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# Aggregate Hours Adjustment in Frictional Labor Markets\*

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PRELIMINARY AND INCOMPLETE

## Abstract

We evaluate the ability of the labor market search and matching framework to account for the variation in aggregate hours worked. The model we develop and estimate features search frictions in the labor market, capital and investment adjustment costs, as well as variable hours at the worker level. Firms and workers bargain efficiently over wages and hours worked, and relative price setting is monopolistic. Driving forces of aggregate fluctuations are assumed to be productivity, preference, markup, and investment-specific shocks. We find that the basic search and matching business cycle model cannot explain the relative volatilities of hours and employment, just as it cannot explain the volatility of other labor market variables, such as vacancies and unemployment. The latter has been established by Shimer (2005) for plausible calibrations. Furthermore, changes in parameter values that have been found to fix the vacancy/unemployment volatility puzzle, do not suffice to generate realistic hours/employment volatilities and correlations. Nor do we find any particular structural shock that brings the model to match the data. We then estimate the model on aggregate and labor market data for the U.S. using Bayesian techniques. The model is driven by productivity, preference, investment-specific, and mark-up shocks, of which we find the latter to be important in explaining dynamics. Investment-specific shocks, on the other hand, play only a minor role.

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Investment-specific Shocks

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# 1 Introduction

The flexibility of the two margins of labor adjustment, extensive and intensive, determines how aggregate output adjusts over the business cycle. While in the stylized competitive labor market all adjustment is in hours worked per worker (as there is no unemployment), the presence of search and matching frictions adds another possibility, that of changing the size of the workforce. But the frictions that generate a stand-by pool of recruitable workers also make the adjustment of the workforce a more or less time-consuming process.

In this paper, we ask whether or under which assumptions the now standard search and matching model of the labor market can explain the relative role of hours and employment adjustment observed in the data. We first establish the relative volatilities of these variables, and their correlation in U.S. data. Depending on the dataset, 33% to almost 50% of the variation in total hours worked is due to variation in hours per worker. This is somewhat in contrast to earlier studies that have found a contribution of about 25%, assigning the remainder to adjustment at the extensive margin, i.e., the number of workers.<sup>1</sup>

We try to match this regularity in the business cycle extension of the search and matching model by Mortensen and Pissarides (1994). Search for matches is time-consuming and the wage is determined in a bilateral Nash bargain. Bargaining takes place over both the wage and hours worked, the two variables that effectively transfer utility between firm and worker. Aggregate consumption is governed by the choices of large a representative household's preferences. These households aggregate the income of their members, thereby insuring consumption risk across workers. Households also accumulate capital that firms rent. Firms are monopolistic, so that apart from technology and preference shocks there are markup shocks driving the economy.

We find that the basic search and matching business cycle model cannot explain the relative volatilities of hours and employment, just as it cannot explain the volatility of other labor market variables, such as vacancies and unemployment. The latter has been established by Shimer (2005) for plausible calibrations. In most cases, hours per worker explains almost 90 percent of total hours variation. Furthermore, changes in parameter values that in the literature have been found to fix the vacancy/unemployment volatility puzzle, do not suffice to generate realistic hours/employment volatilities and correlations. Nor do we find any particular structural shock that perturbs the model quantitatively closer to the data.

The key problem of the model is that time-consuming search forces all instantaneous adjustment into the hours margin. Hence the high volatility of hours. In fact, we show that the volatility of hours per worker is intricately linked to the volatility of employment. The lower the volatility of employment is in response to shocks, the larger must be the instantaneous adjustment of hours per worker. Time-consuming search that makes instant changes in the workforce impossible takes this mechanism to the extreme.

In an extension, we change the timing of employment adjustment to allow for instantaneous hiring (as first previously by Rotemberg, 2006, and Blanchard and Gali, 2008). This mitigates the need for firms to use hours as a short-run margin to respond to shocks. Which fraction of employment can be adjusted instantly is however an empirical question.

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<sup>1</sup>See for example, Cho and Cooley (1994).

