985).

between periods t and $t+1$

$$\dot{U}_{t+\tau} = \underbrace{\widetilde{sep}_t E_{t+\tau}}_{\textbf{INFLOWS}} - \underbrace{\widetilde{hir}_t U_{t+\tau}}_{\textbf{OUTFLOWS}} , \tag{1}$$

where $\dot{X}_{t+\tau}$ denotes the time derivative.

The CPS contains data on the short-term unemployment of less than 5 weeks, U^s. Within a period, the pool of *short-term* unemployment evolves according to

$$\dot{U}^s_{t+\tau} = \widetilde{sep} E_{t+\tau} - \widetilde{hir}_t U^s_{t+\tau}, \tag{2}$$

where $U^s_{t+\tau}$ measures the pool of workers who have become unemployed since the beginning of period t.

Combining (1) and (2), and solving the resulting differential equation using $U^s_t = 0$ yields

$$U_{t+1} = U_t e^{-\widetilde{hir}_t} + U^s_{t+1} \tag{3}$$

Given data on U_t, U_{t+1}, and U^s_{t+1}, (3) can be used to construct the job-finding rate $\widetilde{hir}_t$. The separation rate then follows from

$$U_{t+1} = (1 - e^{-\widetilde{hir}_t - \widetilde{sep}_t}) \frac{\widetilde{sep}_t}{\widetilde{hir}_t + \widetilde{sep}_t} L_t + e^{-\widetilde{hir}_t - \widetilde{sep}_t} U_t, \tag{4}$$

where $L_t \equiv U_t + E_t$ is the labor force. Given the job finding rate $\widetilde{hir}_t$, and labor force data L_t and U_t, equation (4) uniquely defines the separation rate $\widetilde{sep}_t$. Note that the rates $\widetilde{sep}_t$ and $\widetilde{hir}_t$ are time-aggregation adjusted versions of $\frac{U^s_{t+1}}{E_{t+1}}$ and $\frac{U_t - U_{t+1} + U^s_{t+1}}{U_{t+1}}$ respectively. The construction of $\widetilde{sep}_t$ and $\widetilde{hir}_t$ takes into account that workers may experience multiple transitions between dates t and $t+1$. The corresponding probabilities used in the VAR are $sep_t = 1 - e^{-\widetilde{sep}_t}$ and $hir_t = 1 - e^{-\widetilde{hir}_t}$. These correspond to the separation and job finding rates in the discrete-time model formulated in Section 3.

Using a sample overlapping with BLS data constructed by Bleakley, Ferris, and Fuhrer (1999) that includes flows for the non-participation state, Shimer (2005b) shows that movements in the separation and job finding rates account for the bulk of unemployment and – to a lesser extent – employment changes. For a further discussion of the construction, business cycle properties, sensitivity to adjustments necessitated by the 1994 CPS redesign, and a comparison to job flows data see Braun, De Bock, and DiCecio (2005).

Figures 1 and 2 from Braun, De Bock, and DiCecio (2005) show the cyclical and trend behavior of the series, filtered using an HP filter with smoothing parameter 1600. Shaded areas denote NBER recession dates. Both job finding and separation probabilities show a strong cyclicality. Spikes in the separation rate are distinct during recessions, although their magnitude has decreased in the past two recessions.

For the VAR, I use quarterly averages of the monthly data. Vacancies are measured using the Conference Board Help Wanted Index, scaled by the labor force.[4] Figure 3 shows the business cycle and trend behavior of the vacancy series.

The sample used in the VAR covers the period 1954:Q3-2003:Q4. All variables in the VAR except for the Fed Funds rate have been logged. Details of the remaining data sources can be found in appendix A.

2.2 VAR Representation

Consider the following reduced form VAR:

$$Y_t = \mu + \textstyle\sum_{j=1}^{p} A_j Y_{t-j} + u_t, \ E u_t u_t' = V, \tag{5}$$

[4] Scaling by working age population did not lead to significant differences.

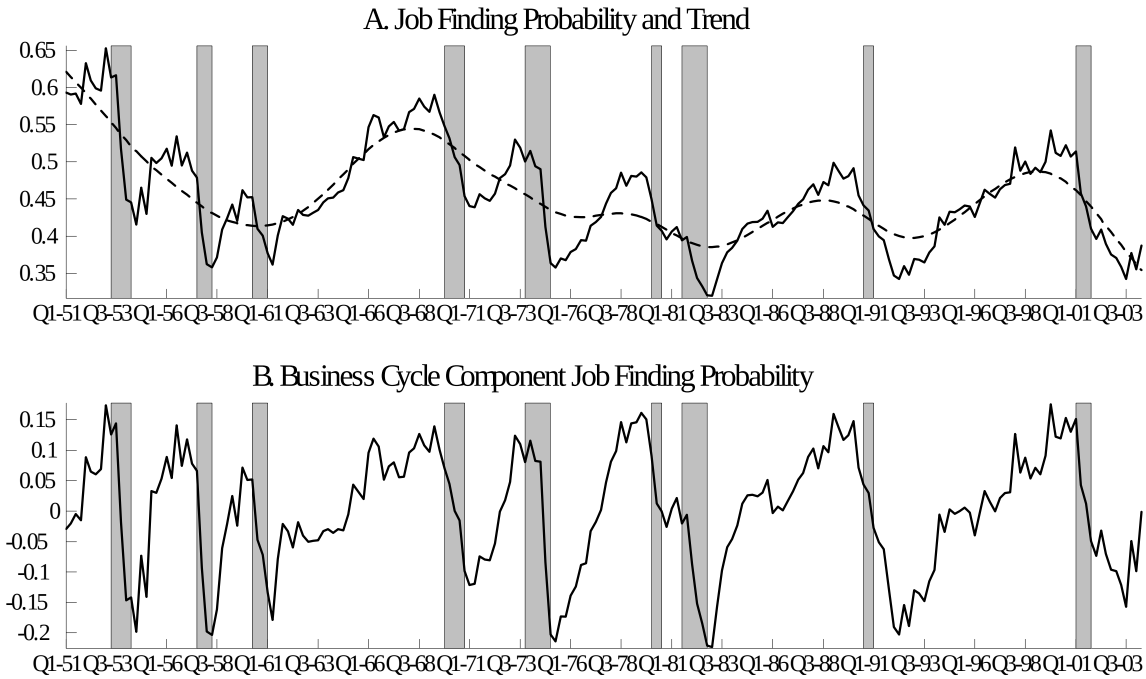

Figure 1: Job Finding Probability

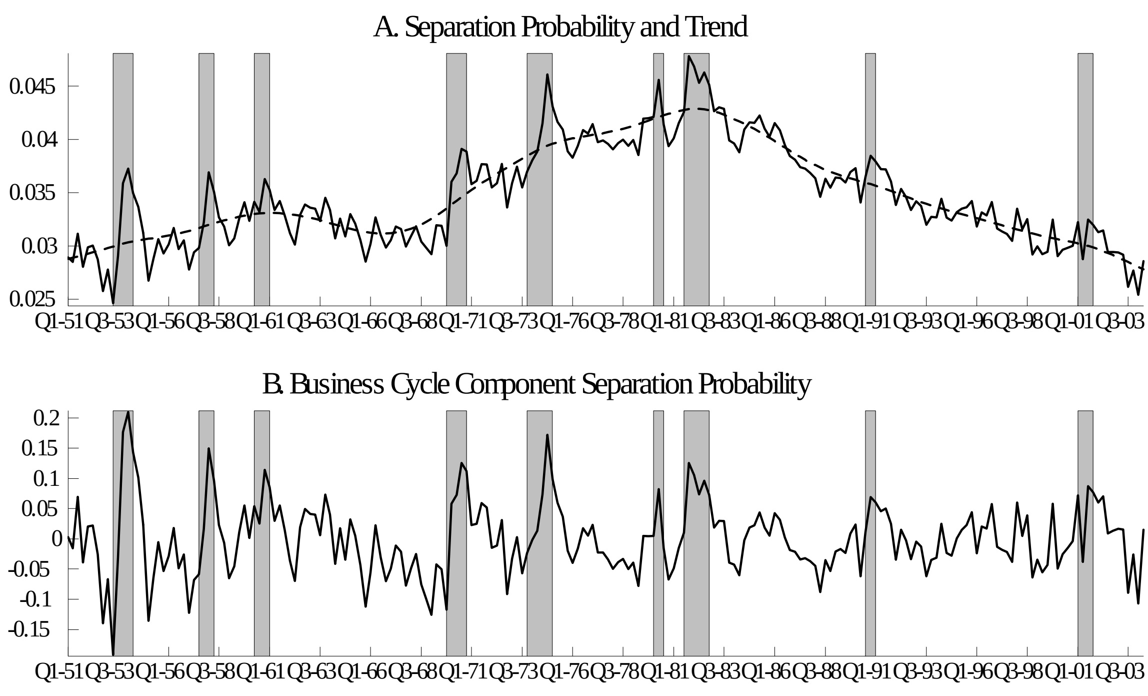

Figure 2: Separation Probability

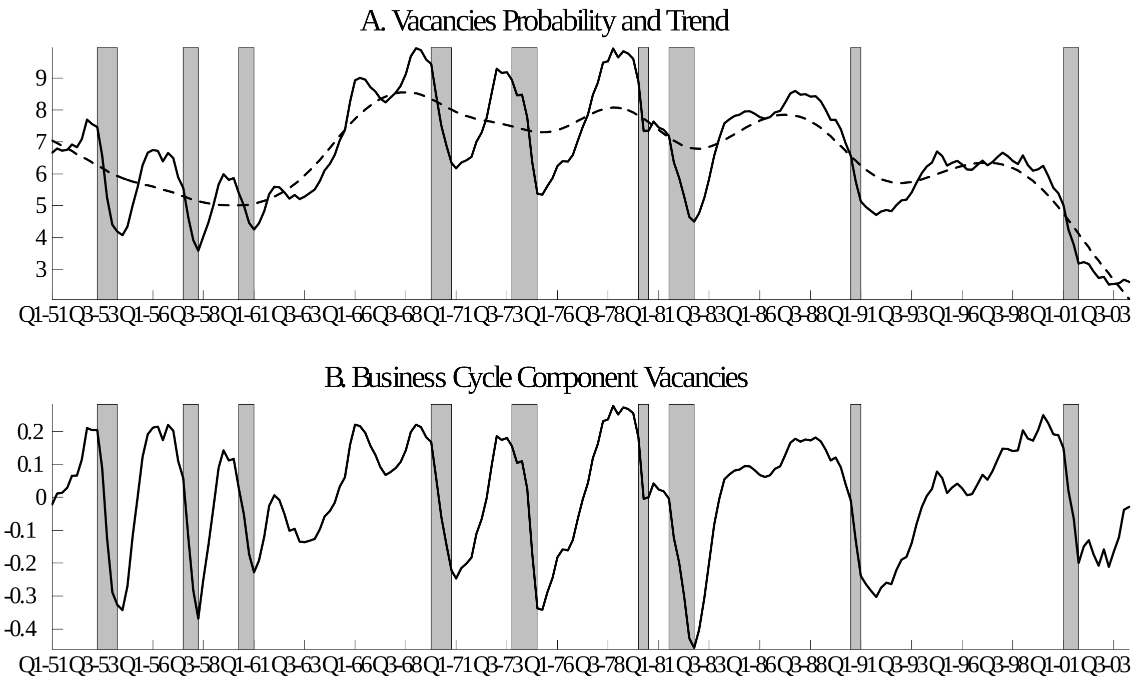

Figure 3: Vacancies

where p is the number of lags.

In the analysis that follows Y_t is defined as:

$$Y_t = \begin{bmatrix} \ln(Y_t), \ln(P_t), \ln(w_t), \ln(H_t), \ln(hir_t) \\ \ln(sep_t), \ln(v_t), \ln(C_t), \ln(I_t), R_t \end{bmatrix}'.$$

I estimate the reduced form VAR (5) including $p = 3$ lags using OLS.[5] The reduced form residuals, u_t, are related to the structural shocks, ϵ_t, by $\epsilon_t = A_0 u_t$ or equivalently by $u_t = C\epsilon_t$, where $C = A_0^{-1}$. The structural shocks are orthogonal to each other, i.e., $E\epsilon_t\epsilon_t' = I$. The last element of ε is the monetary policy shock; The remaining elements of ϵ_t are not identified. Monetary policy shocks are identified as in CEE by assuming that the 10^{th} column of A_0 has the following structure:

$$A_0(:, 10) = [0_{1\times 9}, a_0]'.$$

The identifying assumption can be interpreted as the monetary authority following a Taylor rule like policy, which responds to all the variables ordered before the interest rate in the VAR.

The solid lines in Figure 4 display the impulse response functions (IRFs) of output, inflation, the Fed funds rate, hours, the real wage, the job finding rate, the separation rate, vacancies, consumption, and investment to a one standard deviation monetary policy shock. Except for the responses of the nominal interest rate and inflation which are represented in annualized percentage point deviations, all variables are expressed in percentage deviations. The shaded areas are bootstrapped 95% confidence intervals around the point estimates. The alternative specification of the VAR within this identification framework that imposes cointegration relationships between variables (Altig, Christiano, Eichenbaum, and Lindé (2005)) did not alter the estimates of the impulse response functions considerably.

[5] The lag length was selected with the Akaike Information Criterion.

		4 quarters	8 quarters	20 quarters
Y	output	$9\,(3,18)$	$10\,(4,23)$	$6\,(3,18)$
π	inflation	$3\,(1,11)$	$3\,(1,10)$	$4\,(2,11)$
R	Fed Funds Rate	$20\,(11,25)$	$13\,(8,19)$	$12\,(7,18)$
H	hours	$8\,(3,18)$	$15\,(6,30)$	$12\,(5,25)$
w	wage	$1\,(.05,2)$	$1\,(0.3,2)$	$1\,(.09,2)$
hir	job finding	$5\,(1,11)$	$11\,(4,22)$	$9\,(4,19)$
sep	separations	$7\,(3,16)$	$9\,(4,16)$	$6\,(3,13)$
v	vacancies	$10\,(4,20)$	$14\,(6,27)$	$11\,(5,22)$
C	consumption	$1\,(.2,2)$	$2\,(.3,5)$	$2\,(.5,8)$
I	investment	$11\,(5,21)$	$12\,(5,24)$	$10\,(5,20)$

Table 1: Percentage of Variance of the Forecast Error due to Monetary Policy Shocks (95 percent bootstrapped confidence interval boundaries in parentheses)

The last panel shows the response of unemployment and the contributions of the separation and job finding probabilities to unemployment. Unemployment is approximated using the steady state relationship $u_{t+1} = \frac{\widetilde{sep}_t}{\widetilde{sep}_t + \widetilde{hir}_t}$. The approximation is very accurate for the aggregate data (Shimer (2005b)). The contributions of inflows and outflows are calculated using $\frac{\widetilde{sep}_t}{\widetilde{sep}_t + \overline{hir}}$ and $\frac{\overline{sep}}{\overline{sep} + \widetilde{hir}_t}$ respectively, where $\overline{hir}$ and $\overline{sep}$ are sample means.

In response to an expansionary monetary policy shock, the fall in the interest rate leads to a persistent, hump shaped increase in output, reaching a peak after about 5 quarters. Inflation initially *falls* before increasing slightly (the 'price puzzle'). The Fed Funds Rate returns to its steady state level after about 10 quarters. Similarly to output, hours respond in a hump-shaped manner, but show slightly more persistence. There is no clear response of the real wage. The job finding rate and vacancies exhibit strong hump shaped responses, while the separation rate's response is U-shaped and less persistent. Notice that the largest effect is reached earlier for the separation rate than for the job finding rate. In the early phase following the shock, separations contribute about one third to the change in unemployment. This is in line with the findings in Braun, De Bock, and DiCecio (2005) who identify a broader set of shocks using sign restrictions. The shape and magnitude of the responses of output, inflation, the Fed Funds rate, hours, consumption, and investment are consistent with those estimated in CEE.

Table 1 presents the percentage variance of the k-step ahead forecast errors due to monetary policy shocks. As discussed in CEE, these estimates are imprecise, sensitive to the VAR specification and should hence be interpreted with caution. Nevertheless, monetary policy shocks contribute a non-trivial fraction to the variance of the variables of interest.

