Search with Wage Posting under Sticky Prices

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Abstract

We consider the macroeconomic implications of the interaction between nominal rigidities and labor market frictions in a framework where firms jointly make pricing and hiring decisions. In our New Keynesian model, workers randomly search for jobs and are matched with firms that post take-it-or-leave-it contracts and are subject to sticky prices. Relative to the typical model that separates search frictions and nominal frictions into wholesale and retail firms, respectively, our model implies smoother wages because firms can affect their marginal costs by adjusting prices. A consequence of smoother wages is that the vacancy-to-unemployment ratio responds much more than under the standard model. Additionally, our baseline model shows larger effects of changing the inflation target and smaller effects of changing unemployment benefits. We also show that combining search and price frictions in one firm leads to less volatility after technology shocks but more volatility after monetary policy shocks.

Keywords: Search, Matching, Inflation, Sticky Prices

JEL: E10, E30, E50, J60.

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1 Introduction

After the Great Recession, labor markets recovered at an anemic rate, and their slow recovery produced a drag on the economy as a whole. High unemployment and low inflation persisted for many years after the end of the recession, leading to renewed investigation of the importance of search frictions paired with inflation in determining unemployment. In particular, the interaction between labor market frictions and aggregates such as output and inflation now plays a central role in understanding the macroeconomy.

In this paper, we consider labor market frictions as a source of real rigidities, how those frictions interact with nominal rigidities in the form of sticky prices, and the implications of this interaction for the macroeconomy. We develop a framework where firms jointly post vacancies, offer workers a compensation-hours contract, and make pricing decisions. The presence of search, compensation, and pricing decisions within the same firm produces trade-offs that affect the labor market and key macroeconomic variables.

We show that the coupling of labor market and pricing frictions has important implications for the behavior of marginal costs and unemployment compared to a similar model that separates hiring in the frictional labor market and infrequent price adjustment into two types of firms. In the steady state of our baseline model changes in trend inflation have much larger effects on aggregates such as output and unemployment because price stickiness has a direct impact on hours worked. We also find that our baseline model is less sensitive to changes in benefits paid to unemployed workers because hiring firms with pricing power adjust to workers’ changing reservation wages by adjusting prices and hence their own labor demand.

We also show that the response to technology and monetary policy shocks changes once combining labor market and pricing frictions. In absolute terms, our model shows more muted responses to technology shocks and more amplified responses to monetary policy shocks than the alternative model with the wholesaler-retailer structure. Over the cycle, wages are smoother in our baseline model, which leads to greater volatility in vacancy posting and hence labor market tightness. Lastly, the loss of output due to price dispersion, a feature absent in typical models, is cyclically volatile in our baseline model because of the interaction between price stickiness
and labor demand.

Our paper builds upon the literature analyzing the role of frictional unemployment for inflation dynamics by developing a framework that allows firms to jointly make pricing and hiring decisions. Typically, papers specify labor market arrangements that preclude the direct interaction of frictions stemming from the job search process and frictions associated with infrequent price adjustment. For example, Trigari (2006), Walsh (2005), and Christiano et al. (2013) assume a wholesaler-retailer structure, where hiring in the frictional labor market is done by wholesale firms, whereas prices are set separately by monopolistic retail firms. By separating these decisions, the wholesaler-retailer structure mutes the impact of their interactions. In our model, firms making the pricing decisions also make hiring and wage posting decisions, leading to a stronger degree of interaction between these frictions. In particular, because search frictions make labor a firm-specific factor in the short-run, pricing decisions at the firm-level critically depend on the curvature of labor disutility from the existing worker.¹

In addition to dropping the wholesaler-retailer structure, we also allow firms to post wages rather than Nash bargain with the worker as is typically assumed.² By assuming take-it-or-leave-it wage offers, our current structure severs the link between individual wages and aggregate labor market tightness. Hall (2005) and Hall and Milgrom (2008) emphasize that standard search models require a loose connection between individual wages and aggregate conditions in order to generate realistic unemployment fluctuations. Nash bargaining generates too strong of a linkage which produces little volatility in unemployment and vacancies. More recently, Christiano et al. (2013) find that incorporating the bargaining protocol developed by Hall and Milgrom (2008) into a New Keynesian model significantly improves its statistical fit compared to sticky wage alternatives.

In contrast to the random search that we use, Hall and Krueger (2012) and Rogerson and Shimer (2010) note that wage posting models typically assume workers direct their search toward vacancies. Cooper et al. (2007) allow for wage posting and random search, but by focusing on

¹Kuester (2010) obtains a similar result when wages and prices are infrequently bargained.
²See for example, Kuester (2010), Barnichon (2010), Thomas (2011), and Dossche et al. (2014), for papers that combine search and pricing frictions within the same firm when wages are Nash bargained.
a real economy, lack the ability to discuss the relationship between inflation and unemployment and the effects of monetary policy on both. Our analysis of wage posting and random search in a New Keynesian environment complements their work. From an empirical standpoint, evidence from Hall and Krueger (2012) suggests wage posting is at least as common as bargaining over pay. Finally, compared to sticky wage models along the lines of Christiano et al. (2005), in our framework firms rather than workers post wages.