## 2 A Look at the Data

We construct several measures of total hours worked and its individual components. This is mainly motivated by the availability of various hours and employment series. The sample period is 1964:1 to 2007:4. All series are extracted from Haver Analytics database, except where noted otherwise. Variable mnemonics are in parentheses. All series are seasonally adjusted and transformed by taking natural logs. Our data are quarterly, which, if necessary, are obtained by simple averaging of monthly data.

Our baseline measure (data set 1) uses average weekly hours of people in the non-farm business sector (`LRPRIVA`), which we multiply by non-farm employment (`LAPRIVA`). The total hours measure is scaled by dividing by the civilian labor force 16 years or older (`LF`). We plot the raw data in Figure ?. The individual series both exhibit trends. The weekly hours series shows a decline from 38.4 hours worked to 33.8 hours over the sample period, which, however, seems to be stabilizing over the last two decades. The employment ratio is steadily increasing which reflects the decline in importance of the agricultural and public employment sector. On the other hand, the total hours series appears persistent, but stationary. Since our modeling framework is not equipped to handle these secular movements, we consequently pass the series through the HP-filter with a smoothing parameter of 1600.<sup>2</sup>

An alternative measure of hours worked (data set 2) is based on data from the household survey. We multiply average hours of persons at work (`LENCHLWHN`) by the number of persons at work (`LENCLWHN`) and scale by the civilian labor force. Since the raw data are not seasonally adjusted we use the X-12 ARIMA procedure provided by the Census Bureau. Our third measure (data set 3) uses civilian non-institutional population (`LN16`) as a scale variable. Both measures are computed only from 1976:3 on because of lack of availability of the hours series.

Table 1 reports statistics for the respective hours measures. The business cycle statistics are similar across the different data sets. Total hours is less volatile than GDP over the sample period, which is even more pronounced in data set 2. In the baseline measure, roughly a quarter of the volatility in total hours can be attributed to movements in average hours, that is, along the intensive margin. The household survey-based measure in data set 2, however, reveals an hours contribution of 50%. This discrepancy can be due to measurement issues<sup>3</sup>, or simply due to different sample periods. We can rule out the last case, as the statistics (not reported) for the first measure over the sub-sample show the same contribution of hours to total volatility.<sup>4</sup> Employment and hours are positively correlated in both data sets which indicates that, say, in an upturn firms adjust their labor input using both margins in the same direction, but not overly so.

In Table 2 we present additional business cycle statistics. The hours measures are based on data set 1. We report the standard deviations of the variables of interest relative to that of

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<sup>2</sup>Chang et al. (2007) make an attempt at modelling non-stationary hours in an estimated DSGE environment. They find that the preferred specification is a stochastic trend in hours unless the model includes labor adjustment costs.

<sup>3</sup>It is well known, for instance, that the establishment survey, the basis for data set 1, understates employment because of difficulties in capturing firm entry and exit, and the lack of coverage of small firms.

<sup>4</sup>Interestingly, the volatility of each variable as well as the hours-employment correlation decline relative to the baseline measure. This likely reflects the reduction in macroeconomic volatility in the early 1980s, the Great Moderation. The values are still above those of the second hours measure.

GDP over the sample period. As is well established, unemployment, vacancies and therefore the tightness ratio  $v/u$  are an order of magnitude more volatile than GDP, whereas hours per worker is only one fifth as volatile. Similarly, the movements of wages are smoother over the business cycle. Total hours on the other hand moves closely with GDP in terms of volatility and correlation. The table also depicts the highly negative correlation ( $-0.93$ ) between unemployment and vacancies, the so-called Beveridge-curve, which is a well-established stylized fact in labor markets across countries and sample periods. Furthermore, hours and wages are positively correlated with each other and with GDP, but to a somewhat smaller degree than other series.

Consequently, in other calibration exercise, we focus on replicating the low volatility of hours and its small contribution to total hours worked, and its comovement pattern with employment, wages and GDP. As a consistency check on the overall efficacy of our modelling framework we want it to replicate the Beveridge curve and come as close as possible to matching the high volatility of vacancies and tightness.