The volatility of the job finding rate has increased relative to the separation rate (Shimer (2005b)). This may be connected to the past two 'jobless' recoveries. (Schreft and Singh (2003), Groshen and Potter (2003)). Furthermore, monetary policy or its transmission may have changed in the post Volcker period (Boivin and Giannoni (2002)). Overall, volatility of aggregate real variables has decreased since the early 1980's (Kim and Nelson (1999), Stock and Watson (2002)). I estimated a VAR on the post 1980:I sample: The magnitude of the monetary policy shock and the persistence of its effects are somewhat smaller and the price puzzle is absent. The fall in the separation rate is smaller relative to the increase in the job finding rate, but remains distinctly negative.

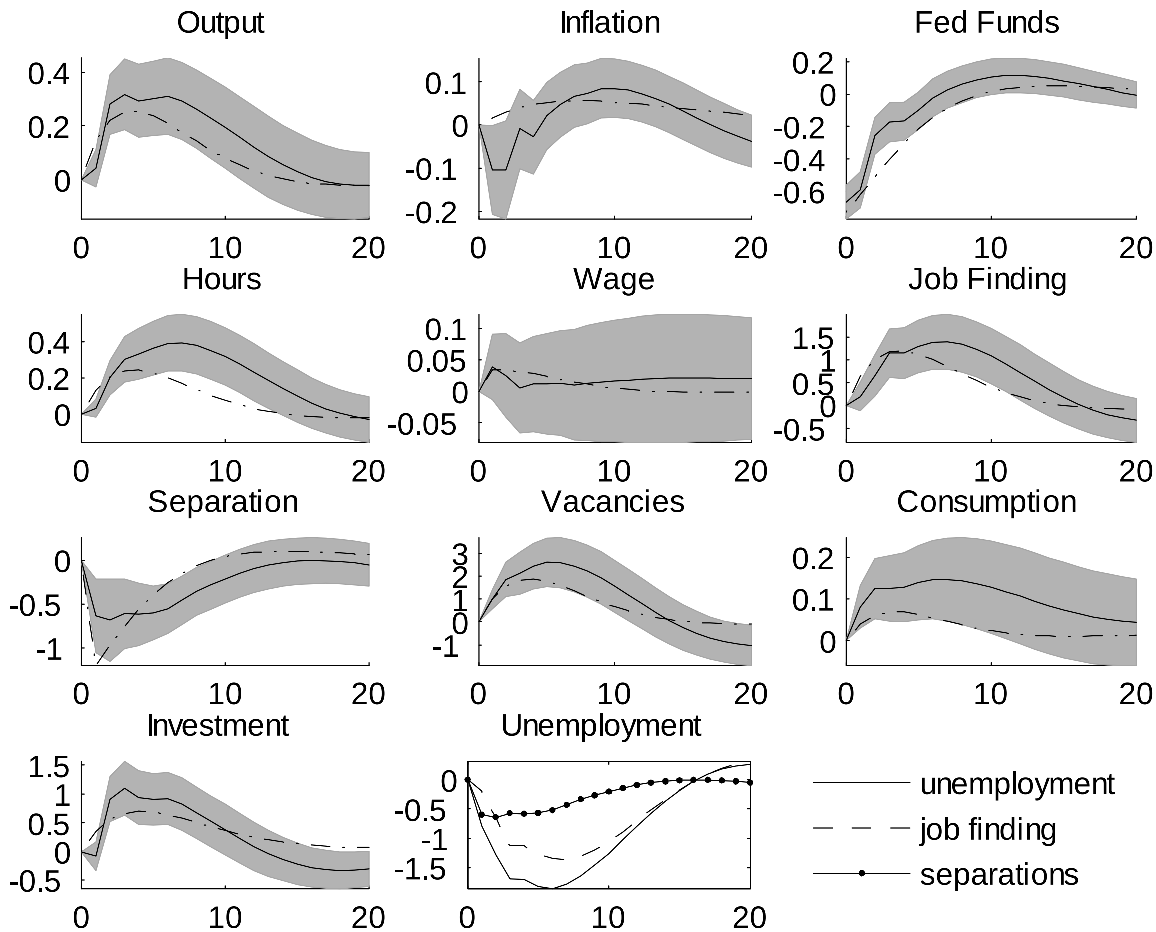

Figure 4: IRFs to a Monetary policy shock (in % deviations, annualized for inflation and the Fed Funds Rate). Dashed lines are model IRFs (see below). The last panel shows contributions of changes in the job finding and the separation rate to unemployment changes.

3 The Model

This Section develops the general equilibrium model.

Consumption and investment goods are produced in a competitive final good sector using differentiated intermediate goods supplied by a monopolistically competitive sector ('Intermediate Goods Sector'). The latter in turn uses goods produced by 'jobs' as an input. Jobs combine capital services and labor to produce a homogenous good, sold in a competitive market. In the 'job' sector, workers and firms meet in a frictional labor market. Households supply labor, accumulate capital and rent capital services to jobs. Profits of firms are rebated to households. Unemployment risk is diversified among 'families' (Andolfatto (1996) and Merz (1995)).

Figure 5 summarizes the sectoral structure of the economy. Instead of modelling search frictions and nominal price rigidities in separate sectors, one could assume that there are quadratic price adjustment costs in conjunction with search frictions in the monopolistically competitive sector (see e.g. Krause and Lubik (2003)). The results would be equivalent. I use the sectoral structure to make the comparison to the existing literature immediate.

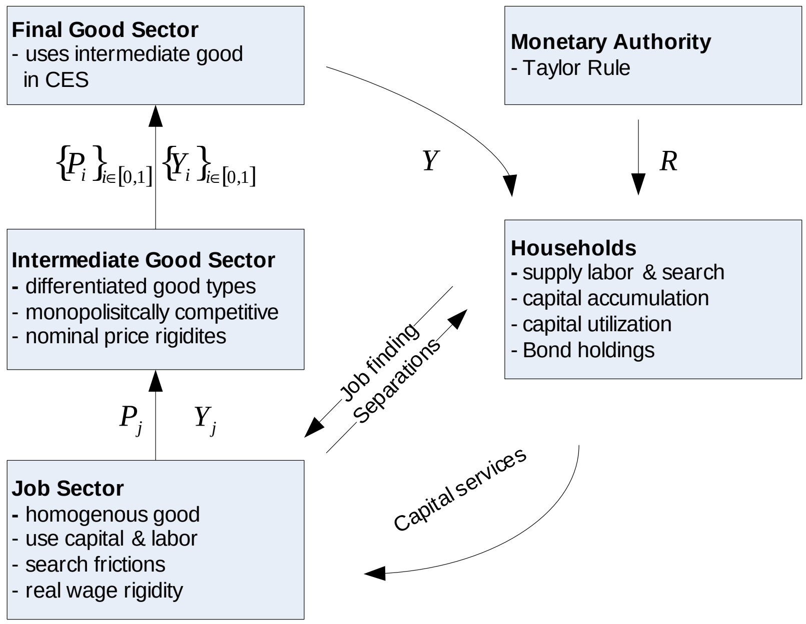

Figure 5: Sectoral Structure of the Model Economy

After developing the job sector, I describe the intermediate good sector, the final good sector, households, and the policy of the monetary authority.

3.1 Jobs and the Labor Market

A job is a 'firm-worker' pair.[6] Job output is produced according to

$$A_t k^{\alpha},$$

where k denotes capital services rented from households at rental rate r_t^k, α is the elasticity of match output with respect to capital, and A_t measures aggregate productivity, identical across jobs. The goods produced by jobs are sold to intermediate good firms in a competitive market at relative price p_{jt}.

For existing jobs, the timing is as follows. At the beginning of the period, the firm decides how much capital to rent for that period. Subsequently, the worker draws an iid idiosyncratic utility cost of working, $a \sim F(\bullet)$.[7] The realization of this preference shock is observable to the firm. If the realization is less than a certain endogenous threshold $\overline{a}_t$, match continuation is jointly optimal for the firm-worker pair. Then, wages are determined via a variant of Nash-Bargaining and production takes place.

If the value of the preference shock exceeds the threshold, match continuation would be too costly due to the participation constraints of firm and worker, the worker separates and enters the pool of unemployed and searching workers. The probability of endogenous worker separation is hence $1 - F(\overline{a}_t)$. The firm chooses the

[6] The model abstracts from job-to-job transitions of workers. Hence, job and worker flows are tied.

[7] Here I deviate from the multiplicative productivity shock specification of most of the literature on endogenous job destruction. In this literature, a lognormal distribution of idiosyncratic match productivity shocks is assumed. This assumption implicitly pins down both the elasticity of the separation rate with respect to changes of the threshold $\overline{a}_t$ which determines the response of the separation rate to shocks **and** the relation of fixed match components (such as unemployment benefits) to average productivity. Thus, the costliness of separations is tied to propagation on the hiring margin due to fixed cost-components of the match. A global distributional assumption is (i) not necessary for the local analysis undertaken here and (ii) makes comparisons to the literature on exogenous destruction difficult. The preference shock specification has also been used by Cooley and Quadrini (1999) and Trigari (2004) and is similar to an overhead cost shock sepcification on the firm side.

threshold value $\overline{a}_t$ at the beginning of the period. As I show below, one can equally think of a joint decision of the firm and worker pair because the firm wants to discontinue the match if and only if the worker finds separation optimal. Furthermore, the assumption that the capital intensity and separation threshold decisions are made before the realization of the idiosyncratic preference shock serves purely to simplify the exposition.

The match survives into the next period with probability $(1-\rho^x)$, where ρ^x is the exogenous separation probability.

Unmatched firms ('vacancies') and unemployed workers meet in a frictional labor market described by a matching function. Firms decide wether or not to post vacancies at the beginning of the period. If a firm meets a suitable worker, production can take place in the following period. Vacancy creation is subject to free entry.

The vacancy filling probability q_t and the job finding probability hir_t depend on the measure of vacancies posted v_t and the size of the pool of searching (unemployed) workers u_t. In particular, the number of matches in period t is determined by a standard constant returns to scale matching function $mv_t^{\mu}u_t^{1-\mu}$, where m is a matching efficiency parameter and $\mu \in (0,1)$.

The probability of filling a vacancy in a period satisfies

$$q_t = min\left\{m\left(\frac{v_t}{u_t}\right)^{-(1-\mu)}, 1\right\},$$

and the job finding probability is

$$hir_t = min\left\{m\left(\frac{v_t}{u_t}\right)^{\mu}, 1\right\}.$$

Note that the vacancy filling probability is decreasing and the job finding probability is increasing in market tightness $\frac{v_t}{u_t}$, reflecting congestion externalities on either side of the labor market.

The pool of employed workers evolves according to

$$n_t = \left(1-\rho_{t-1}\right) n_{t-1} + hir_{t-1}u_{t-1},$$

where $\rho_t = 1-(1-\rho^x) F(\overline{a}_t)$ is the separation rate. Since worker separation takes place at the beginning of the period before production takes place and new matches are formed, the period t pool of unemployed workers is $u_t = 1-(1-\rho_t) n_t$.

We now turn to the three central economic decisions governing: (i) vacancy posting, (ii) separations, and (iii) wage determination. To spare notation, I will specify the information available when the decisions are made after laying out the model. The information set is consistent with the identifying assumptions of the VAR.

3.1.1 Value Functions

Denote the beginning-of-period t firm value of being matched to a worker with J_t and the worker's value of being matched to a firm with W_t. All values are measured in consumption units. The relevant stochastic discount factor for workers and firms (which are owned by households) is $\beta_{t+1} = \beta\frac{\lambda_{t+1}}{\lambda_t}$, where λ_t is the marginal utility of consumption in period t and $\beta < 1$.

The revenue product of a match net of capital costs is

$$\Lambda_t = p_{jt}A_t k^{\alpha} - r_t^k k.$$

The value of a filled job to a firm before the preference shock is realized satisfies the Bellman equation

$$J_t = max_k \int max\left\{\Lambda_t - w_t + (1-\rho^x) E_t\beta_{t+1}J_{t+1} + \rho^x E_t\beta_{t+1}V_{t+1}, V_t\right\} dF(a), \tag{6}$$

where w_t is the wage bill. The firm value J is either equal to current profits $\Lambda_t - w_t$ plus the expected continuation value weighed by the relevant discount factor, or equal to the value of a vacancy V if the latter exceeds the former. The wage bill may in turn depend on the realization of the preference shock. Equation (6) takes into account that for some (high) realizations of the preference shock, a separation of the match is optimal and the firm is left with a vacancy. Note also that capital costs are only incurred if the match finds it optimal to produce.

A vacant firm incurs vacancy posting costs of κ_t^{vac} per period and is matched to a suitable worker with probability q_t. A new match survives into the following period with probability $(1-\rho^x)$, when production takes place.

The value of a vacancy satisfies

$$V_t = -\kappa_t^{vac} + q_t\,(1-\rho^x)\,E_t\beta_{t+1}J_{t+1} + (1 - q_t\,(1-\rho^x))\,E_t\beta_{t+1}V_{t+1}. \tag{7}$$

Vacancy posting costs κ_t^{vac} will enter the resource constraint of the economy.

The worker value of being matched to a firm at the beginning of the period satisfies

$$W_t = \int max\left\{w_t - \frac{a}{\lambda_t} + (1-\rho^x)\,E_t\beta_{t+1}W_{t+1} + \rho^x\beta_{t+1}U_{t+1}, U_t\right\} dF\,(a)\,, \tag{8}$$

where U_t is the value of being unemployed.

When unemployed, the worker receives income b, measured in consumption units. The value b encompasses unemployment benefits and home production and is assumed to be fixed ('non-responsive').[8]

With probability hir_t, the unemployed worker is matched to a vacancy at the end of the period and the match survives into the following period with probability $(1-\rho^x)$. The unemployment value U_t satisfies:

$$U_t = b + hir_t\,(1-\rho^x)\,E_t\beta_{t+1}W_{t+1} + (1 - hir_t\,(1-\rho^x))\,E_t\beta_{t+1}U_{t+1}. \tag{9}$$

Define the expected *surplus* value of an employed worker as $\Omega_t = W_t - U_t$. Combining (8) and (9) yields

$$\Omega_t = \int max\left\{w_t - \frac{a}{\lambda_t} - b - hir_t\,(1-\rho^x)\,E_t\beta_{t+1}\Omega_{t+1} + (1-\rho^x)\,E_t\beta_{t+1}\Omega_{t+1}, 0\right\} dF\,(a)\,. \tag{10}$$

Note that the value of continuing at the current job in the next period is equal to the the value of finding a job at another firm for the next period, because preference shocks are iid across matches and time and there is no heterogeneity across matches or firms.

The iid assumption is made in the business cycle literature with few exceptions (e.g. Hussey (2005)) and greatly simplifies the analysis because knowledge of a distribution of 'job-' or 'worker'- types is not necessary. I discuss the drawbacks of this assumptions in the conclusion.

3.1.2 Vacancy Creation

Vacancy creation is subject to free entry, such that $V_t = 0$ for all t. Equation (6) reduces to the vacancy creation condition

$$\frac{\kappa_t^{vac}}{q_t} = (1-\rho^x)\,E_t\beta_{t+1}J_{t+1}. \tag{11}$$

Recall that the vacancy filling probability q_t is decreasing in labor market tightness, i.e., decreasing in the ratio of vacancies to unemployed workers. An increase in labor market tightness makes it harder for firms to find

[8] This assumption would need to be modified if *persistent* shocks were considered. For example, unemployment benefits would depend on previous or aggregate wages.

workers and increases effective recruiting costs on the left hand side of (11). For standard calibrations of the MP-model, fluctuations of the firm value J are not large enough in response to reasonably sized shocks to account for the observed volatility of labor market tightness (the Beveridge curve).

Most amplification mechanisms model discussed in the literature and in developed in this paper serve to directly increase the variability of J in the vacancy creation condition (11). One exception is De Bock (2005) who shows that capital embodied technology shocks increases the persistence of vacancies and improves the MP models ability to match the business cycle facts. Another are amplification and persistence mechanisms introduced through recurrent job loss (Pries (2004)) and job ladders (Krause and Lubik (2004b)) which mitigate the decrease in q_t through a delayed decrease in the number of searching workers.

Also, most of the recent literature on the evaluation of the Mortensen Pissarides Model does not directly deal with the persistence of the response of vacancies and the job finding rate to aggregate shocks.