The remainder of the paper is as follows. Section 2 describes our model of search with wage posting and sticky prices; we also outline an alternative model that separates search and pricing frictions into separate firms. Section 3 considers comparative statics of the steady state of our baseline model, and contrasts these results with the alternative model. Section 4 discusses the dynamic properties of our model, first looking at impulse responses and then examining important labor market ratios; again we contrast our results with the alternative setup. Finally, Section 5 concludes.

2 Model

The model we present is a variant of the conventional New Keynesian monetary framework. The key changes involve the labor market and the contractual environment. Unemployment is modeled by introducing random search. Rather than assuming firms and workers bargain over wages, hiring firms post take-it-or-leave-it offers that stipulate compensation and hours worked. Nominal rigidities are introduced by assuming hiring firms set prices subject to Calvo frictions. This feature that the same firms make the hiring, wage posting, and pricing decision is the key feature of our model.

The following subsections describe the model: individuals who supply labor and consume, final goods producers that bundle intermediate goods, intermediate goods firms that set prices and hire workers in a frictional labor market by posting wages, the evolution of the labor market, the monetary authority and government, and the market clearing conditions. We then sketch an alternative model that separates labor market frictions from price setting frictions. The section
concludes with a discussion of the calibration.

2.1 Individuals

There is a unit mass of individuals, indexed by \( i \in [0, 1] \), who consume \( C_{i,t} \) and work hours \( H_{i,t} \), obtaining utility from the period utility function

\[
U(C_{i,t}, H_{i,t}) = \frac{(C_{i,t} - \varphi H_{i,t}^{1+1/\psi})^{1-\gamma} - 1}{1 - \gamma} \quad (1)
\]

The period utility function depends on the constant relative risk aversion \( \gamma \), a disutility of labor \( \varphi \), and the Frisch elasticity \( \psi \). Individuals discount future utility at rate \( \beta \).

Preferences are of the form devised by Greenwood et al. (1988), which eliminates any wealth effect on the labor supply, an assumption that provides multiple benefits in our framework. First, it greatly simplifies the contractual environment, as the presence of wealth effects on labor supply would imply that firms would vary their wage offering depending upon the wealth of the worker. Wealth effects on labor supply would also counterfactually imply asset-rich individuals preferring unemployment over employment. Second, along with the assumption on the contracting environment, it allows us to dispatch with perfect consumption insurance or a large household assumption typical in New Keynesian models with search (for example, Kuester (2010)). In these models, individuals typically are forced by the household to undertake potentially sub-optimal hours decisions from an individual standpoint to benefit the household as a whole. Instead, our model has individuals optimizing their labor market choice without consideration for other individuals.

Individuals purchase consumption goods at price \( P_t \) and buy nominal bonds \( B_t \) which have gross return \( R_t \) in period \( t + 1 \). They also own shares in a mutual fund that owns all other firms.

\(^3\) Mustre-del Río (2014) finds that for prime age males employment is roughly flat with household wealth.

\(^4\) Given the contracting environment and utility specification, our model with individuals making independent choices would be equivalent to a large household model with perfect utility insurance, with all utility of individuals equalized. There has been some progress in considering sticky-price models with more general types of heterogenous consumers, but computational difficulties severely constrain the size of the model (Gornemann et al. (2012)).
in the economy; the mutual fund pays real dividends $D_t$.\footnote{Given symmetric initial conditions, in equilibrium all individuals own equal shares in the mutual fund and no trading occurs, so we impose this result from the outset for notational simplicity. A technical appendix for the entire model is available upon request.} Finally, they pay real lump sum taxes equal to $T_t$.

The employment status $N_{i,t}$ of each individual varies between being unemployed ($N_{i,t} = u$) and employed ($N_{i,t} = e$). In each period a fraction $n_t$ of individuals are employed, and $u_t = 1 - n_t$ are unemployed.

Unemployed individuals work zero hours ($H_{i,t}^u = 0$), collect real unemployment benefits from the government equalling $b_t$, and search for employment the subsequent period, which occurs in equilibrium with probability $s_t$.\footnote{For simplicity we abstract from the participation decision, hence all non-employed individuals are active searchers.} If $E_t$ denotes the expectations operator conditional on time $t$ information, an unemployed worker’s problem is therefore

$$W_{i,t}^u = \max_{C_{i,t}^u, B_{i,t}^u} \left\{ \frac{(C_{i,t}^u)^{1-\gamma} - 1}{1 - \gamma} + \beta E_t \left[ s_t W_{i,t+1}^e + (1 - s_t) W_{i,t+1}^u \right] \right\}$$

subject to

$$P_tC_{i,t}^u + B_{i,t}^u + P_tT_t = P_tb_t + R_{t-1}B_{i,t-1} + D_t.$$ \hfill (3)

Employed workers, on the other hand, work nonzero hours $H_{i,t}$ and are paid a real compensation level $\omega_{i,t}$. Their existing job ends with probability $\delta$, in which case they enter unemployment the following period; with probability $(1 - \delta)$ they remain employed. An employed worker’s problem is therefore

$$W_{i,t}^e = \max_{C_{i,t}^e, B_{i,t}^e} \left\{ \frac{(C_{i,t}^e - \varphi H_{i,t}^{1+1/\psi})^{1-\gamma} - 1}{1 - \gamma} + \beta E_t \left[ (1 - \delta) W_{i,t+1}^e + \delta W_{i,t+1}^u \right] \right\}$$

subject to

$$P_tC_{i,t}^e + B_{i,t}^e + P_tT_t = P_t\omega_{i,t} + R_{t-1}B_{i,t-1} + D_t.$$ \hfill (5)

Note that employed workers do not choose $H_{i,t}$, as hours are determined within the firm’s
contracting environment.