### 3 The Model

Our model economy is comprised of households, firms, and the government. Households and firms interact in product and labor markets. The product market is monopolistically competitive, with differentiated goods being produced by heterogeneous firms. Households have a preference for variety which results in downward-sloping demand curves for the firms' products. The labor market is subject to frictions to the effect that workers and firms cannot meet instantaneously, but must go through a time-consuming search process. The costs of finding a partner give rise to rents that firms and workers share between each other. We first describe the optimisation problems of households and firms, followed by a discussion of the labor market and wage determination.

#### 3.1 Households

The economy is populated by a continuum of households which are distributed along the unit interval. Households are in turn composed of a continuum of workers of measure one. Individual households send out their workers to the labor market, where they search for jobs when unemployed, and supply labor when employed. During unemployment the household member receives government benefits, whereas employed workers earn a bargained wage. Total income is shared equally among all members.<sup>5</sup> The welfare of a representative household is:

$$\mathcal{W}(N_{it}) = \max_{C_{it}} E_{\tau} \sum_{t=0}^{\infty} \beta^t \zeta_t \left[ \frac{C_{it}^{1-\sigma} - 1}{1-\sigma} - \chi_t N_{it} \frac{H_{it}^{1+\mu}}{1+\mu} \right],$$

where  $\beta \in (0, 1)$  is the discount factor, and  $C_{it}$  consumption. This welfare function already assumes that all members of the household consume the same amount of goods, and supply

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<sup>5</sup>We follow the literature and abstract from heterogeneity in asset holdings and consumption of individual workers and households (see Merz, 1995). Trigari (2006) gives a concise description of the assumptions needed for this construct. In what follows we therefore drop any household- and worker-specific indices.

the same amount of hours  $H_{it}$  when employed. The fraction  $N_{it}$  of employed household members is determined in the matching market and not subject to the household's control. The parameter  $\sigma$  governs risk aversion, and  $\mu$  is the inverse Frisch elasticity of labor supply. We allow household welfare to be affected by an intertemporal preference shock  $\zeta_t$  and an intratemporal labor supply shock  $\chi_t$ .

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

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

with  $\epsilon_t$  the stochastic elasticity of substitution between goods. The associated minimum expenditure price index is  $P_t = \left( \int_0^1 P_{jt}^{1-\epsilon_t} dj \right)^{1/(1-\epsilon_t)}$ . The household owns the capital stock  $K_i$  which evolves according to:

$$K_{it+1} = (1 - \delta)K_{it} + \varphi_t \left[ 1 - S \left( \frac{I_{it}}{K_{it}} \right) \right] I_{it},$$

where  $I_i$  is investment and  $\varphi_t$  an investment-specific shock that affects the rate at which investment is transformed into capital. The capital adjustment cost function  $S(\cdot)$  has the properties:  $S(\delta) = S'(\delta) = 0$ , and  $S''(\delta) \equiv s > 0$ ;  $0 < \delta < 1$  is the depreciation rate.

The household's flow budget constraint for period  $t$  is

$$C_{it} + I_{it} + T_t = w_t n_{it} h_{it} + r_t K_{it} + (1 - n_{it})b + d_{it}.$$

where  $w$  is the hourly wage rate per worker and  $r$  is rental rate on capital supplied to firms. The household receives unemployment benefits  $b$  from the government, which are financed by a lump-sum tax  $T$ ;  $d_{it}$  is a nominal dividend from firms, which are owned by households.

The first-order conditions for the household's optimisation problem are (after suppressing individual indices):

$$\begin{aligned} \zeta_t C_t^{-\sigma} &= \lambda_t, \\ \mu_t &= \beta E_t \mu_{t+1} \left[ (1 - \delta) + \varphi_{t+1} S' \left( \frac{I_{t+1}}{K_t} \right) \left( \frac{I_{t+1}}{K_t} \right)^2 \right] + \beta E_t \lambda_{t+1} r_{t+1}, \\ \lambda_t &= \mu_t \varphi_t \left[ 1 - S \left( \frac{I_t}{K_t} \right) - S' \left( \frac{I_t}{K_t} \right) \frac{I_t}{K_t} \right]. \end{aligned}$$

On account of perfect risk sharing, the sole problem of the household is to determine the consumption path of its members. There is no explicit household labor supply choice. It is chosen at the firm level during negotiations.