To account for the persistent, hump-shaped response of vacancies assume

$$\kappa_t^{vac} = \varkappa \left(\frac{v_t}{v_{t-1}} \right)^{\sigma_v}, \tag{12}$$

with $\sigma^v \geq 0$ and $\varkappa > 0$.

Suppose a small 'advertising' sector of the economy specializes in the provision of recruiting services. Suppose that – due to specialization – it takes time for this sector to expand its services. We would expect the marginal costs and hence the service price to be decreasing in the resources available in that sector at a given point in time. One can think of v_{t-1} as a proxy for these resources. Hence, when v_{t-1} is large, the costs associated with a given level of v_t are small.

Vacancy posting costs are increasing in the growth rate of vacancies. A similar assumption will be made for investment adjustment costs, as in CEE. For investment, Lucca (2005) shows that random maturity time-to-build or time-to-plan in conjunction with imperfect substitutability between investment projects leads to a specification as in (12). In work in progress, Braun, De Bock, and Lucca (2005) tie vacancy creation and investment to explain the persistent and hump-shaped responses of vacancies and investment observed in the data.

Note that the effect of vacancy posting on future vacancy posting costs is external to the vacancy creation decision (11). The same is true for the effect that current vacancy posting has on q_t (the congestion externality). One can formulate a model where firms of non-degenerate size internalize the effect of vacancy posting on κ_t^{vac}. This does not alter the results qualitatively, although the estimated value of σ_v would change.

3.1.3 Endogenous Worker Separations

When the realized preference shock of existing matches is too high, continuation of the match is not profitable and worker and firm find it optimal to separate.

Consider the joint surplus value of a match, i.e., the sum of the firm and worker values of being matched, $J_t + W_t$, net of the outside option of the firm and worker, $V_t + U_t$. V_t and U_t constitute the participation constraints of the match. Because $V_t = 0$, the surplus value of a match is $S_t = J_t + \Omega_t$ or –using (6) and (10):

$$\begin{aligned} S_t &= J_t + \Omega_t \\ &= \int max \left\{ \Lambda_t - \frac{a}{\lambda_t} - b - (1-\rho^x)\, hir_t E_t \beta_{t+1} \Omega_{t+1} + (1-\rho^x)\, E_t \beta_{t+1} S_{t+1}, 0 \right\} dF(a). \end{aligned} \tag{13}$$

The first term in braces is strictly decreasing in a. Hence, there exists a threshold value $\overline{a}_t$, such that

$$\Lambda_t - \frac{\overline{a}_t}{\lambda_t} - b - (1-\rho^x)\, hir_t E_t \beta_{t+1} \Omega_{t+1} + (1-\rho^x)\, E_t \beta_{t+1} S_{t+1} = 0. \tag{14}$$

This is the jointly privately efficient separation threshold. Match continuation is optimal iff $a \leq \overline{a}_t$. Note that the wage payment is absent from (13). The separation threshold is independent of wage transfers between firm and worker: It is jointly efficient. The variants of wage determination considered below all satisfy this property. Hence, the values can be expressed as

$$J_t = max_{k,\overline{a}} \int^{\overline{a}_t} \Lambda_t - w_t + (1-\rho^x)\, E_t \beta_{t+1} J_{t+1} dF(a)$$

and

$$\Omega_t = \int^{\overline{a}_t} w_t - \frac{a}{\lambda_t} - b + (1-\rho^x)(1 - hir_t)\, E_t \beta_{t+1} \Omega_{t+1} dF(a),$$

and the jointly efficient separation requirement may be stated as

$$argmax_a J = argmax_a \Omega = argmax_a S.$$

3.1.4 Real Marginal Costs and Propagation

Recall that job output is sold to the intermediate good sector in a competitive market at relative price p_{jt}. For the monopolistically competitive firms in the intermediate sector, p_{jt} represents real marginal cost. The response of real marginal costs is in turn the key determinant of inflation and output responses to the monetary policy shock.

Condition (11) sheds light on how real marginal costs are related to the wage, the rental rate of capital services, and recruiting costs. Substituting the firm value (6) into the vacancy creation condition (11) yields

$$\frac{\kappa_t^{vac}}{q_t} = max_k E_t \left(1-\rho_{t+1}\right) \beta_{t+1} \left(p_{jt+1} A_{t+1} k_{t+1}^{\alpha} - r_{t+1}^k k_{t+1} - \overline{w}_{t+1}\right) + E_t \left(1-\rho_{t+1}\right) \beta_{t+1} \frac{\kappa_{t+1}^{vac}}{q_{t+1}}, \tag{15}$$

where $\overline{w}_{t+1} = \int^{\overline{a}_{t+1}} w_{t+1} \frac{dF(a)}{F(\overline{a}_t)}$ is the average wage. Note that p_{jt+1} is related to current and future (expected) recruiting costs $\frac{\kappa^{vac}}{q}$. In particular, if current recruiting costs increase, p_{jt+1} increases ceteris paribus. The extent to which p_{jt+1} must increase in percentage terms in turn depends on the response and level of $\overline{w}_{t+1}$. Hence there is a relationship between real marginal costs, wages, and vacancy creation, through its positive effect of the latter on recruiting costs. Of course this relationship is confounded by reactions of the interest rate, the discount factor, the separation rate, expected future recruiting costs, and wage determination (see below).

The model solution will be approximated by linearizing the equilibrium conditions around the non-stochastic steady state. To gain intuition for the propagation mechanisms and determinants of the dynamics of marginal costs, it is useful to consider the linearized version of (15). Assume that aggregate technology A is fixed. As shown below, capital choice is jointly efficient –also under the deviation from Nash-Bargaining considered in this paper. Hence $\Lambda_{t+1} = p_{jt+1} A k_{t+1}^{\alpha} - r_{t+1}^k k_{t+1} = (1-\alpha)\, p_{jt+1}^{\frac{1}{1-\alpha}} \left(r_{t+1}^k\right)^{\frac{\alpha}{\alpha-1}} A^{\frac{1}{1-\alpha}}$ and

$$\begin{aligned} E_t \widehat{p}_{jt+1} = {} & \frac{1-\alpha}{1-(1-\rho)\beta} \left(1 - \frac{\overline{w}}{\Lambda}\right) \left(\widehat{\kappa}_t^{vac} - \widehat{q}_t - (1-\rho)\beta E_t \left(\widehat{\kappa}_{t+1}^{vac} - \widehat{q}_{t+1}\right) - E_t \varepsilon_{F,\overline{a}} \widehat{\overline{a}}_{t+1} + E_t \widehat{\beta}_{t+1}\right) \\ & + (1-\alpha) \frac{\overline{w}}{\Lambda} E_t \widehat{\overline{w}}_{t+1} + \alpha E_t \widehat{r}_{t+1}^k, \end{aligned} \tag{16}$$

where the time index is dropped to signify steady state values, $\widehat{x}_{t+1} = \frac{x_{t+1} - x}{x}$, and $\varepsilon_{F,\overline{a}} = \frac{f(\overline{a})\overline{a}}{F(\overline{a})}$ is the steady state elasticity of the preference shock distribution with respect to the separation threshold $\overline{a}$.

First, note that for $\frac{\overline{w}}{\Lambda} = 1$, the marginal cost equation (16) collapses to one that holds in an economy without search frictions. In that case, the dynamics of marginal costs are governed by movements in the wage and the rental rate of capital, as determined by the capital share α. In the presence of search frictions, terms involving current and future recruiting costs, the separation rate, and the discount factor also determine the reaction of marginal costs.

Second, a value of $\frac{\overline{w}}{\Lambda}$ close to 1 implies a relatively small effect of changes of current recruiting costs $\frac{\kappa_t^{vac}}{q_t}$ on real marginal costs. Stated differently, a given change in p_j has a large effect on recruiting costs. The same would be true for a shock to aggregate productivity A. Effective recruiting costs are in turn an increasing function of vacancies for two reasons: An increase in vacancies decreases the vacancy filling probability q (the congestion externality), and increases $\kappa_t^{vac} = \varkappa \left(\frac{v_t}{v_{t-1}}\right)^{\sigma_v}$. Hence, vacancies react strongly to shocks in p_j if $\frac{\overline{w}}{\Lambda}$ is close to one. A strong reaction of vacancies in turn implies a large effect on the job finding rate. This propagation channel is stressed by Hagedorn and Manovskii (2005) in a model without endogenous separations. The expression $1 - \frac{\overline{w}}{\Lambda}$ represents flow profits of the firm relative to the net revenue product of the match. In equilibrium, profits compensate the firm for recruiting costs due to the free entry condition. A small value of $1 - \frac{\overline{w}}{\Lambda}$ hence implies that recruiting costs are small.

As discussed in Section 6, capital outlays in the form of fixed overhead costs as in Fujita and Ramey (2005) induce additional amplification. Fixed capital costs are, however, grossly inconsistent with the behavior of the capital share in income over the business cycle. A general equilibrium model must take into account that capital outlays are an endogenous variable.

Third, notice that a high elasticity of the preference shock distribution with respect to the threshold $\overline{a}$ reduces the response of real marginal costs for a given change in $\overline{a}$. The elasticity governs the costliness of separations. If $\varepsilon_{F,\overline{a}}$ is large, separations can be reduced for a small increase in the threshold $\overline{a}$ in response to an expansionary shock. Because every increase in $\overline{a}$ requires compensation of the worker, a large elasticity $\varepsilon_{F,\overline{a}}$ makes adjustments on the separation margin inexpensive for the match. Finally, note that the presence of search frictions does not eliminate the influence of wages on marginal costs.

Of course, movements in the threshold $\widehat{\overline{a}}_{t+1}$ and the average wage $\widehat{\overline{w}}_{t+1}$ in turn depend on the endogenous variables. To pin down these relationships we now turn to the determination of wages.

3.1.5 Wage Determination

Wages are transfers from the firm to the worker. If there is no intensive margin of hours adjustment, wages do not have allocational implications for the current firm-worker relationship as long as they do not induce inefficient separations between firm and worker. As explained above, I require that wage determination induces separations that are jointly privately efficient. In other words, separations do not occur merely because the wage is not renegotiated when it would be efficient to do so.

Wage determination *outside* of the match does have an impact through the outside option and participation constraint of the worker (U) and the free entry condition of firms ($V = 0$). Recall that the job finding rate (hir), the worker surplus value of outside job opportunities (Ω), and the joint continuation value (S) enter the separation condition (14). How wages are determined in other available jobs influences the separation decision, through firms' vacancy creation decision, the implied job finding probability, and the worker value of outside job opportunities.

Assume that wage payments are made after choice of k has been made and after the preference shock $a \leq \overline{a}_t$. has been realized. Denote the firm, worker, and joint surplus values at a particular value of $a \leq \overline{a}_t$ and a given wage schedule $w_t(a)$ by $\Omega_t(a, w(a))$, $J_t(a, w_t(a))$, and $S_t(a, w_t(a))$ respectively.

We proceed by presenting the Nash-Bargaining approach to wage determination, which is standard in the literature.[9]

Nash Bargaining Nash-Bargaining with worker share $\eta \in (0,1)$ and firm share $1-\eta$ implies

$$\forall a \leq \overline{a}_t : (1-\eta)\,\Omega_t\left(w_t\left(a\right),a\right) = \eta J_t\left(w\left(a\right),a\right). \tag{17}$$

Using the value expressions (6) and (10) and solving for the wage yields

$$\begin{aligned} w_t^{\text{nash}}\left(a\right) &= (1-\eta)\left(\frac{a}{\lambda_t} + b + (1-\rho^x)\,hir_t E_t\beta_{t+1}\Omega_{t+1}\right) + \eta\Lambda_t \\ &\quad + \eta\left(1-\rho^x\right)E_t\beta_{t+1}J_{t+1} - (1-\eta)\left(1-\rho^x\right)E_t\beta_{t+1}\Omega_{t+1}. \end{aligned} \tag{18}$$

Because wages in period $t+1$ are also determined via Nash-Bargaining, the difference between the last terms in (18) is zero. Also $hir_t\left(1-\rho^x\right)E_t\beta_t\Omega_{t+1} = hir_t\frac{\eta}{1-\eta}\left(1-\rho^x\right)E_t\beta_t J_{t+1} = hir_t\frac{\eta}{1-\eta}\frac{\kappa_t^{vac}}{q_t}$. Hence the average wage satisfies

$$\overline{w}_t^{\text{nash}} = \int^{\overline{a}_t}\frac{a}{\lambda_t}\frac{dF\left(a\right)}{F\left(\overline{a}_t\right)} + b + hir_t\frac{\eta}{1-\eta}\frac{\kappa_t^{vac}}{q_t} + \eta\Lambda_t. \tag{19}$$

The worker is compensated for utility costs, the value of non-market activities, the rents she could appropriate through outside job offers, and obtains a share of the match revenue product Λ_t.

The separation condition (14) becomes

$$\Lambda_t - \frac{\overline{a}_t}{\lambda_t} - b + \frac{1-hir_t\eta}{1-\eta}\frac{\kappa_t^{vac}}{q_t} = 0. \tag{20}$$

Clearly, Nash-Bargaining satisfies the requirement that separations are jointly efficient, because the surplus S is shared.

Linearizing (19) around the non-stochastic steady state and using the expression for marginal costs (the linearized vacancy creation condition (16)) and (20) yields

$$\begin{aligned} &\widehat{p}_{jt+1} - \alpha\widehat{r}_{t+1}^{k} = \\ &\left(\widehat{\kappa}_t^{vac} - \widehat{q}_t - (1-\rho)\,\beta\left(1-\eta hir\right)\left(\widehat{\kappa}_{t+1}^{vac} - \widehat{q}_{t+1}\right) - \Phi^{\lambda}\widehat{\lambda}_{t+1} + \widehat{\lambda}_t + (1-\rho)\,\beta\eta hir\widehat{hir}_{t+1}\right)\Phi^1, \end{aligned} \tag{21}$$

where $\Phi^1 = \frac{(1-\alpha)}{(1-(1-\rho)\beta(1-\eta hir))}\left(\frac{\Lambda - \frac{H(a)}{\lambda} - b}{\Lambda}\right)$ governs the response of marginal costs to search frictions, $H\left(\overline{a}\right) = \int^{\overline{a}}\frac{a}{\lambda}\frac{dF(a)}{F(\overline{a})}$ is the truncated mean of utility costs – measured in consumption units, and $\Phi^{\lambda} = \left(1-(1-\rho)\,\beta\left(1-\eta hir\right)\right)\left(\frac{\Lambda-b}{\Lambda-\frac{H(a)}{\lambda}-b}\right)$. Note that $\widehat{\overline{a}}_{t+1}$ does no enter (21).

The level of wages relative to revenue Λ which determines the magnitude of the response of marginal costs in (16) is replaced by the level of 'cost components' of the match, $\widetilde{b} = \frac{H(a)}{\lambda} + b$, in relation to the revenue Λ. Training and overhead costs considered in Section 6 enter in a similar fashion.

The bargaining share η enters (16) directly only in conjunction with the outside option value of the worker. A higher η increases the effect of the job finding rate, reduces the magnitudes of effects of current and future effective hiring costs, $\widehat{\kappa}_t^{vac} - \widehat{q}_t$, and the magnitude of the effect of the marginal utility of consumption. However, the bargaining share determines $\frac{\frac{H(a)}{\lambda}+b}{\Lambda}$. A higher worker share η increases this ratio.

[9] Exceptions are Delacroix (2004) and Hall and Milgrom (2005). Also see the discussion in Mortensen and Nagypal (2005).

Real Wage Rigidity The Nash-Bargaining assumption pins down the transfer from firm to worker in one particular way. An alternative is proposed by Hall (2005). Suppose there exists a social norm wage payment w^s and assume that – whenever possible – workers receive the norm wage. Deviations from w^s only take place if the joint surplus value S is non-negative and w^s violates the participation constraints of firms or workers (and would hence lead to inefficient separations). Either aggregate or idiosyncratic shocks could necessitate such deviations.[10]

Similarly to Hall (2005), I refine this form of wage rigidity by introducing a notion of the *degree* of real wage rigidity. Assume that wages are equal to the normed wage w^s unless the worker's surplus share induced by this wage becomes either too high or too low. In that case, the surplus is divided with the respective 'boundary' shares η^{max} and η^{min}. The degree of wage rigidity is governed by the extent to which these boundary shares differ from each other and could be loosely interpreted as a reduced form stemming from costs associated with the bargaining process.