Standard optimality conditions for unemployed and employed individuals yield an Euler equation for the unemployed

\[
\lambda_{i,t}^u = \beta \mathbb{E}_t \left[ \frac{s_t \lambda_{i,t+1}^u + (1 - s_t) \lambda_{i,t+1}^u}{\Pi_{t+1}} \right] R_t, \tag{6}
\]

and for the employed

\[
\lambda_{i,t}^e = \beta \mathbb{E}_t \left[ \frac{(1 - \delta) \lambda_{i,t+1}^e + \delta \lambda_{i,t+1}^u}{\Pi_{t+1}} \right] R_t, \tag{7}
\]

where \(\Pi_{t+1} = P_{t+1}/P_t\) is the gross inflation rate. The marginal utility of consumptions for the unemployed are given by

\[
\lambda_{i,t}^u = (C_{i,t}^u)^{-\gamma},
\]

and for the employed are

\[
\lambda_{i,t}^e = \left( C_{i,t}^e - \varphi H_{i,t}^{1+1/\psi} \right)^{-\gamma}. \tag{8}
\]

Given symmetric initial conditions on bond-holdings, the optimal contact to be discusses equalizes the value of employed and unemployed workers, which implies

\[
C_{i,t}^u = C_{i,t}^e - \varphi H_{i,t}^{1+1/\psi}.
\]

As a result, we get symmetry of the marginal utilities of consumption

\[
\lambda_t = \lambda_{i,t}^u = \lambda_{i,t}^e. \tag{9}
\]

2.2 Final Goods Producers

Final goods producers operate competitively, purchasing \(Y_{j,t}\) from \(j \in [0, n_t]\) operating intermediate goods firms and combine them into final output \(Y_t\) using a technology with constant elasticity of substitution \(\epsilon\) :

\[
Y_t = n_t \left( \frac{1}{n_t} \int_0^{n_t} Y_{j,t} \frac{\epsilon-1}{\epsilon} dj \right)^{\frac{\epsilon}{\epsilon-1}}. \tag{10}
\]
Standard cost minimization implies that the demand for each intermediate good $Y_{d,j,t}$ depends on its relative price according to

$$ Y_{d,j,t} = \left( \frac{P_{j,t}}{P_t} \right)^{-\epsilon} \frac{Y_t}{n_t}. \quad (11) $$

The aggregate price level is related to the individual prices by

$$ P_{t}^{1-\epsilon} = \frac{1}{n_t} \int_{0}^{n_t} P_{j,t}^{1-\epsilon} dj. \quad (12) $$

### 2.3 Intermediate Goods Producers

Intermediate goods firms are indexed by $j$, and produce using the linear technology

$$ Y_{s,j,t} = Z_t H_{j,t}, \quad (13) $$

where $H_{j,t}$ is hours at firm $j$ and total factor productivity $Z_t$ follows

$$ \log Z_t = \rho_z \log Z_{t-1} + \sigma_z \varepsilon_{z,t}. \quad (14) $$

Firms sell their output at price $P_{j,t}$ and are subject to a Calvo friction when setting prices. Firms employ a single worker; conditional on being matched with a worker the firm negotiates a contract $\Upsilon_{j,t} = (\omega_{j,t}, H_{j,t})$ that determines a compensation level $\omega_{j,t}$ and an hours requirement $H_{j,t}$. Firms face a two-stage problem: in the first stage they set prices and in the second stage they contract with labor and produce.

In the second stage, given a price $P_{j,t}$, firms make a take-it-or-leave-it offer to their worker. They choose a contract $\Upsilon_{j,t}$ to maximize current period profits

$$ D_{j,t} = \left( \frac{P_{j,t}}{P_t} \right) Y_{d,j,t} - \omega_{j,t}, \quad (15) $$

subject to their demand (11), the constraint that they must meet demand at the posted price.
$Y_{j,t}^s \geq Y_{j,t}^d$, and their matched worker’s participation constraint

$$W_{i,t}^u \leq W_{i,t}^e.$$  

Since the firm will always choose to make the participation constraint (16) bind, then for symmetric initial conditions on asset holdings, the value function for an unemployed individual (2) and an employed one (4) imply the optimal contract satisfies

$$\omega_{j,t} = b + \varphi H_{j,t}^{1+\frac{1}{\beta}}.$$  

This equation reveals that the equilibrium compensation contract when firms make take-it-or-leave-it offers to workers is a special case of Nash bargaining when workers’ bargaining weight is zero. Under this scenario individual wages no longer depend on aggregate labor market tightness. Thus, cyclical variation in compensation is solely due to changes in labor demand through hours worked $H_{j,t}$, which will also depend on the firm’s set price.