Suppose a realization $\widetilde{a}$ is associated with a wage payment $\widetilde{w}$. Denote the worker value induced by this wage and shock realization with $\Omega_t(\widetilde{w},\widetilde{a})$ and the joint surplus value of the match with $S_t(\widetilde{a})$. $S_t(\widetilde{a})$ does not depend on wages, because the wage schedule satisfies the jointly efficient separation condition. Intuitively, the wage adjusts in regions close to the participation constraints.

The share of the worker surplus in the total surplus is $\frac{\Omega_t(\widetilde{w},\widetilde{a})}{S_t(\widetilde{a})}$. Under Nash bargaining, $\frac{\Omega_t(\widetilde{w},\widetilde{a})}{S_t(\widetilde{a})}$ is equal to the fixed fraction η – the worker's bargaining share – for all realizations of $\widetilde{a} \leq \overline{a}_t$. In other words, the wage adjusts to changes in $\widetilde{a}$ or aggregate conditions and $\frac{\Omega_t(\widetilde{w},\widetilde{a})}{S_t(\widetilde{a})}$ remains constant. Let η^{min} and η^{max} denote the minimum and maximum worker shares that do not lead to a renegotiation of the wage. Implicitly, these define cutoffs for the realization of the preference shock. In particular, for realizations of the preference shock in the range $\left[a^{min}, a^{max}\right]$, the normed wage induces a worker share between η^{min} and η^{max}, where the former are defined by the conditions $\frac{\Omega\left(w^s,a^{min}\right)}{S\left(a^{min}\right)} = \eta^{max}$ and $\frac{\Omega(w^s,a^{max})}{S(a^{max})} = \eta^{min}$, or

$$w_t^s = \left(1-\eta^{min}\right)\left(\frac{a^{max}}{\lambda_t} + b - (1-\rho^x)(1-hir_t)\,E_t\beta_{t+1}\Omega_{t+1}\right) + \eta^{min}\left(\Lambda_t + (1-\rho^x)\,E_t\beta_t J_{t+1}\right) \tag{22}$$

and

$$w_t^s = \left(1-\eta^{max}\right)\left(\frac{a^{min}}{\lambda_t} + b - (1-\rho^x)(1-hir_t)\,E_t\beta_{t+1}\Omega_{t+1}\right) + \eta^{max}\left(\Lambda_t + (1-\rho^x)\,E_t\beta_t J_{t+1}\right), \tag{23}$$

Now consider a realization of the shock that is smaller than a^{min}. If the worker were paid w_t^s, her share would be less than η^{min}. Assume that in such a case, the wage is reset to a value that guarantees the share η^{min}. For $a < a^{min}$:

$$w_t(a) = \left(1-\eta^{min}\right)\left(\frac{a}{\lambda_t} + b - (1-\rho^x)(1-hir_t)\,E_t\beta_{t+1}\Omega_{t+1}\right) + \eta^{min}\left(\Lambda_t + (1-\rho^x)\,E_t\beta_t J_{t+1}\right). \tag{24}$$

Expression (24) is equivalent to wage determination via Nash-Bargaining with worker share η^{min}. An analogous expression holds for wage payments for realizations of the preference shock above the threshold a^{max} and below the destruction threshold $\overline{a}$.[11]

[10] This is one difference to the Calvo-Pricing that will be assumed in the intermediate goods market. Furthermore, participation constraints are not violated ex-post. Note that endogenous wage adjustments take place in the non-stochastic steady state due to idiosyncratic shocks.

[11] Note that the wage schedule is discontinuous at the cutoffs a^{max} and a^{min}.

Define $\overline{w}_t = \int^{\overline{a}} w_t(a) \frac{dF(a)}{F(\overline{a})}$. For given choices of $(k, \overline{a})$, expected wage payments $\overline{w}_t$ satisfy:

$$\overline{w}_t = \phi_t w_t^s \tag{25}$$

$$+ \int^{a_t^{min}} \left((1-\eta^{max}) \left(\frac{a}{\lambda_t} + b - (1-\rho^x)(1-hir_t) E_t \beta_{t+1} \Omega_{t+1} \right) + \eta^{max} \left(\Lambda_t + (1-\rho^x) E_t \beta_t J_{t+1} \right) \right) \frac{dF(a)}{F(\overline{a}_t)}$$

$$+ \int_{a_t^{max}}^{\overline{a}_t} (1-\eta^{min}) \left(\frac{a}{\lambda_t} + b - (1-\rho^x)(1-hir_t) E_t \beta_{t+1} \Omega_{t+1} \right) + \eta^{min} \left(\Lambda_t + (1-\rho^x) E_t \beta_t J_{t+1} \right) \frac{dF(a)}{F(\overline{a}_t)}$$

where $\phi_t^w = \frac{F(a_t^{max}) - F(a_t^{min})}{F(\overline{a}_t)}$ is the fraction of matches that does not experience a wage adjustment in period t.

We can verify that the wage schedule given by (25) satisfies the condition of jointly privately efficient separations by substituting (25) into the firm value (6). Differentiating with respect to the threshold yields the separation condition (14).

How should wage rigidity be parameterized? Given a distribution of idiosyncratic preference shocks and given shares η^{max} and η^{min}, definitions (22) and (23) would pin down steady state values of the adjustment thresholds a^{max} and a^{min}. Condition (25) would then pin down a value of the norm wage w^s consistent with the distributional assumption and a given level of the average wage. I follow a different route here which is feasible because the model solution is approximated by a first order linear approximation. It allows a parsimonious parameterization of wage rigidity with a single parameter. More importantly, changes in the degree of wage rigidity do not affect the level of wages. As discussed above, the level of wages is a propagation mechanism itself and needs to be isolated from the rigidity of wages. Instead of specifying a distribution and the boundary shares, I parameterize wage rigidity by the fraction of wages adjusted in steady state, ϕ^w, and assume that

1. the steady state social norm wage is equal to the steady state average wage,

$$\overline{w} = w^s \tag{26}$$

2. the mass of steady state adjustments and the boundary shares are symmetric with respect to the truncated preference shock distribution, where the truncation point is the separation threshold $\overline{a}$.

In particular, assume

$$\frac{\eta^{max} + \eta^{min}}{2} = \eta \tag{27}$$

$$\frac{F(\overline{a}) - F(a^{max})}{F(\overline{a})} = \frac{F(a^{min})}{F(\overline{a})} = \frac{1-\phi^w}{2}, \tag{28}$$

where η is the worker share that determines the steady state division of Ω and J.

In Appendix B, I show that – given restrictions (26), (27) and (28) – the linearized version of the average wage equation (25) around the steady state is:

$$\widehat{\overline{w}}_t = \phi^w \left(\widehat{w}_t^s + \left(\frac{\frac{\overline{a}}{\lambda}}{\overline{w}} \right) \varepsilon_{F,\overline{a}} \widehat{\overline{a}}_t \right) + (1-\phi^w) \widehat{\overline{w}}_t^{\text{nash}}, \tag{29}$$

where $\varepsilon_{\overline{a}} = \frac{f(\overline{a})\overline{a}}{F(\overline{a})}$, $\underline{w} = b - (1-\rho^x)(1-hir)\beta\Omega$, and $\widehat{\overline{w}}_t^{\text{nash}}$ is derived from the linearized version of (18).[12] The dynamics of the real wage are governed by the weighted average of the normed wage and the Nash bargained

[12] The term $\eta(1-\rho^x) E_t\beta_{t+1} J_{t+1} - (1-\eta)(1-\rho^x) E_t \beta_{t+1} \Omega_{t+1}$ in (18) is not zero here because future values are *not* shared via Nash bargaining. Expression (29) differs from the one postulated in Krause and Lubik (2003) because it (i) takes into account that future wages are not Nash bargaining wages and (ii) satisfies the requirement of jointly efficient separations.

wage. The term involving $\widehat{\overline{a}}_t$ 'corrects' the weighted average for wage adjustments necessitated by the jointly efficient separations requirement. Note also that expression (29) allows for dynamics of the social norm wage. For example, *nominal* wage rigidity could be introduced through the dynamics of w^s. Dynamics of the social norm w^s are an interesting extension for the response of the economy to *persistent* shocks. Here, assume for simplicity that w^s remains fixed.

Wage dynamics following (29) with small or no responses of w^s to shocks induce procyclical fluctuations of the firm share in the joint surplus. A positive aggregate shock leads to an increase in J exceeding the increase under Nash-Bargaining. The vacancy creation condition (11) then implies that $\frac{\kappa_t^{vac}}{q_t}$, vacancies and hence the job finding probability of unemployed workers react more strongly to shocks. As the wage is non-allocational for continuing matches, wage rigidity is relevant only insofar as it impacts the division of the joint surplus for newly formed matches.[13]

3.1.6 Capital Services

A job's demand for capital services follows from (6) using the expression for wage payments (25). Capital services demand is jointly privately efficient, with first order condition[14]

$$F\left(\overline{a}_t\right)\left(1-\frac{F\left(a_t^{min}\right)}{F\left(\overline{a}_t\right)}\eta^{min}-\frac{\left(F\left(\overline{a}_t\right)-F\left(a_t^{max}\right)\right)}{F\left(\overline{a}_t\right)}\eta^{max}\right)\left(\frac{\alpha}{k}p_j k^{\alpha}-r_t\right)=0, \text{ or}$$

$$\frac{\alpha}{k}p_{jt}k^{\alpha}-r_t^k=0. \tag{30}$$

3.1.7 Limited Information Decisions

In order to simplify the notation above, the information available to the agents when the decisions are made was not specified. In agreement with the identification strategy used in the VAR, assume that the choice of vacancies v_t (associated with the vacancy creation condition (11)), the wage schedule, and the separation cutoff $\overline{a}_t$ (associated with the separation condition (14)) do not respond contemporaneously to monetary policy shocks.

3.1.8 Aggregate Job-Output, Hours, and Demand for Capital Services

Aggregate output of the job sector is

$$Y_{jt}=A_t N_t^{1-\alpha}K_t^{\alpha},$$

where

$$N_t=\left(1-\rho_t\right)n_t$$

measures aggregate hours worked and

$$K_t=\left(1-\rho_t\right)n_t k_t$$

is the aggregate demand for capital services.

3.2 Final and Intermediate Goods Sectors

The presentation of the final and intermediate goods sectors and households follows CEE. Details of the derivations can be found in the technical appendix to their paper.

[13] This is called the 'outside' wage in the literature.

[14] To see this, use the definitions of a^{max} and a^{min} to that the derivatives of the wage bill w.r.t. the cut-offs a^{min} and a^{max} are zero.

The period t final good is produced in a perfectly competitive sector using intermediate goods according to

$$Y_t = \left(\int_0^1 Y_{it}^{\frac{1}{\lambda_f}} di \right)^{\lambda_f},$$

where $i \in [0, 1]$ indexes intermediate good types, and $\lambda_f \geq 1$. Denote the final good price by P_t and the intermediate good prices by P_{it}. Profit maximization yields

$$\left(\frac{P_t}{P_{it}} \right)^{\frac{\lambda_f}{\lambda_f - 1}} = \frac{Y_{it}}{Y_t} \tag{31}$$

and the aggregate final good price can be expressed as

$$P_t = \left[\int_0^1 P_{it}^{1/(1-\lambda_f)} \right]^{(1-\lambda_f)}. \tag{32}$$

Each intermediate good firm uses job output Y_{jt} to produce intermediate goods according to

$$Y_{it} = \begin{cases} Y_{ijt} - \phi^f \text{ if } Y_{ijt} \geq \phi^f \\ 0 \text{ otherwise} \end{cases}$$

Here, $\phi^f > 0$ is a fixed cost of production. As in CEE, the value of ϕ^f will be chosen such that steady state profits of intermediate good firms are zero. There is no entry or exit in the intermediate good sector.

Nominal price stickiness is modelled as in CEE. In each period, a firm i may reoptimize its nominal output price P_i with a constant probability ψ (iid across firms and time). In line with the identifying assumption of the VAR, reoptimization takes place before the realization of the monetary policy shock. If the firm cannot reoptimize its price, the current price is indexed by lagged inflation $\pi_{t-1} = P_{t-1}/P_{t-2}$, i.e., $P_{it} = \pi_{t-1} P_{it-1}$.

Firms which can reoptimize choose the price $\widetilde{P}_t$ that maximizes expected discounted profits that accrue until the next random reoptimization opportunity [15]

$$E_{t-1} \sum_{\tau=0}^{\infty} \Pi_{j=0}^{\tau} \left(\beta_{t+j} \psi \right) \left[\left(\widetilde{P}_t \Pi_{j=0}^{\tau} \pi_{t+j} - P_{jt+\tau} \right) Y_{it+\tau} \right] \tag{33}$$

subject to the demand relationship (31). In (33), $P_j = p_j P$ is the nominal price of the input goods produced by jobs.

The linearized version of the resulting aggregate final good price (32) is the Phillip's curve

$$E_{t-1} \widehat{\pi}_t = E_{t-1} \frac{1}{1+\beta} \widehat{\pi}_{t-1} + \frac{\beta}{1+\beta} \widehat{\pi}_{t+1} + (1 - \beta\psi) \frac{1-\psi}{\psi (1+\beta)} \widehat{p}_{jt}. \tag{34}$$

Current inflation depends on lagged inflation through indexing, and marginal costs and future inflation through reoptimization.

3.3 Households, Capital Utilization, and Investment Adjustment Costs

Households accumulate physical capital, rent capital services to firms, search for jobs if unemployed, receive profits, and receive labor income if employed. The representative household chooses consumption C, investment

[15] All reoptimizing firms choose the same price (see Woodford (1996)).

I, capital utilization $\widetilde{u}_t$ and one-period bond holdings B_t to maximize

$$E_{t-1}\sum_{\tau=0}^{\infty}\beta^{\tau}U\left(C_{t+\tau}-eC_{t+\tau-1}\right)$$

subject to the budget constraint

$$b\left(1-N_{t+\tau}\right)-T_{t+\tau}+d_{t+\tau}+N_{t+\tau}\overline{w}_{t+\tau}+r^{k}_{t+\tau}K_{t+t}+\frac{B_{t+\tau-1}}{P_{t+\tau}}=\left[C_{t+\tau}+I_{t+\tau}+a\left(\widetilde{u}_{t+\tau}\right)\overline{K}_{t+\tau}+\frac{B_{t+\tau}}{P_{t+\tau}R_{t+\tau}}\right], \tag{35}$$

the evolution of the stock physical capital $\overline{K}$

$$\overline{K}_{t+\tau+1}=\left(1-\delta\right)\overline{K}_{t+\tau}+\left(1-\Phi\left(\frac{I_{t+\tau}}{I_{t+\tau-1}}\right)\right)I_{t+\tau}, \tag{36}$$

and the relevant transversality conditions. Households' consumption, capital utilization, and investment decisions are made before the monetary policy shock is realized.

Capital services are related to the stock of physical capital by

$$K_t=\widetilde{u}_t\overline{K}_t.$$

In (35), T represents lump sum taxes,[16] d are profits of intermediate good and job sector firms, R_t-1 is the nominal interest rate, and $a\left(\widetilde{u}_t\right)$ measures the resource cost associated with capital utilization. As in CEE, steady state utilization is normalized to 1 and associated costs are normalized to $a\left(1\right)=0$. To solve the linearized version of the model, only $\frac{a''(1)}{a'(1)}=\phi^u>0$ needs to be parameterized. If ϕ^u is high, increases in the utilization rate induce a large increase in utilization costs, making adjustment on this margin more costly.

Variable capital utilization increases the supply elasticity of capital services with respect to changes in the rental rate of capital and hence lowers the response of marginal costs in response to a monetary policy shock. For a shorter sample, CEE show that available measures of capital utilization respond positively to an expansionary monetary shock. Quantitatively, their model responses are consistent with the estimated ones. This is also the case for the model estimates presented below.

In (36), δ is the rate of depreciation and $\Phi\left(\frac{I_t}{I_{t-1}}\right)$ measures investment adjustment costs, with $\Phi\left(1\right)=\Phi'\left(1\right)=0$ and $\Phi''\left(1\right)=\phi^I>0$ is parameterized.