Typically, New Keynesian models focus on the per hour wage rate that firms and workers either bargain over, or that is determined in a frictional or frictionless equilibrium. In our setup, we focus on compensation due to the tight link between hours and compensation in the optimal contract equation (17). This compensation scheme is isomorphic to a contract that specifies hours and a wage, since $\Upsilon_{j,t} = (\omega_{j,t}, H_{j,t}) = (W_{j,t}H_{j,t}, H_{j,t})$, where $W_{j,t}$ denotes the wage. However, Figure 1 shows that, while compensation is increasing in hours, the effective wage is non-monotonic due to the fact that base compensation with zero hours must equal the unemployment benefits $b$. In addition, the figure highlights the impact of the Frisch elasticity on compensation and the effective wage: for a given number of hours, a higher Frisch implies larger compensation and a higher effective wage.

Given the optimal contract, in the first stage a matched firm can re-optimize its price subject to a Calvo friction. The value of an operating firm with price $P_{j,t}$ is given by

$$J_t (P_{j,t}) = \left( \frac{P_{j,t}}{P_t} \right) Y_{j,t}^d - \omega_{j,t} + \beta (1 - \delta) E_t \frac{\lambda_{t+1}}{\lambda_t} \left[ \zeta J_{t+1} (P_{j,t}) + (1 - \zeta) J_{t+1} (P_{t+1}^*) \right],$$  

(18)
where $\frac{\lambda_{t+1}}{\lambda_t}$ denotes the stochastic discount factor, $\zeta$ the probability of not re-optimizing prices, and $P_t^*$ denotes the optimal price set by a firm that can re-optimize in $t$. Since the optimal compensation scheme depends on hours, and firms must meet demand at the posted price, the value is given by

$$
J_t(P_{j,t}) = \left( \frac{P_{j,t}}{P_t} \right)^{1-\epsilon} \frac{Y_t}{n_t} - b - \varphi \left( \frac{P_{j,t}}{P_t} \right)^{-\epsilon} \frac{Y_t}{Z_t n_t} \right)^{1+\frac{1}{\epsilon}} + \beta (1-\delta) \mathbb{E}_t \frac{\lambda_{t+1}}{\lambda_t} \left[ \zeta J_{t+1}(P_{j,t}) + (1-\zeta) J_{t+1}^* \right]
$$

which highlights the fact that prices, by pinning down demand, consequently pin down hours and hence total compensation. A firm that can re-optimize prices, hence, takes this dependence
of hours and compensation on the relative price, with the optimal price satisfying

\[ P_t^* = \arg \max J_t(P_{jt,t}). \] (20)

### 2.4 Vacancy Posting and the Labor Market

Firms post vacancies at cost \( \kappa \), which are filled with probability \( q_t \) and become productive the following period. At the beginning of \( t + 1 \) price adjustment occurs, then contracting and production. New entrants inherit a price level in period \( t \) equal to the aggregate price level \( (P_{jt,t} = P_t) \), and receive a Calvo shock before production in \( t + 1 \). Because of free entry, firms post vacancies until the vacancy posting cost equals the expected return which implies

\[ \kappa = q_t \beta \delta_t \frac{\lambda_{t+1}}{\lambda_t} \left[ \zeta J_{t+1}(P_t) + (1 - \zeta) J_{t+1}(P_{t+1}^*) \right]. \] (21)

Matches \( m_t \) depend upon the number of unemployed \( u_t \) and the number of vacancies \( v_t \) according to

\[ m_t = \sigma_m u_t^\alpha v_t^{1-\alpha} \] (22)

where \( \sigma_m \) governs the efficiency of the matching function, and \( \alpha \) is the elasticity of matches with respect to the number of unemployed. The job filling rate is \( q_t = m_t/v_t \).

New matches take one period to form, and existing matches are destroyed at an exogenous rate \( \delta \). Consequently, employment evolves according to

\[ n_t = (1 - \delta) n_{t-1} + m_{t-1}. \] (23)

### 2.5 Monetary Authority and Government

Monetary policy follows a Taylor Rule, setting the nominal rate \( R_t \) according to

\[ \frac{R_t}{R_{ss}} = \left( \frac{R_{t-1}}{R_{ss}} \right)^{\rho_r} \left( \frac{\Pi_t}{\Pi_{ss}} \right)^{(1-\rho_c)\gamma_r} \exp \left( \sigma_r \varepsilon_{r,t} \right), \] (24)
where $\Pi_{ss}$ indicates the inflation target, $R_{ss}$ the nominal rate target, $\rho_r$ the degree of interest rate persistence, $\gamma_\pi$ the response to inflation, and $\varepsilon_{r,t}$ denotes a monetary policy shock.

Fiscal policy adjusts lump sum taxes to balance the budget. The government pays unemployment benefits $b$ and interest on debt by issuing debt and collecting lump-sum taxes:

$$P_t u_t b + B_{t-1} R_{t-1} = B_t + P_t T_t.$$  \hfill (25)

### 2.6 Market Clearing

Market clearing requires that aggregate output equals aggregate consumption

$$Y_t = C_t,$$  \hfill (26)

while aggregate consumption is the consumption of all individuals

$$C_t = \int_0^{n_t} C_{i,t}^e di + \int_{n_t}^1 C_{i,t}^u di.$$  \hfill (27)

Aggregate hours is defined as the hours worked by all employed individuals

$$H_t = \int_0^{n_t} H_{i,t} di,$$  \hfill (28)

which is related to aggregate output by

$$Z_t H_t = \varsigma_t Y_t.$$  \hfill (29)

The rate of domestic absorption, also called the loss in output due to price dispersion, is defined as

$$\varsigma_t = \frac{1}{n_t} \int_0^{n_t} \left( \frac{P_{j,t}}{P_t} \right)^{-\varepsilon} dj.$$  \hfill (30)

This concludes the discussion of our baseline model.
2.7 Alternative Model with Wholesalers

To isolate the importance of allowing pricing and labor market frictions to interact within the firm we outline an alternative model with the customary wholesaler-retailer structure and posted wages. Wholesale producers hire labor in the frictional labor market using wage posting and produce a competitively priced good. Monopolistically competitive retail firms face Calvo price frictions and purchase the wholesale good and convert it into a differentiated good. The remaining aspects of the alternative model are the same as the baseline.

Focusing on the wholesaler problem, they operate a linear technology

\[ Y^w_t = Z_t H_t. \] (31)

Wholesalers take their price \( P^w_t \) as given and choose hours worked to maximize

\[ J_t = \max_{H_t} \frac{P^w_t}{P_t} Z_t H_t - b - \varphi H_t^{1+1/\psi} + \beta (1 - \delta) E_t \frac{\lambda_{t+1}}{\lambda_t} J_{t+1} \]

Note that this expression already includes the definition of the optimal contract when firms offer take-it-or-leave-it contracts to workers. The first-order condition with respect to hours implies:

\[ H_t = \left[ \frac{P^w_t Z_t}{\varphi (1 + 1/\psi)} \right]^\psi \] (32)

Under this alternative structure the free-entry condition takes the usual form

\[ \kappa = q_t \beta E_t \frac{\lambda_{t+1}}{\lambda_t} J_{t+1} \] (33)

Retailers face a standard problem that can be summarized by the condition characterizing the optimal reset price

\[ \sum_{k=0}^{\infty} (\beta \zeta)^k \frac{\lambda_{t+k}}{\lambda_t} \left[ \frac{P^*_t}{P_{t+k}} - \mu \frac{P^w_{t+k}}{P_{t+k}} \right] Y_{t+k} P^c_{t+k} = 0 \] (34)
where $\mu = \frac{1}{1-\zeta}$ is the flexible price markup, $Y_t$ is demand for the final good, and $P_t$ is the aggregate price level.

To gain insight into the difference between our baseline model and this alternative model with the wholesaler-retailer structure consider the expression the optimal reset price satisfies in our baseline model

$$
\sum_{k=0}^{\infty} (\beta(1-\delta))^k \frac{X_t}{\lambda_t} \left[ \frac{P^*_t}{P_{t+k}} - \mu \frac{\varphi(1+1/\psi)H^{1/\psi}_{j,t+k}}{Z_{t+k}} \right] \frac{Y_{t+k}}{n_{t+k}} P^*_{t+k} = 0. \tag{35}
$$

There are two important differences between equations (34) and (35). First, in our baseline model because intermediate firms face pricing and labor market frictions they discount future revenues both by the expected duration of the current price $\zeta$ and the expected duration of the current match $(1-\delta)$. In contrast, in the alternative model retail firms do not care about match duration when setting their prices. Additionally, across the two models marginal costs are notably different. In the alternative model, marginal costs are simply given by the relative price of wholesale goods $\frac{P^w_{t+k}}{P_{t+k}}$, whereas in our baseline model marginal costs depend on the marginal disutility of hours worked $\varphi(1+1/\psi)H^{1/\psi}_{j,t+k}$.

### 2.8 Calibration

The parameters fall into two categories: parameters that are fixed at standard values and parameters that are chosen to match certain targets in steady state.

Table 1 lists the parameters fixed at standard values. The discount factor $\beta$ is set to imply a model period is one quarter. The coefficient of risk aversion $\gamma$ and the Frisch elasticity of labor supply $\psi$ are set to standard values in the literature. The probability of not re-optimizing prices $\zeta$ is set to match a median price duration of six months as reported in Bils and Klenow (2004). Following Gertler et al. (2008), we set the elasticity of substitution across goods to $\epsilon = 10$. Consistent with empirical estimates in Shimer (2005) and den Haan et al. (2000) we target a quarterly separation rate of 10 percent, so $\delta = 0.10$. The elasticity of the matching function with respect to unemployment $\alpha$ is set to 0.5, which is the midpoint of values typically cited
Table 1: Standard Calibrated Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\beta$</td>
<td>Discount factor</td>
<td>0.9951</td>
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<tr>
<td>$\gamma$</td>
<td>Risk aversion</td>
<td>2</td>
</tr>
<tr>
<td>$\psi$</td>
<td>Frisch elasticity</td>
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</tr>
<tr>
<td>$\zeta$</td>
<td>Prob. not re-optimizing prices</td>
<td>0.66</td>
</tr>
<tr>
<td>$\epsilon$</td>
<td>Elasticity of substitution</td>
<td>10</td>
</tr>
<tr>
<td>$\delta$</td>
<td>Separation rate</td>
<td>0.1</td>
</tr>
<tr>
<td>$\alpha$</td>
<td>Matching function elasticity</td>
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</tr>
<tr>
<td>$\rho_r$</td>
<td>Policy persistence</td>
<td>0.6</td>
</tr>
<tr>
<td>$\gamma_\pi$</td>
<td>Response to inflation</td>
<td>1.5</td>
</tr>
<tr>
<td>$\rho_z$</td>
<td>Technology persistence</td>
<td>0.95</td>
</tr>
<tr>
<td>$\sigma_r$</td>
<td>Std Dev MP shock</td>
<td>0.001</td>
</tr>
<tr>
<td>$\sigma_z$</td>
<td>Std Dev technology shock</td>
<td>0.001</td>
</tr>
</tbody>
</table>

in the literature. Lastly, the parameters governing shocks and monetary policy are also set to standard values.