As noted above for vacancy adjustment costs, investment adjustment costs in the growth rate of investment are a reduced-form representation of time-to-build frictions in investment across a range of projects with random maturities and imperfect substitutability between investment types (Lucca (2005)). This formulation of investment adjustment costs will be responsible for the model's ability to match the hump shaped response of investment to aggregate shocks observed in the data.[17]

Denote the multiplier on the evolution of physical capital (36) by $\lambda_t^{\overline{K}}$ and the multiplier associated with the budget constraint by λ_t.

The household's consumption choice satisfies

$$E_{t-1}\left(\lambda_t-U_{c,t}\right)=0, \tag{37}$$

[16] Recall that the component of b that represents unemployment benefits is financed via lump sum taxes.
[17] see also Basu and Kimball (2005) and Smets and Wouters (2003).

where the marginal utility of consumption is

$$U_{c,t} = \frac{\partial U\left(c_t, c_{t-1}\right)}{\partial c_t} + e\beta \frac{\partial U\left(c_{t+1}, c_t\right)}{\partial c_t}.$$

Define the price of physical capital as $P_{\overline{K}',t} = \frac{\Lambda_t^{\overline{K}}}{\lambda_t}$. The first order condition for physical capital is

$$E_{t-1}\left\{\lambda_t P_{\overline{K}',t} - \beta\lambda_{t+1}\left[\widetilde{u}_{t+1} r_{t+1}^k - a(\widetilde{u}_{t+1}) + (1-\delta)P_{\overline{K}',t+1}\right]\right\} = 0. \tag{38}$$

The first order condition for capital utilization is

$$E_{t-1}\lambda_t\left[r_t^k - a'(\widetilde{u}_t)\right] = 0 \tag{39}$$

and the Fisher equation is

$$\frac{\lambda_t}{P_t} = \beta E_t \frac{\lambda_{t+1}}{P_{t+1}} R_{t+1}. \tag{40}$$

3.4 Monetary Authority

The monetary authority follows a Taylor-Rule of the form

$$R_t = \left(R_{t-1}\right)^{\rho_R} E_t\left(\left(\pi_t/\pi\right)^{\gamma_\pi}\left(Y_t/Y\right)^{\gamma_y}\right)^{1-\rho_R}\varepsilon_t, \tag{41}$$

where R_t is the (gross) nominal interest rate, ρ_R is a policy persistence parameter, and γ_π and γ_y gauge the policy responses of the monetary authority to current inflation and output respectively. Monetary policy shocks are serially uncorrelated. The nominal interest rate falls in response to an expansionary monetary policy shock $\varepsilon_t < 0$.

3.5 Resource Constraint

The unweighted sum of output of the intermediate good sector Y_t^* satisfies

$$Y_t^* = \int_0^1 Y_{ijt} di - \phi^f = \int_0^1 \left[\frac{P_t}{P_{jt}}\right]^{\frac{\lambda_f}{\lambda_f - 1}} Y_t dj = \left(\frac{P_t}{P_t^*}\right)^{\frac{\lambda_f}{\lambda_f-1}} Y_t,$$

where $P_t^* = \left[(1-\xi_f)\left(\tilde{P}_t\right)^{\frac{\lambda_f}{1-\lambda_f}} + \xi_f\left(\bar{\pi}P_{t-1}^*\right)^{\frac{\lambda_f}{1-\lambda_f}}\right]^{\frac{1-\lambda_f}{\lambda_f}}$.

Y_t^* equals aggregate output of the job sector, net of the fixed costs incurred in the intermediate good sector. Y_t^* does not correspond to aggregate output in the data because it does not take into account relative price differences between intermediate good types.

GDP in the data corresponds to final good output Y_t, and can be divided between consumption, C_t, investment, I_t, capital utilization costs, $a\left(\widetilde{u}_t\right)\overline{K}_t$, and aggregate vacancy posting costs $\Gamma_t = v_t\kappa_t^{vac}$. The resource constraint is

$$C_t + I_t + \Gamma_t + a\left(\widetilde{u}_t\right)\overline{K}_t = \left(\frac{P_t^*}{P_t}\right)^{\frac{\lambda_f}{\lambda_f-1}} Y_t^* = \left(\frac{P_t^*}{P_t}\right)^{\frac{\lambda_f}{\lambda_f-1}}\left[A_t N_t^{1-\alpha} K_t^{\alpha} - \phi\right]. \tag{42}$$

In the linearization around the steady state, $\widehat{\frac{P_t^*}{P_t}}$ is zero such that

$$s_c\widehat{C}_t + s_I\widehat{I}_t + s_\Gamma\widehat{\Gamma}_t + s_K a'\left(\widetilde{u}_t\right)\widehat{\widetilde{u}}_t + s_K\widehat{\overline{K}}_t = \widehat{Y}_t^*,$$

where $s_c = \frac{C}{Y^*-\phi}$, $s_I = \frac{I}{Y^*-\phi}$, and $s_K = \frac{K}{Y^*-\phi}$.

3.6 Approximate Model Solution

The model solution is approximated by linearizing the equilibrium conditions around the steady state and solving the system with the method of undetermined coefficients described in Christiano (2002).

4 Estimation

I follow the estimation strategy in CEE. A subset of parameters Θ is calibrated (Θ^c) and the remaining parameters are estimated (Θ^e) by minimizing a measure of the distance between the empirical estimates of the impulse response functions, $\widehat{\Psi}$, and corresponding model impulse responses $\Psi(\Theta^e)$. The estimator of Θ^e solves

$$\widehat{\Theta}^e = \arg\min_{\Theta} \left[\widehat{\Psi} - \Psi(\Theta)\right] V^{-1} \left[\widehat{\Psi} - \Psi(\Theta)\right],$$

subject to theoretical constraints on the parameters, where V is a diagonal matrix with the sample variances of $\widehat{\Psi}$.

In effect, Θ^e is chosen such that the model impulse responses lie as closely as possible within the confidence bands of the empirical estimates. The first 20 quarters of the impulse responses were used in the construction of $\widehat{\Psi}$ and $\Psi(\Theta^e)$.

First, I discuss the benchmark values for Θ^c. I will discuss the sensitivity of the results to alternative values of some calibrated parameters and alternative partitions of the sets of calibrated and estimated parameters after the presentation of the benchmark estimates.

For the labor market parameters, the set of calibrated parameters includes steady state values of employment relative to the labor force n, the separation rate ρ, the fraction of exogenous in total separations (ρ^x/ρ), the vacancy filling rate (q), and the elasticity of the matching function with respect to vacancies (μ).

The employment ratio and the quarterly separation rate are set to their respective sample means, $n = 0.94$ and $\rho = 0.1$. These values of n and ρ imply $u = 1 - (1-\rho)n = 0.1525$, $hir = 0.6125$ and $N = 0.8475$. 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). The value used here is consistent with those used in the literature to account for the pool of searching workers. For a thorough discussion see Yashiv (2005).

The ratio of exogenous to total separations is set to $\rho^x/\rho = 0.68$ (from data on the quit versus the layoff rate) and the vacancy filling probability q is set to 0.71 (see den Haan, Ramey, and Watson (2000)). These two parameters are irrelevant for the dynamic implications of the model. They play a role for the response of job flows as defined in the literature using job flows data.

In the benchmark, the elasticity of the matching function μ is set to the full sample point estimate obtained from the relationship between the job finding rate, vacancies, and unemployment, with $\mu = 0.3$.[18] The scale parameter m of the matching function is pinned down by the equilibrium conditions evaluated in the non-stochastic steady state.

Of the remaining labor market parameters, I estimate non-market opportunities b and workers' average opportunity costs of employment, $\widetilde{b} = H(\overline{a})/\lambda + b$, which include disutility costs in the form of the preference shocks, and the forgone values of unemployment benefits and home production. As explained in Section 3.1.4,

[18] The estimate is from an IV regression using lagged values of vacancies and the unemployment rate.

Parameter	Description	Value	Source
n	employment ratio	0.94	data
ρ	separation rate	0.1	data
$\frac{\rho^x}{\rho}$	'quits/all separations	0.68	den Haan et al. (2000)
q	vacancy filling rate	0.7	den Haan et al.(2000)
β	discount factor	$1.03^{-.25}$	real interest rate
δ	depreciation rate	0.025	as in CEE
λ^f	mark-up	1.2	consistent with CEE estimates
α	capital share	0.36	as in CEE
μ	matching elasticity	0.3	estimate from aggregate data
ψ	price stickiness	0.85	consistent with CEE estimates
ρ_R	policy persistence	0.85	Clarida, Gali, and Gertler (1999)
γ_y	Taylor rule	0.5	Clarida, Gali, and Gertler (1999)
γ_π	Taylor rule	1.5	Clarida, Gali, and Gertler (1999)

Table 2: Calibrated Parameters

these parameters are crucial for the propagation mechanisms governing the responses of worker flows and inflation.

The value of the threshold $\overline{a}$ follows from the separation condition (14) evaluated in the non-stochastic steady state. Also, I estimate the bargaining share η, the parameter governing wage rigidity, ϕ^w, the elasticity of the preference shock distribution with respect to the threshold $\overline{a}$, $\varepsilon_{F,a}$, and the parameter σ^{vac} of the vacancy adjustment cost function. Along with the other parameters, the bargaining share determines the steady state revenue product of a match (Λ) and steady state vacancy posting costs, $\kappa^{vac} = \varkappa$. The average steady state wage $\overline{w}$ is normalized to 1. Hence, $b, \widetilde{b}$, and $\varkappa$ are reported relative to the steady state average wage.

For instantaneous utility, I assume $U\left(c_t - ec_{t-1}\right) = log(c_t - ec_{t-1})$. As in CEE, the discount factor is set to $\beta = 1.03^{-.25}$, the depreciation rate to $\delta = 0.025$, and the capital share to $\alpha = 0.36$. The parameter governing the mark-up of intermediate goods firms is set to $\lambda^f = 1.2$ in the benchmark. This value is consistent with estimates reported in CEE. As noted above, fixed costs of the intermediate goods sector, ϕ^f, are set such that steady state profits of that sector are zero. The parameters $\phi^u$and ϕ^I governing utilization and investment adjustment costs and the habit persistence parameter e are estimated.

In the benchmark estimation, the price rigidity parameter ψ is set to 0.85. This value is also used by Trigari (2004) and is consistent with estimates in CEE for the corresponding version of their model without a working capital channel (see below). The parameters of the Taylor rule are set to $\gamma_y = 0.5$, and $\gamma_\pi = 1.5$, policy persistence $\rho_R = 0.85$. These values are consistent with estimates reported in Clarida, Gali, and Gertler (1999).

Table 2 summarizes the values of the parameters Φ^c that are fixed in the benchmark.

5 Results and Discussion

5.1 Benchmark

Table 3 presents the parameter estimates. The corresponding model impulse responses are displayed as dashed lines in Figure (4) above. Overall, the model is able to replicate the empirical IRFs reasonably well. Consider the model response of the job finding rate, vacancies, the separation rate, and output. All of these responses lie within the 95% confidence bands but tend to show less persistence than their empirical counterparts. Inflation shows little response, due to (i) nominal price rigidity, (ii) a strong response of employment for a given increase of the price of job-output, (iii) an increase in capital utilization, and (iv) wage rigidity.

Parameter	Description	benchmark (1)
ϕ^w	wage rigidity	0.49 (.049)
η	worker share	0.77 (.032)
b	unemp. ben./home prod	0.96 (.011)
$\varepsilon_{F\overline{a}}$	elasticity of F	0.17 (.071)
$\widetilde{b}$	'match costs'	0.97 (.002)
σ^{vac}	convexity of vac. costs	2.63 (.22)
e	habit persistence	0.82 (.0027)
ϕ^I	investment adj.	3.46 (.064)
ϕ^u	utilization	0.013 (.0041)

Table 3: Benchmark Parameter Estimates (Standard Errors in Parentheses)

Note that the model's IRF for inflation cannot account for the price puzzle in the first quarters after the shock. In CEE, firms must finance the wage bill at nominal interest rate R. In response to an expansionary monetary shock, R falls and marginal costs may *fall* initially, due to the drop in the effective wage bill Rw in the case of 'sticky' wages. I chose not to include the working capital channel because it would introduce an additional propagation mechanism on the labor market side of the model and complicate comparisons to the existing literature. Most importantly, this channel is directly related only to monetary shocks.

First, consider the parameters that are common to this model and CEE. The estimate of the habit persistence parameter and the investment adjustment cost parameters are 0.82 and 3.46 respectively. These values are high compared to estimates in CEE ($e = 0.65$ and $\phi^I = 2.48$), but comparable to others in the literature. For example, Del Negro, Schorfheide, Smets, and Wouters (2004) obtain $e = 0.725$ and $\phi^I = 3.24$, DiCecio (2005) estimates $e = 0.76$ and $\phi^I = 3.54$. The estimate of the capital utilization parameter ϕ^u is also higher than in CEE, where ϕ^u is set to a value close to zero. The response of capital utilization (not shown) is consistent with the estimated responses in CEE. In CEE, the Calvo parameter and the mark-up of intermediate good firms is estimated. In the benchmark, these parameters are set to values consistent with the CEE estimates for the variant of their model that shuts down the working capital channel.

The estimated degree of wage rigidity is $\phi^w = 0.49$. To interpret this parameter, note that it implies that *in steady state*, wages are approximately changed every 2 quarters. The implied duration of wage contracts is short, especially in comparison to the duration of price contracts (6.5 quarters). Recall however, that a strong restriction is imposed on wage rigidity: Wages are changed if they deviate too far from a social norm average level and whenever a fixed wage would violate participation constraints and hence induce privately inefficient separations. The latter is not true for the Calvo-style pricing in the intermediate goods sector, a feature that has often been criticized in the literature, especially in conjunction with Calvo-style wage rigidity. Furthermore, relatively frequent wage changes do not imply that the resulting wage changes are large. The magnitude of the response of the wage is governed by the parameter b (and $\widetilde{b}$).

The estimates of $\widetilde{b}$ and b imply that the average wage is very close to workers' opportunity costs of employment, and almost all of these opportunity costs are non-utility costs, such as foregone income and home production, (b). Furthermore, the estimated value of the worker bargaining share is high. This parameter governs the steady state relationship of the wage to firm profits. A high value of b in conjunction with a high worker share implies that steady state firm profits are small. In particular, the estimates imply firm profits relative to the wage bill of $\frac{\Lambda - \overline{w}}{\overline{w}} = 0.13\%$. Hence, the value of b relative to the match revenue *net of capital* *costs,* $b/\Lambda = 0.96$ is also high.

The ratio b/Λ has been the focus of the recent literature on the evaluation of the MP model. Hagedorn and Manovskii (2005) report a value of $\widetilde{b}/\Lambda = 0.94$ in conjunction with a bargaining share of $\eta = 0.06$, consistent with (i) wage determination via Nash-Bargaining in a model without endogenous worker separations and without capital, (ii) the response of wages to productivity shocks (using Solon, Barsky, and Parker (1994)'s data), and (iii) profit data from Basu and Fernald (1997).

The benchmark estimate of b/Λ reported here is consistent with their result. Note however that wage determination deviates from Nash-Bargaining in the model discussed here. The value of the worker share is much higher than the one reported in Hagedorn and Manovskii (2005). Stated differently, I find that profits must be low. Recall that – in the job sector – profits compensate firms for recruiting costs. Hence, if steady state profits are low, recruiting costs must be low. The estimates imply that recruiting costs are $\frac{\kappa^{vac}}{q} = 1\%$ of the (quarterly) wage bill. Low recruiting costs in turn imply that the effect of search frictions on marginal costs and hence inflation is small (see the discussion in Section 3.1.4). This value of recruiting costs may be too low, and is lower than most values used calibration exercises. Reliable data on these costs are not available (Hamermesh (1993)).

Recall that b not only encompasses unemployment benefits, whose value is about 40% of wages (the replacement ratio), but also elusive costs such as home production. If, however, b consists mostly of alternative income sources such as unemployment benefits, its high value relative to the wage is inconsistent with evidence on income losses of displaced workers (Davis (2005)).

Because of these uncertainties, I conduct a sensitivity analysis in Section 5.3. I re-estimate the model for the cases of (i) a fixed value of $\widetilde{b} = 0.85$, and (ii) a fixed value of recruiting costs $\frac{\kappa^{vac}}{q} = 10\%$. Furthermore, the previous analysis has ignored the potential role of overhead and turnover costs as propagation mechanisms and determinants of the response of marginal costs. I integrate these in Section 6. Overhead costs are an additional source of amplification. If overhead costs are quantitatively important, the model and empirical impulse responses may be consistent with a lower value of b.