Table 2 lists the parameters calibrated to match steady state values. In general, these steady state values depend on the level of the inflation target. The calibration uses a constant price level, $\Pi_{ss} = 1$. Following Blanchard and Diamond (1990) we target a steady state unemployment rate of 11 percent, which includes both individuals who are categorized as unemployed and those out of the labor force who want a job. Following den Haan et al. (2000), we target a steady state worker finding rate of 70 percent, so $q_{ss} = 0.7$. These assumptions directly pin down the matching efficiency parameter $\sigma_m$.

The remaining parameters to be determined are $b$, $\varphi$, and $\kappa$. We choose $b$ such that in steady state the replacement ratio, defined as the ratio of unemployment benefits to the average compensation in steady state, equals $1/2$, which is roughly the mid-point between values in the literature.\footnote{For example, Shimer (2005) considers a value of 0.4 while Hagedorn and Manovksii (2008) consider a value close to one.} Note that our model by construction implies a replacement ratio of one if unemployment benefits include the consumption equivalent of the disutility of hours worked. We choose the disutility of hours worked $\varphi$ such that steady state hours worked per employed person equal $1/3$. These assumptions ensure that steady state profits are positive. Lastly, $\kappa$ is
Table 2: Parameters Calibrated to Match Steady State Targets

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
<th>Value</th>
<th>Target</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Pi_{ss}$</td>
<td>Inflation target</td>
<td>1</td>
<td>Normalization</td>
</tr>
<tr>
<td>$\sigma_m$</td>
<td>Matching efficiency</td>
<td>0.7526</td>
<td>$u_{ss} = 0.11$</td>
</tr>
<tr>
<td>$\kappa$</td>
<td>Vacancy posting</td>
<td>0.8895</td>
<td>$q_{ss} = 0.70$</td>
</tr>
<tr>
<td>$b$</td>
<td>Unemployment benefits</td>
<td>0.1</td>
<td>$b/\omega_{ss} = 1/2$</td>
</tr>
<tr>
<td>$\varphi$</td>
<td>Disutility of labor</td>
<td>2.7</td>
<td>$H_{j,ss} = 1/3$</td>
</tr>
</tbody>
</table>

directly implied from the steady state free-entry condition.

3 Steady State Comparative Statics

In order to gauge the importance of wage posting and search in our environment, we first turn to analyzing the steady state of the economy. The steady state of the model has no aggregate shocks, but with idiosyncratic firm- and individual-level shocks still operational. In our framework, the result is a stationary distribution where the number of entering firms equals the number that exit, and the number of unemployed workers that are matched with firms equals the number of employed workers that find their matches severed. In addition, the economy has a distribution of relative prices. Given a zero inflation steady state this distribution is degenerate with all firms having the same price. However, given the lack of price indexation of non-optimizing firms, positive trend inflation creates a non-degenerate distribution of prices and hence real effects, a feature that is informative about the importance of our wage posting framework.

Firms set prices subject to a Calvo friction. With their relative price leading to the level of demand they face prices pin down hours demanded and ultimately the compensation they must pay their worker. From the equation determining the optimal contract (17), compensation must pay the worker the level of unemployment benefits $b$ plus the consumption value of their hours $\varphi H_{j,t}^{1+\frac{1}{\psi}}$. A higher level of unemployment benefits $b$ implies a higher base level of compensation. A higher Frisch elasticity $\psi$ implies a higher compensation given a fixed number of hours. In steady state, operating firms must also be able to make a profit, otherwise no entry will occur.
and the economy will degenerate.

Figure 2 shows how the maximum unemployment benefits $b$ varies depending upon the Frisch elasticity $\psi$. In our calibration, $\psi = 0.5$ implies that $b = 0.233$ is the maximum allowed. If $b > 0.233$, given our parameterization of the vacancy posting cost $\kappa$, firms are not willing to post vacancies, and the economy breaks down. Lower values of the unemployment benefits, such as our calibration of 0.1, imply a lower compensation rate, meaning existing firms make profits to offset the cost of posting vacancies. As the Frisch elasticity $\psi$ increases (holding the vacancy posting cost constant), so does compensation for a given number of hours, so the maximum base level of compensation decreases.

Figure 2 also shows that the effects of higher trend inflation shift the maximum allowed unemployment compensation downward. Higher trend inflation lowers the maximum allowable unemployment compensation because it erodes expected profits of operating firms. Firms that
have re-optimized recently have relatively high prices, sell a small quantity, require few hours, and hence earn higher profits and pay less compensation. Firms that have not re-optimized recently have low relative prices, sell a high quantity that requires many hours and a high compensation level, which leads to negative profits. Firms consider the expected present discounted value of profits when deciding to post a vacancy. High inflation lowers their expected profits and increases their expected labor compensation leading to the need for a lower $b$ in order for firms to enter. None of these effects exist in the alternative model since wholesale firms take prices as given when considering to post vacancies.