The following section analyzes the contribution of b and wage rigidity to the responses of the job finding rate, vacancies, and the inertial response of inflation.

5.2 The Role of Wage Rigidity and the Opportunity Costs of Employment

Hagedorn and Manovskii (2005)'s results may lead one to conclude that a high value of opportunity costs (b) and wage rigidity (ϕ^w) do not have different implications. This is not the case in the model developed here, and is due to the inclusion of the worker separation margin.

Figure 6 shows model impulse response functions for perturbations of $\widetilde{b}$ and the degree of wage rigidity from the estimated values to gauge their respective contributions. In the following experiments, the ratio $b/\widetilde{b}$ is held constant. The starting point are the dotted IRFs. These were constructed by setting ϕ^w to 0 (Nash-Bargaining) and $\widetilde{b}$ to a lower than estimated value (0.85). Inflation reacts strongly, whereas the job finding rate and vacancies do not react enough.

Now increase the degree of wage rigidity to its estimated value ($\Diamond$-marked IRFs). Vacancies and the job finding rate react much more strongly. Note however, that – for this moderate degree of wage rigidity – wages and inflation still react too much. The strong rise in labor market tightness increases marginal costs, through an increase of recruiting costs (κ_t^{vac}/q_t) and the wage, through a strong response of the outside option of the worker.[19]

[19] See equation (16) and the explanation given there.

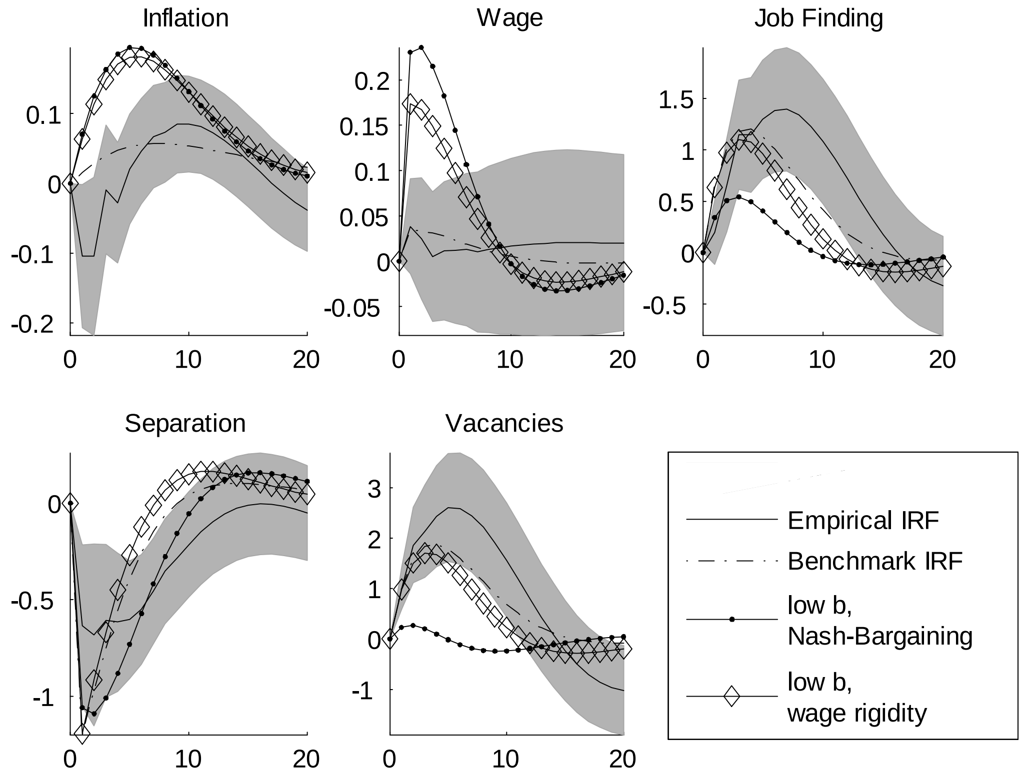

Figure 6: **Propagation Mechanisms in the Labor Market**. $\Diamond$: low $\widetilde{b}$ and real wage rigidity; $\bullet$: low $\widetilde{b}$ and Nash Bargaining.

The left panel of Figure 7 shows the percentage deviations from steady state of the joint surplus value of the match, (S_t), the firm value (J_t), and the worker surplus value (Ω_t) for the estimated degree of wage rigidity.

Under Nash-Bargaining, the percentage deviations of these values would be identical. Wage rigidity increases the response of the firm value and decreases the response of the worker value. To clarify this, suppose that there were no idiosyncratic shocks and assume that the wage is completely fixed. The current flow profits of the firm are $\Lambda_t - w^s$. The current flow surplus value of the worker is $w^s - b - hir_t\,(1-\rho^x)\,E_t\beta_{t+1}\Omega_{t+1}$, i.e., wage payments net of unemployment benefits and net of the value of outside job opportunities available through search. Now suppose a shock increases Λ_t. The firm value J_t rises. Because of free entry, vacancies and the hiring rate increase. For a given value Ω_{t+1}, the current worker value decreases if wages are fixed. For the estimated degree of wage rigidity, Ω_t does not decrease. This possibility is important in order to understand why a higher degree of wage rigidity cannot be a substitute for a high value of b, allowing profits, recruiting costs, and income losses upon worker displacement to be larger.

Figure 8 plots the case of high wage rigidity ($\phi^w = 0.9$), keeping $\widetilde{b}$ fixed at 0.85. The responses of the job finding rate and vacancies exhibit strong amplification, but separations *increase* after about 4 quarters. The reason is the high outside option of workers, stemming from the high job finding rate. As shown in the second panel of Figure 7, the worker value Ω_t falls, leading to a drop in the joint continuation surplus value (last panel of the figure). Because the joint continuation value drops, separations increase. The strong increase in vacancy creation creates a negative externality on existing jobs, by tightening the participation constraints.[20]

[20] This would also be the case under alternative formulations of wage determination that yield 'sticky' wages (e.g. Hall and

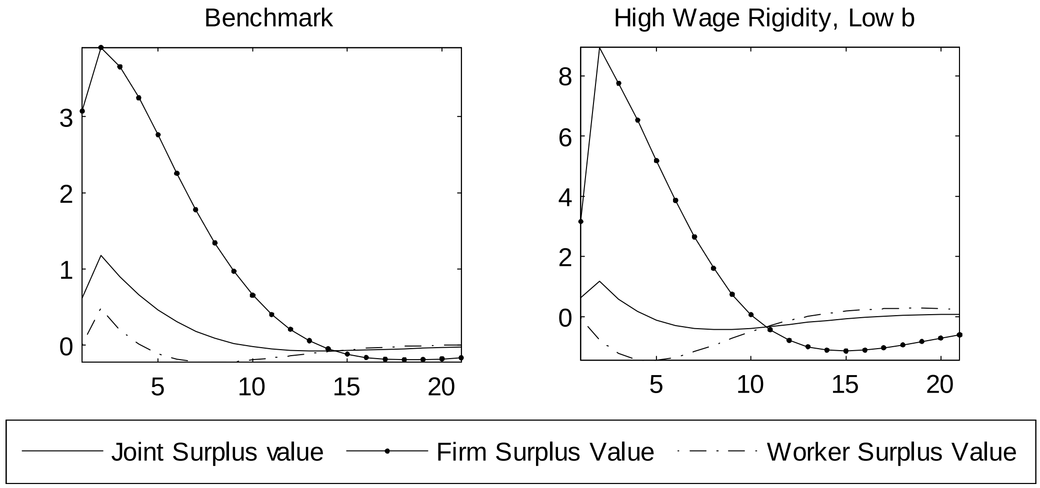

Figure 7: Surplus Values

Furthermore, inflation reacts more strongly, driven by a higher steady state value of recruiting costs and a strong response of recruiting costs.

Although the job finding rate reacts more strongly under high wage rigidity, the response of aggregate hours (not shown) is not amplified considerably. In particular, the *number of workers* relative to the work force, $hir_t u_t/N_t$, may not increase after the shock because the unemployment pool diminishes quickly and because separations drop by a smaller amount. A strong reaction of the job finding rate does not necessarily imply a strong reaction of the number of hires. This is consistent with the Bleakley, Ferris, and Fuhrer (1999) data on hiring from unemployment and non-participation (Braun, De Bock, and DiCecio (2005)), but is incompatible with the view that the hiring margin drives *employment* growth. Figure 9 plots the responses of (approximated) unemployment and the contributions of the job finding and separation rates for the VAR representation, the benchmark model estimates, and the high wage rigidity regime.[21]

Is wage rigidity irrelevant in the sense of being substitutable to a high value of the opportunity costs of employment? Figure 10 displays the IRFs (dotted lines) of the model when $\phi^w = 0$ (Nash-Bargaining) and the other parameters, including $\widetilde{b}$, are set to the benchmark estimates. Note that the job finding rate and vacancies react much less to shocks. Hence, wage rigidity plays a distinct role in the propagation of the monetary policy shock.

In Figure 10, the response of vacancies is small partly because of the convex vacancy adjustment costs needed to reconcile the model with the persistent, hump-shaped response of vacancies. Because an initial increase in vacancies is costly, amplification must be very strong. This is in line with Fujita and Ramey (2005), whose 'standard' calibration of the search model also shows large propagation due to fixed capital overhead costs.

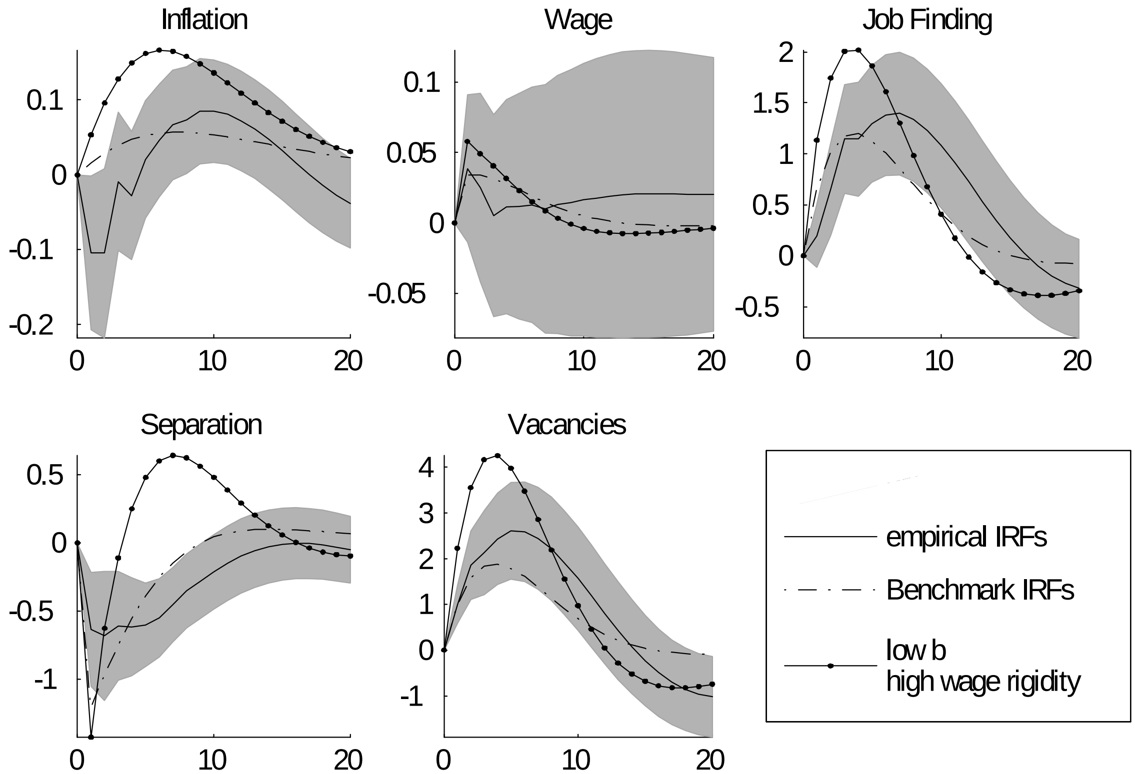

Figure 8: **High Wage Rigidity** (dotted line: $\phi^w = .9$, $\widetilde{b} = .85$)

5.3 Sensitivity Analysis

5.3.1 Fixed Recruiting Costs

Recruiting costs are a determinant of the response of marginal costs. In the estimated benchmark, these amount to only 1% of the wage bill. Here, I fix the steady state value of κ^{vac}/q to 10% of the wage bill and re-estimate the model. This value is used in the literature. The value of $\widetilde{b}$ is pinned down by steady state conditions. The parameters in Φ^c are set as in the benchmark.

Column (1) of Table 4 reports the values of the estimated parameters. The value of b is bounded by $\widetilde{b}$. In the estimation, I set $b = \widetilde{b}$, as b approached $\widetilde{b}$. The estimated degree of wage rigidity is now much higher than in the benchmark. The implied value of $\widetilde{b}$ is.0.945 Profits are 0.6% of the wage bill. The only remaining parameter that changes considerably from its benchmark estimate is the worker share η, from 0.77 to 0.61. Figure 11 shows the model's impulse response functions. As expected, the response of inflation is slightly more pronounced.

5.3.2 Fixed Opportunity Costs

Instead of fixing recruiting costs, suppose $\widetilde{b}$ is fixed at 0.85, a value closer to ones used in the endogenous destruction literature (e.g., den Haan, Ramey, and Watson (2000) and De Bock (2005)).

Column (2) of Table 4 reports the estimates. In the estimation procedure, the degree of wage rigidity increased to its upper bound 1. I fixed its value to 0.95. For the same reason, b was set to $\widetilde{b}$.

Milgrom (2005)), because the effect works through the participation constraints and continuation values of firm and worker.

[21] See section 2.1 for the construction.

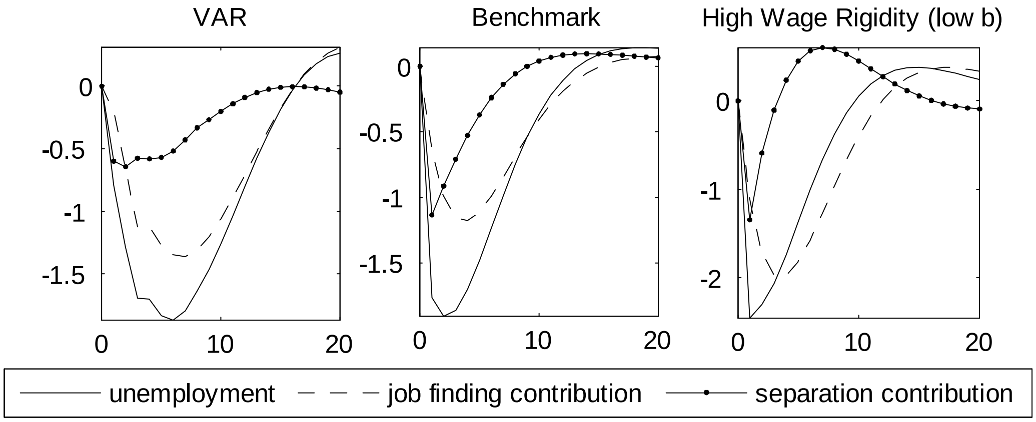

Figure 9: Unemployment and the contribution of job finding and separations

Wage rigidity now plays a crucial role. Note also that the point estimate of the elasticity of the shock distribution is large and imprecise.

5.3.3 Matching Elasticity

There are considerable differences in the calibrated and estimated values of the matching elasticity in the literature. The value used in the benchmark was estimated from aggregate data on vacancies, the official unemployment rate, and the job finding rate of unemployed workers. One of the reasons why this may be problematic is that the official unemployment pool does not include individuals from out of the labor force who search for work. Furthermore, job-to-job transitions are not taken into account in the construction of the pool of searching workers. The value $\mu = 0.3$ is low relative to the plausible range of 0.3 to 0.5 reported in Petrongolo and Pissarides (2001)'s survey of the matching function literature.

In column (3) of Table 4, the elasticity μ is estimated along with the other parameters. The estimate of the elasticity is slightly lower (0.27) and the estimates of the other parameters do not change significantly. This is consistent with Braun, De Bock, and DiCecio (2005), who find that shock specific estimates of the matching elasticity for a broad set of shocks do not differ significantly from one another.