Given our calibrated unemployment benefit of $b = 0.1$, Figure 3 shows how increasing trend inflation from an annualized rate of 0% to one of 3% affects the economy, relative to the zero trend inflation case. Higher inflation distorts the economy by eroding prices and diminishing profits through the lack of price indexation. In general equilibrium this effect leads to fewer willing entrants, which distorts the labor market, output, and consumption. Figure 3 reveals that as trend inflation increases, firms post fewer vacancies, which in turn lowers the job finding rate, and increases the unemployment rate. The net effect on the matching market is a higher job-filling rate with a lower matching rate.

The hump shape in hours worked and output is the result of two opposing forces. For low levels of inflation, there is little movement in the number of employed workers, and some firms with old prices demand much more hours, leading to an increase in aggregate hours. As inflation increases, employment drops more rapidly as the job creation margin is distorted. Reduced job creation more than offsets the fact that firms demand more hours when they have old prices. As a result, aggregate hours drops rapidly for higher levels of inflation, a pattern also seen in aggregate output. Trend inflation also leads to a higher dispersion of prices, and the loss of output due to price dispersion increases.

The fact that firms must pay compensation to their matched worker who is supplying hours, and that this compensation is subject to curvature in the amount of hours produces the stark differences relative to the alternative model with a wholesaler-retailer structure, as Figure 3 shows. Recall this alternative framework separates price-setting and wage contracting. In the
baseline model, higher trend inflation has much stronger effects on most of the variables, since price stickiness directly impacts the worker’s hours through demand and the production function. Greater degrees of price dispersion have larger effects due to the curvature of the utility function. In the alternative model, price stickiness does not interact directly with compensation of workers and hours, so as trend inflation increases the labor market shows relatively little change, as do aggregate hours and output.

Figure 4 gives more indication as to the differences between our baseline model and the alternative that separates price-setting and wage-setting. The figure shows the effect, in steady state, of changing the unemployment benefits $b$ to vary the replacement ratio, relative to our calibrated replacement ratio of $1/2$ ($b = 0.1$), all under zero trend inflation. In our model,
as the replacement ratio and unemployment benefits decrease, the base level of compensation that firms must pay to workers decreases, which makes them more willing to post vacancies, so unemployment declines, and aggregate hours and output increase.

In the alternative model, these same effects are present, but to a greater degree. Average compensation in the alternative model moves less because of level effects. Average steady state compensation in the alternative model is higher than in the baseline model. Hence, a similar absolute change in benefits implies a smaller relative change in compensation. The fact that aggregates in the alternative model are more responsive to changes in the replacement ratio is critically due to the separation of price and wage-setting. In the alternative model hiring wholesale firms take the price of their goods as given and hence can only respond to changes in $b$
by adjusting hours worked. In contrast, in the baseline model hiring firms can also adjust prices in response to changes in \( b \). Since hours adjust more in the alternative model unemployment and all other aggregates are more responsive. These results highlight the importance of market power for hiring firms. Without market power the economy is more responsive to changes in the level of unemployment benefits even when wages are posted rather than bargained.

4 Effects of Shocks

Having discussed some of the steady state properties of our model, we now turn to considering the dynamics associated with different shocks. Again we compare our specification of wage posting and search directly by firms that have pricing power with the alternative retailer-wholesaler environment that separates the these actions into different firms. The two shocks in the model are total factor productivity and monetary policy innovations; their effects differ in magnitude and persistence depending on the model assumptions.

Figure 5 shows the response to a one standard deviation positive innovation in total factor productivity. In our baseline model, higher productivity increases firms profitability, leading them to increase hours. In the period of the shock, the level of employment is predetermined, fostering a spike in hours and output. The persistence of the shock induces more firms to post vacancies \( v \), which increases the job finding rate \( s \), and lowers unemployment \( u \). Consumption of both the unemployed and the employed increase, the former because of dividends from more profitable firms, the latter from dividends plus higher compensation from the increase in hours. Since hours and compensation are tightly linked to a firm’s relative price, it is reluctant to increase prices. As a result, inflation exhibits essentially no response, and the monetary authority therefore keeps nominal rates fixed. Unlike typical models, our baseline model implies a loss of output due to price dispersion even to a first-order approximation. This finding is precisely due to the fact that dispersion interacts with the curvature in hours of the utility function.

The alternative model generates much starker effects from a technology shock. Since firms searching in the labor market operate in a competitive market, they do not face the same pricing
and compensation trade-off faced by firms in the baseline model. As a result, more firms enter, driving employment up, along with hours and output. Retail firms with the opportunity to set their price do not have to worry about the effect of prices on compensation, and increase prices by a larger amount in response to the shock. As a result the nominal rate increases more significantly, dampening inflation and leading to below-target inflation for several periods after the shock.

Figure 6 shows the responses to a one standard deviation monetary policy shock and how, in contrast to technology shocks, our baseline model shows more responsiveness than the alternative model. In our baseline model, an increase in the interest rate lowers consumption of both the unemployed and the employed, thereby affecting the stochastic discount factor firms are using to discount profits. In an environment where firms make both the search and pricing decisions,
firms that can re-optimize respond by increasing the size of their markup by lowering their hours and compensation in order to improve current margins. Hours and output therefore fall on impact. Potential entrants have a lower incentive to enter because expected profits are discounted more, so they post fewer vacancies leading to higher unemployment. Absent other frictions in the economy, the effects of monetary policy on variables such as output, hours, and inflation, are short lived. However, labor market variables show a longer lasting impact.