Another data source to estimate the matching elasticity is the three-pool BLS data from Bleakley, Ferris, and Fuhrer (1999). Since this data, encompasses inflows into employment from out-of-the labor force, one can regress the *number of hires* on the (official) unemployment rate and vacancies, yielding $\mu = 0.45$. In column (4), μ is set to this value. The estimated degree of wage rigidity and the bargaining share are lower, and the elasticity of the separation margin is higher. The estimates are sensitive to the value of μ because it governs the joint responses of vacancies, the job finding rate, and unemployment.

5.3.4 Size of the Pool of Searching Workers

The average separation rate from the three-pool data is $\rho = 0.13$. In Column (5), we set the separation rate to this value while keeping n constant. The implied pool of searching workers and the job finding probability are $u = 0.18$ and $hir = 0.67$ respectively. Hence, the pool of searching workers is larger.

The estimated values of the degree of wage rigidity ϕ^w and $\widetilde{b}$ decrease. When the pool of searching workers is larger, the 'echo effect' on vacancies is less severe. As workers leave the unemployment pool, vacancy creation

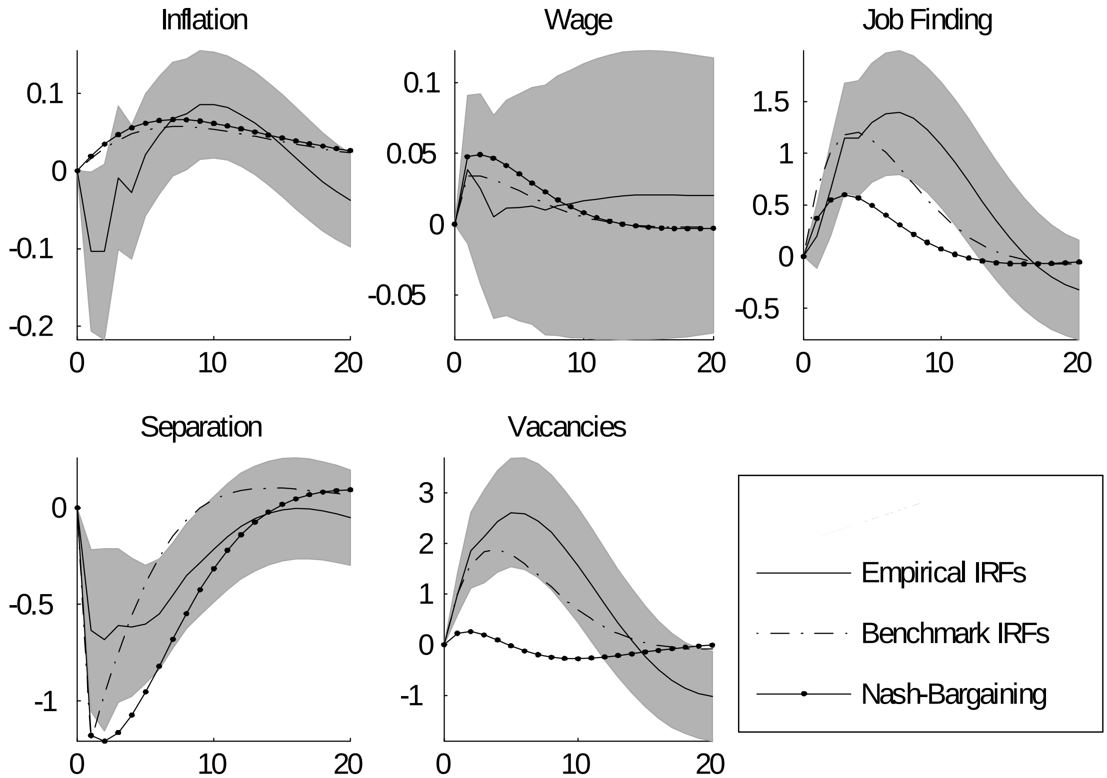

Figure 10: **Nash Bargaining:** Dotted lines are model IRFs with $\phi^w = 0$ (Nash Bargaining). The other parameters set to the benchmark point estimates.

slumps as it becomes harder for firms to find workers. But if the separation rate is high, the decrease of the unemployment pool is less pronounced. Hence, the estimates of the parameters governing the propagation are somewhat lower.

5.3.5 Nominal Price Stickiness

In Column (6), the Calvo parameter governing nominal price rigidity is set to a lower value of $\psi = 0.75$. The estimated degree of wage rigidity and $\widetilde{b}$ are now higher. The value of b is bounded by $\widetilde{b}$. In the estimation, I set $b = \widetilde{b}$, as b approached $\widetilde{b}$.[22]

6 Overhead Costs and Comprehensive Hiring Costs

Non-responsive costs accruing to the firm are a further potential propagation mechanism that has so far been omitted from the analysis. These could be fixed flow costs ω or sunk up-front training costs κ^{hir} incurred by the firm when the match is initiated, or firing taxes when the match is terminated. The former enter the surplus

[22] Attempts to estimate ψ and the markup λ^f failed. During the estimation, ψ decreased together with an increase in wage rigidity and $\widetilde{b}$. For these parameter values the solution of the model is indeterminate. See Krause and Lubik (2004a) for an analysis of indeterminacy and instability in the search model.

Parameter	Description	$\frac{\kappa^{vac}}{q}=.1$ (1)	$\widetilde{b}=.85$ (2)	μ (3)	high μ (4)	high ρ (5)	ψ (6)
ϕ^{w}	wage rigidity	0.91 (.046)	0.95 fixed	0.51 (.047)	0.43 (.053)	0.45 (.045)	0.76 (.054)
η	worker share	0.61 (.016)	0.66 (.005)	0.81 (.044)	0.69 (.037)	0.83 (.033)	0.56 (.028)
b	unemp. ben./home prod	$b=\widetilde{b}$ fixed	$b=\widetilde{b}$ fixed	0.96 (.013)	0.97 (.009)	0.95 (.015)	$b=\widetilde{b}$ fixed
$\varepsilon_{F\overline{a}}$	elasticity of F	0.17 (.073)	4.86 (4.38)	0.12 (.053)	0.29 (.081)	0.21 (.077)	0.11 (.06)
$\widetilde{b}$	'match costs'	0.94 (.012)	0.85 (.–)	0.97 (.002)	0.97 (.002)	0.96 (.002)	0.99 (.0017)
σ^{vac}	convexity of vac. costs	2.64 (.17)	1.86 (.06)	3.13 (.29)	2.47 (.25)	2.51 (.31)	3.21 (.28)
e	habit persistence	0.83 (.002)	0.84 (.002)	0.82 (.003)	0.82 (.003)	0.81 (.003)	0.83 (.0038)
ϕ^{I}	investment adj.	3.78 (.056)	4.37 (.066)	3.54 (.062)	3.53 (.060)	3.12 (.067)	3.52 (.056)
ϕ^{u}	utilization	0.022 (.004)	0.09 (.008)	.013 (.0036)	0.016 (.0039)	0.02 (.006)	0.003 (.004)
μ	matching function	0.3 (–)	0.3 (–)	.27 (.013)	.45 (–)	0.3 (–)	0.3 (–)
ψ	price stickiness	.85 (–)	.85 (–)	.85 (–)	.85 (–)	0.85 (–)	0.75 (–)

Table 4: Parameter Estimates (Standard Errors in Parentheses)

value of matches analogously to $\widetilde{b}$, but on the firm side, with

$$J_t = max_{k,\overline{a}} \int^{\overline{a}_t} \Lambda_t - \omega - w_t + (1-\rho^x)\, E_t\beta_{t+1}J_{t+1}dF(a)\,.$$

Training costs do not enter the firm value of continuing matches but the free entry condition,[23] with $\kappa_t^{vac} = q_t\left[E_t\beta_{t+1}J_{t+1} - \kappa_t^{hir}\right]$ or

$$\frac{\kappa_t^{vac}}{q_t} + \kappa_t^{hir} = E_t\beta_{t+1}J_{t+1},$$

where J_{t+1} is defined as above and we have allowed κ_t^{hir} to depend on t to signify that – like κ_t^{vac} – κ_t^{hir} may include convex adjustment costs. Expected firing taxes enter in a similar way (see Pissarides (2000)).

Expected comprehensive hiring costs per *hired* worker are $\frac{\kappa_t^{vac}}{q_t} + \kappa_t^{hir}$, consisting of the expected costs associated with advertising the vacancy until it is filled, $\frac{\kappa_t^{vac}}{q_t}$, and training costs, κ_t^{hir}. If training costs do not react much to shocks, a smaller fraction of comprehensive hiring costs increases with the fall in the vacancy filling rate q in response to expansionary shocks. Hence, given fluctuations in J translate into larger fluctuations in q_t, labor market tightness, and the job finding rate.

A formulation such as the one derived here can be a basis for the comprehensive hiring cost specification postulated in Yashiv (2005), although in his specification, hiring costs are represented as a disruption of the production process and proportional to output.

In a preliminary analysis of an extended version of the benchmark model which includes fixed values of either ω or κ^{hir}, I found estimates of the degree of wage rigidity to be higher whereas the estimate of $\widetilde{b}$ was lower. Although, ω and κ^{hir} increase the response of vacancies and the job finding rate, the response of wages also increases. Hence, the estimated degree of wage rigidity increases.

Convexities in κ_t^{hir} such as a neoclassical formulation $\kappa_t^{hir} = \left(\frac{v_t q_t}{N_t}\right)^{\gamma_{hir}}$, i.e., convexity in the *number of hires* relative to the work force, or in the *growth rate* of hires $\kappa_t^{hir} = \left(\frac{v_t q_t}{v_{t-1}q_{t-1}}\right)^{\gamma_{hir}}$ were not able to generate

[23] Formally, they are not subject to an initial wage bargain between the firm and worker. In the terminology of the literature, the 'outside wage' of newly formed matches is equal to the 'inside wage' of continuing matches. If these costs were shared between firm and worker, they would be representable as flow overhead costs. Sharing of the costs is typically assumed for firing taxes.

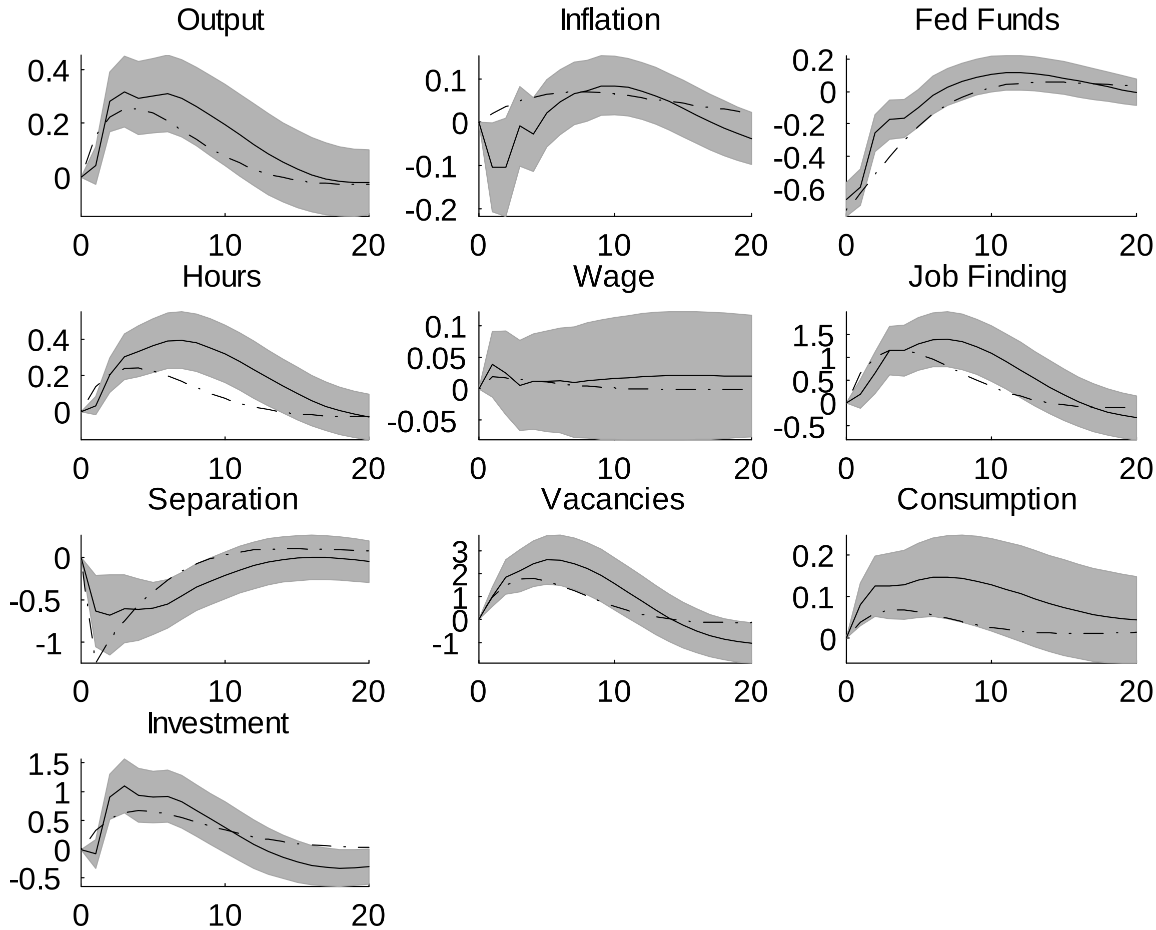

Figure 11: Fixed Steady State Recruiting Costs $\left(\frac{\kappa^{vac}}{q} = 0.1\right)$

persistent, hump-shaped response of vacancies. This did not depend on whether the adjustment costs were internal or external to the firm.

Regarding the criticism of a high value of workers' opportunity costs of employment and low recruiting costs and profits mentioned in Section 5.1 ,an implication of the inclusion of overhead and turnover costs is that the surplus value of working Ω, comprehensive hiring costs, and firm profits can be higher for a similar amplification of aggregate shocks. I am continuing to explore this propagation mechanism. Clearly, evidence on these costs is needed to disentangle them from workers' opportunity costs of employment.

7 Intensive Margin

In the benchmark model, all employment adjustment was on the extensive margin, i.e., in the number of workers. In this Section, an hours choice is introduced along the lines of Trigari (2004) to study the effects of wage rigidity on this margin.

Assume that the firm has the right to manage and that the firm chooses hours before the realization of the

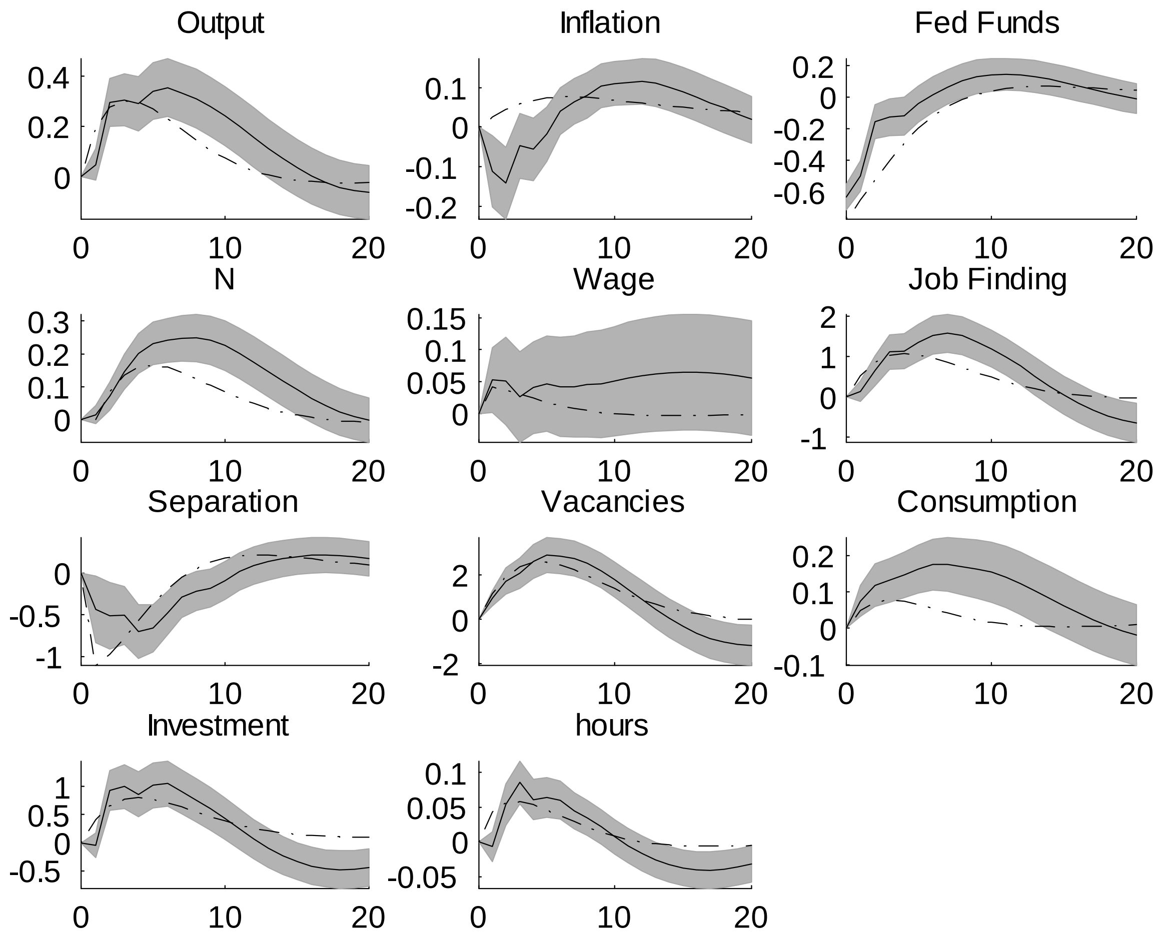

Figure 12: Empirical and Model IRFs: Intensive Margin of Hours

preference shock.[24] The firm takes into account the effect of the hours choice on subsequent wage negotiations and the separation threshold. Under Nash-Bargaining, the hours choice would be jointly efficient, in analogy to capital choice. Under wage rigidity, this is only true in steady state, when $w^s = \overline{w}$.

Job output now depends not only on capital per worker but also on hours h per worker, with

$$A_t h^{1-\alpha} k^{\alpha}$$

Firm and worker values are

$$\begin{aligned} J_t &= max_{k,h,\overline{a}} \int^{\overline{a}} \Lambda_t - w_t h + (1-\rho^x) E_t \beta_{t+1} J_{t+1} dF(a) \\ \Omega_t &= \int^{\overline{a}} wh - \frac{a + g(h)}{\lambda_t} - \underline{w}_t dF(a) \end{aligned}$$

[24]Otherwise, the firm could force the worker to her participation constraint.

where $g(h)$ is the disutility of work. Assume $g(h) = \frac{\Phi_h}{1+\sigma_h} h^{1+\sigma_h}$. The separation condition becomes

$$\Lambda_t + (1-\rho^x) E_t \beta_t J_{t+1} - \frac{g(h) + \overline{a}_t}{\lambda_t} - \underline{w}_t = 0,$$

and the average hourly wage $\overline{w}_t$ satisfies

$$\begin{aligned} F(\overline{a}_t) \overline{w}_t h &= \left(F(a_t^{max}) - F\left(a_t^{min}\right)\right) w^s h + \\ &+ \int^{a^{min}} \left((1-\eta^{max})\left(\frac{g(h)+a}{\lambda_t} + \underline{w}_t\right) + \eta^{max}\left(\Lambda_t + (1-\rho^x) E_t \beta_t J_{t+1}\right)\right) dF(a) \\ &+ \int_{a^{max}}^{\overline{a}} \left(1-\eta^{min}\right)\left(\frac{g(h)+a}{\lambda_t} + \underline{w}_t\right) + \eta^{min}\left(\Lambda_t + (1-\rho^x) E_t \beta_t J_{t+1}\right) dF(a). \end{aligned} \tag{43}$$

Assume that the firm chooses hours prior to the realization of a, and takes the effect on subsequent wage determination into account. The first order condition for h is [25]

$$(1-\alpha) \frac{p_{jt} A_t h^{1-\alpha} k^\alpha}{h} = \frac{\left(F(a_t^{max}) - F\left(a_t^{min}\right)\right)}{F(\overline{a})} w^s + F\left(a_t^{min}\right)\eta^{min} + \left(F(\overline{a}) - F(a_t^{max})\right)\eta^{max} \frac{g'(h)}{\lambda_t} \tag{44}$$

Assume that the monetary policy shock induces small changes in the fraction of wages that deviate from w^s. The linearized version of the firm's FOC for the choice of hours (44) becomes:

$$\frac{\Lambda}{h}\left(\widehat{\Lambda}_t - \widehat{h}_t\right) = \phi^w \widehat{w}^s + (1-\phi^w)\,\eta \widehat{\frac{g'(h)}{\lambda_t}}. \tag{45}$$

In effect, (45) assumes that the elasticities of the distribution at the steady state values of a^{min} and a^{max} are small. As noted before, a full specification of the distribution would allow us to include the effects working through the shares of changing wages, at the cost, however, of representing the degree of rigidity in a parsimonious way and isolating the rigidity from the level effect of wages.

Variable	Intensive Margin (1)
ϕ^w	0.78 (.05)
η	0.72 (.04)
b	set to $\widetilde{b}$ (-)
$\varepsilon_{F\overline{a}}$	0.08 (.04)
$\widetilde{b}$	0.96 (.0014)
σ^{vac}	6.5 (.16)
e	0.79 (.004)
ϕ^I	2.8 (.07)
ϕ^u	0.006 (.001)
σ^h	10 (−)

Table 5: Parameter Estimates: Intensive Margin (Standard Errors in Parentheses)

[25] To see this, use the definitions of a^{max} and a^{min} to show that the derivatives of the wage bill w.r.t. the cut-offs a^{min} and a^{max} are zero.

In the VAR, total hours are now disaggregated into employment and hours per worker. The employment series is from the BLS, hours per worker are average hours from the CES. The latter's availability limits the sample to 1964:Q3-2003:Q4. The remaining variables are unchanged. Figure 12 presents the estimated impulse response functions. Note that the responses of the variables are similar to the ones reported above. For the estimation, the parameter σ_h is set to 10 as in Trigari (2004) and is consistent with microeconomic evidence. All other parameters a set as in the benchmark.

Table 5 presents parameter estimates. The estimated degree of wage rigidity is now 0.78, much higher than in the benchmark, whereas the value of $\widetilde{b}$ is roughly unchanged.

8 Conclusion

I formulate and estimate a New-Keynesian DSGE model with search frictions in the labor market to understand (i) the propagation mechanisms generating strong and persistent responses of vacancies and the job finding rate of unemployed workers, (ii) the weaker but distinct response of worker separations, and (iii) the interaction of search frictions, wage rigidity, and inflation in response to monetary policy shocks. The model developed here can be used as a framework for designing optimal monetary policy and gauging the interaction between monetary and labor market policies. The analysis can be extended to study the interaction of other aggregate shocks with search frictions, wage rigidity, unemployment, and, for example, labor market and fiscal policies.

Both wage rigidity and a high value of workers' opportunity costs of employment are key features of the model that generate the strong responses of vacancy creation and the job finding rate observed in the data. A high value of opportunity costs of a firm-worker match in conjunction with moderate recruiting costs is responsible for the inertial response of inflation, allowing output to expand without a large increase in marginal costs. Adjustment costs in vacancies generate the persistent, hump-shaped responses of vacancies and the job finding rate. The latter could be explained together with investment adjustment costs in a time-to-build framework, a line of research followed by Braun, De Bock, and Lucca (2005).

Wage rigidity generates sufficient amplification of vacancies and the job finding rate even when workers' unresponsive opportunity costs are relatively small. However, wage rigidity is not a substitute for high opportunity costs of employment. If wage rigidity is high, vacancies and the job finding rate show a strong response. But the joint continuation value of the match may eventually fall after an expansionary shock, due to a tightening of workers' participation constraint. The decline in the continuation value may in turn induce an increase in separations that is incompatible with the data. This effect is large if opportunity costs of employment are low, because the separation margin is then mostly determined by movements in continuation values and outside job opportunities of the worker. This finding points to the importance of integrating on-the-job search. A rise in the value of outside job opportunities in response to expansionary shocks is compatible with pro-cyclical job-to-job transitions which are arguably observed in the data (Nagypal (2004)). Ignoring the cyclical properties of worker separations in explanations of unemployment and employment dynamics is not only at odds with the available data, but may also lead to erroneous conclusions about the importance of the economic mechanisms at work.

The form of wage rigidity developed here should be interpreted as a simplification that allows a general equilibrium analysis with endogenously determined worker separations into unemployment. Future research should base this reduced form on economic foundations of rigid wages, such as Menzio (2004). Also, further research is needed to understand the qualitative and quantitative aspects of the 'fixed' cost components of the match. These include home production, unemployment benefits, turnover costs such as training and firing costs, and overhead and set-up costs.

The requirement of jointly efficient separations imposed in this paper and the lack of persistence in the idiosyncratic shocks may drive some of the results pertaining to the role of wage rigidity and worker separations.

Nevertheless, the central question of whether or not we have a good understanding of the determinants of worker flows seems to be tied to the separation margin, more broadly consisting of worker separations into unemployment, job-to-job transitions, and job destruction. For such an analysis, *persistent* heterogeneity in firms' productivity and on-the-job search should be introduced.

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Variable	Units	Haver (USECON)
Civilian Noninstitutional Population (16+)	Thousands	LN16N
Real GDP	Bil. Chn. 2000 $, SAAR	GDPH
GDP: Chain Price Index	Index, 2000=100, SA	JGDP
Federal Funds (effective) Rate	% p.a.	FFED
Hours of all persons (Nonfarm Bus. Sector)	Index, 1992=100, SA	LXFNH
Index of Help-Wanted Advertising in Newspapers	Index, 1987=100, SA	LHELP
Average Weekly Hours (Private Industries)	hours, SA	
Civilian Employment (16 +)	Thousands,SA	
Unemployment (16 +)	Thousands,SA	

Table 6: Raw data

A Data

Table 6 describes the raw data used in the paper and provides the corresponding Haver mnemonics. The data are readily available from other commercial (e.g., DRI-WEFA) and non-commercial (e.g., the St. Louis FRB database FREDII) databases, as well as from the original sources (BEA, BLS, Board of Governors of the FRS).

The vacancy series used in the VAR analysis is $v = \frac{\text{LHELP}}{\text{LF}}$.

B Linearization of the Wage Equation

The average wage satisfies

$$F\left(\overline{a}_t\right)\overline{w}_t = \left(F\left(a_t^{max}\right) - F\left(a_t^{min}\right)\right)w^s \tag{46}$$
$$+\int^{a^{min}} \left(\left(1-\eta^{max}\right)\left(\frac{a}{\lambda_t} + b - \left(1-\rho^x\right)\left(1-hir_t\right)E_t\beta_{t+1}\Omega_{t+1}\right) + \eta^{max}\left(\Lambda_t + \left(1-\rho^x\right)E_t\beta_t J_{t+1}\right)\right)dF\left(a\right)$$
$$+\int_{a^{max}}^{\overline{a}} \left(1-\eta^{min}\right)\left(\frac{a}{\lambda_t} + b - \left(1-\rho^x\right)\left(1-hir_t\right)E_t\beta_{t+1}\Omega_{t+1}\right) + \eta^{min}\left(\Lambda_t + \left(1-\rho^x\right)E_t\beta_t J_{t+1}\right)dF\left(a\right)$$

Use the definitions of the cutoffs a^{max} and a^{min} to show that derivative of r.h..s with respect to these variables is zero. The linearize

$$\begin{aligned}
\overline{w}\varepsilon_{F,\overline{a}}\widehat{\overline{a}}_t + \overline{w}\widehat{\overline{w}}_t \quad &= \quad \phi^w w^s \widehat{w}_t^s \\
&+ \left(1-\phi^w\right)\left(1-\eta\right)\left(\left(1-\rho^x\right)hir\beta\Omega\left(\widehat{hir}_t + \widehat{\beta}_t + \widehat{\Omega}_t\right)\right) \\
&- \left(1-\phi^w\right)\left(1-\eta\right)\left(1-\rho^x\right)\beta\Omega\left(\widehat{\beta}_t + \widehat{\Omega}_t\right) \\
&+ \left(1-\phi^w\right)\eta\left(1-\rho^x\right)\beta J\left(\widehat{\beta}_t + \widehat{J}_t\right) \\
&+ \left(1-\phi^w\right)\eta\Lambda\widehat{\Lambda}_t \\
&- \left(\overline{w} - \phi^w w^s - \left(1-\phi^w\right)\left(\underline{w} + \eta\frac{\overline{a}}{\lambda}\right)\right)\widehat{\lambda}_t \\
&+ \left(\frac{\overline{a}}{\lambda} + \underline{w}\right)\varepsilon_{F,\overline{a}}\widehat{\overline{a}}_t
\end{aligned}$$

where we used the separation condition $\Lambda_t - \frac{\overline{a}_t}{\lambda_t} - b - \left(1-\rho^x\right)hir_t E_t\beta_{t+1}\Omega_{t+1} + \left(1-\rho^x\right)E_t\beta_{t+1}S_{t+1} = 0,$

$\underline{w} = b - (1-\rho^x)(1-hir)\beta\Omega$ and we have used

$$\begin{aligned}\left((1-\eta^{max})\int^{a^{min}} \frac{a}{\lambda}\frac{dF(a)}{F(\overline{a})} + (1-\eta^{min})\int_{a^{max}}^{\overline{a}} \frac{a}{\lambda}\frac{dF(a)}{F(\overline{a})}\right) &= \overline{w} - \phi^w w^s - (1-\phi^w)\left(\underline{w} + \eta\frac{\overline{a}}{\lambda}\right) \\ &= \overline{w} - \phi^w w^s - (1-\phi^w)\left(\underline{w} + \eta\frac{\overline{a}}{\lambda}\right)\end{aligned}$$

for the coefficient of $\widehat{\lambda}_t$.

The average wage under Nash Bargaining satisfies

$$\begin{aligned}F(\overline{a})\,\overline{w}_t^{\text{nash}} &= \int^{\overline{a}} (1-\eta)\left(\frac{a}{\lambda_t} + b + (1-\rho^x)\,hir_t E_t\beta_{t+1}\Omega_{t+1}\right) \\ &\quad +\eta\Lambda_t + \eta(1-\rho^x)E_t\beta_{t+1}J_{t+1} - (1-\eta)(1-\rho^x)E_t\beta_{t+1}\Omega_{t+1}dF(a)\end{aligned}$$

$$\begin{aligned}\overline{w}^{\text{nash}}\widehat{\overline{w}}_t^{\text{nash}} &= (1-\eta)\left((1-\rho^x)\,hir\beta\Omega\left(\widehat{hir}_t + \widehat{\beta}_t + \widehat{\Omega}_t\right)\right) \\ &\quad -(1-\eta)(1-\rho^x)\beta\Omega\left(\widehat{\beta}_t + \widehat{\Omega}_t\right) \\ &\quad +\eta(1-\rho^x)\beta J\left(\widehat{\beta}_t + \widehat{J}_t\right) \\ &\quad +\eta\Lambda\widehat{\Lambda}_t \\ &\quad +\left(\frac{\overline{a}}{\lambda} + \underline{w} - \overline{w}\right)\varepsilon_{F,\overline{a}}F(\overline{a})\,\widehat{\overline{a}}_t \\ &\quad -\left(\overline{w} - \underline{w} - \eta\frac{\overline{a}}{\lambda}\right)\widehat{\lambda}_t\end{aligned}$$

Note that $\overline{w}^{\text{nash}} = \overline{w}$ under wage rigidity. Substitute the expression for $\widehat{\overline{w}}_t^{\text{nash}}$ into the expression for $\widehat{\overline{w}}_t$ and use $\overline{w}^{\text{nash}} = \overline{w} = w^s$:

$$\widehat{\overline{w}}_t = \phi^w\left(\widehat{w}_t^s + \left(\frac{\frac{\overline{a}}{\lambda} + \underline{w}}{\overline{w}} - 1\right)\varepsilon_{F,\overline{a}}\widehat{\overline{a}}_t\right) + (1-\phi^w)\left(\widehat{\overline{w}}_t^{\text{nash}}\right)$$