The alternative model, by contrast, shows significantly smaller responses to an interest rate shock. Again, this result is due to the separation of labor search and pricing between two different firms. Since wholesale hiring firms operate in a competitive environment, an interest rate shock that distorts the stochastic discount factor has a smaller impact on hours, vacancy posting, unemployment, and output. This result follows because an interest rate shock does
not have a differential impact on incumbent and entering firms when prices are determined competitively. In contrast, a monetary policy shock leads to a larger decline in inflation in the alternative model, as price-setting firms increase their markup but do not have to consider the direct implications of their relative price change on hours and compensation in the wholesale market. The result is that monetary policy shocks move inflation more in the alternative model, but aggregate quantities and labor market variables less.

Finally, while the impulse responses focused on the effects of single shock on individual variables, we consider what our baseline and alternative models imply about important labor market ratios when both technology and monetary shocks are taken into account. The top panel of Table 3 presents statistics summarizing the movement of key labor market variables in each model. Because the volatility of output differs in each model all standard deviations are normalized relative to output. Looking at the first column, the baseline model implies a relative volatility of the $V/U$ ratio that is nearly 2.5 times larger than what the alternative model delivers. The reason for this difference is due to the behavior of wages. In the baseline model wages (or compensation) are less volatile than in the alternative model because firms have pricing power which ultimately affects labor demand. Because of smoother wages vacancies respond more and hence a more volatile $V/U$ ratio is recovered in the baseline model. In contrast, the alternative model suffers from the same problems that standard search models with Nash bargaining face whereby wages respond too much to technology shocks and hence vacancies respond too little resulting in low variation in the $V/U$ ratio.

The next two panels of Table 3 present statistics when only the technology or monetary shock is active. The basic message does not change when looking solely at technology shocks as the baseline delivers a more volatile $V/U$ ratio than the alternative model because wages are smoother. When monetary shocks are the only source of aggregate uncertainty, in both economies firms rely too much on the intensive margin of labor supply and hence employment and the $V/U$ ratio vary too little. In this case the alternative model implies a counterfactual Beveridge curve as the correlation between vacancies and unemployment is essentially zero.
Table 3: Labor Market Ratios

<table>
<thead>
<tr>
<th></th>
<th>$\frac{\text{std}(Y/U)}{\text{std}(Y)}$</th>
<th>$\text{corr}(U, V)$</th>
<th>$\frac{\text{std}(n)}{\text{std}(Y)}$</th>
<th>$\frac{\text{std}(H/n)}{\text{std}(Y)}$</th>
<th>$\frac{\text{std}(\piomega/H)}{\text{std}(Y)}$</th>
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<tr>
<td>Both Shocks</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Baseline</td>
<td>6.940</td>
<td>-0.858</td>
<td>0.017</td>
<td>0.295</td>
<td>0.627</td>
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<td>Alternative</td>
<td>2.874</td>
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<td>0.018</td>
<td>0.951</td>
<td>0.550</td>
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<tr>
<td>Tech Shock Only</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baseline</td>
<td>7.520</td>
<td>-0.872</td>
<td>0.015</td>
<td>0.316</td>
<td>0.474</td>
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<tr>
<td>Alternative</td>
<td>2.903</td>
<td>-0.895</td>
<td>0.018</td>
<td>0.961</td>
<td>0.528</td>
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<tr>
<td>MP Shock Only</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baseline</td>
<td>2.060</td>
<td>-0.615</td>
<td>0.007</td>
<td>0.090</td>
<td>1.119</td>
</tr>
<tr>
<td>Alternative</td>
<td>0.391</td>
<td>-0.053</td>
<td>0.002</td>
<td>0.087</td>
<td>1.261</td>
</tr>
</tbody>
</table>

5 Conclusion

We consider the macroeconomic implications of the interaction between pricing and labor market frictions. In our New Keynesian model, workers randomly search for jobs and monopolistically competitive firms post take-it-or-leave-it wage contracts taking into account infrequent adjustment of their own price. By allowing for wage posting by firms, the model provides a direct link between pricing and hiring behavior at the micro level.

A comparison of our baseline model with an alternative model that separates pricing and hiring across different sectors reveals key differences. First, in the steady state of our baseline model changes in trend inflation have much larger effects on aggregates such as output and unemployment because price stickiness has a direct impact on hours worked. We also find that our baseline model is less sensitive to changes in benefits paid to unemployed workers because hiring firms, who have pricing power, can adjust to workers’ changing reservation wages by adjusting prices and hence labor demand. Over the cycle, wages are smoother in our baseline model, compared to the alternative model, which leads to greater volatility in vacancy posting and hence labor market tightness. Lastly, the loss of output due to price dispersion, a feature absent in typical models, varies over the cycle because of the interaction between price stickiness and labor demand.

A key message from our analysis is that separating pricing and hiring frictions matters greatly even in our parsimonious framework. Because the curvature in hours worked for the
single-worker plays a central role in our results an immediate extension to our framework is allowing for multi-worker firms. In addition, altering our assumptions on the timing of hiring and price setting generates the possibility for cross-sectional differences in the value of hiring a worker, which would produce incentives for workers to direct their search rather than search randomly.

References