## 3.2 Labor Market

Households supply labor to firms in a frictional labor market. Search frictions are encapsulated in a matching function  $M(U_t, V_t) = m_t U_t^\xi V_t^{1-\xi}$ , which describes the outcome of the search process. Unemployed job seekers  $U_t$  and vacancies  $V_t$  are matched at rate  $M(U_t, V_t)$ , producing new employment relationships with probability  $1 - \rho$ .  $0 < \xi < 1$  is the match

elasticity of the unemployed, and  $m > 0$  describes the stochastic efficiency of the matching process. The aggregate probability of filling a vacancy (taken parametrically by the firms) is  $q(\theta_t) = M(U_t, V_t)/V_t$ , where  $\theta_t = V_t/U_t$  is labor market tightness.

The evolution of employment, defined as  $N_t = 1 - U_t$ , is given by:

$$N_t = (1 - \rho) [N_{t-1} + M(U_{t-1}, V_{t-1})], \quad (1)$$

where  $0 < \rho < 1$  is the separation rates that measures inflows into unemployment. We assume that it takes one period for new matches to become productive and that these newly created jobs are also subject to  $\rho$ .

### 3.3 Firms

There is a continuum of monopolistically competitive firms of measure one, each producing a particular variety of a differentiated product. Each firm faces the downward-sloping demand curve, derived from consumer preferences:

$$Y_{jt} = \left( \frac{P_{jt}}{P_t} \right)^{-\epsilon_t} Y_t,$$

where  $Y_t = \left( \int_0^1 y_{jt}^{(\epsilon_t-1)/\epsilon_t} dj \right)^{\epsilon_t/(\epsilon_t-1)}$  is aggregate income. The firm sets its price  $P_{jt}$  subject to the requirement that demand be satisfied. It produces its differentiated good using  $N_{jt}$  workers according to the following technology:

$$Y_{jt} = A_t K_{jt}^{1-\alpha} (N_{jt} H_{jt})^\alpha,$$

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

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

$$N_{jt} = (1 - \rho) [N_{jt-1} + V_{jt-1}q(\theta_{t-1})].$$

Moreover, we assume that the firm has to pay a flow labor adjustment cost  $c(V_{jt})$ . Allowing for  $c'' \neq 0$  follows Rotemberg (2006) and departs from the standard search and matching model where cost of recruiting are assumed to be linear (Pissarides, 2000).

The firm maximizes its profit function:

$$\mathcal{J}^j(N_t) = E_0 \sum_{t=0}^{\infty} \beta^t \lambda_t \left[ \left( \frac{P_{jt}}{P_t} \right)^{1-\epsilon} Y_t - W_{jt} N_{jt} H_{jt} - r_t K_{jt} - c(V_{jt}) \right],$$

subject to the demand curve, the production function and the equation for the evolution of employment at the firm level, where  $N_t = \int_0^{\infty} N_{jt} dj$ . The first-order conditions for prices,

employment, vacancies, and capital choice are (after abstracting from firm-specific indices):

$$\begin{aligned}
\left(\frac{P_{jt}}{P_t}\right)^{-\epsilon_t} &= \left[(1 - \epsilon_t)\frac{P_{jt}}{P_t} + \epsilon_t mc_{jt}\right]^{-1}, \\
\tau_{jt} &= mc_{jt}\alpha\frac{Y_{jt}}{N_{jt}} - W_t H_t + (1 - \rho)E_t\beta_{t+1}[\mu_{jt+1}], \\
c'(V_{jt}) &= (1 - \rho)q(\theta_t)E_t\beta_{t+1}[\tau_{jt+1}], \\
r_t &= (1 - \alpha)mc_{jt}\frac{Y_{jt}}{K_{jt}}.
\end{aligned}$$

where  $\beta_{t+1} = \beta\lambda_{t+1}/\lambda_t$  is a stochastic discount factor.  $\tau_{jt}$  is the Lagrange multiplier associated with the employment constraint; it represents the current-period marginal value of a job, i.e.  $\tau_{jt} = \frac{\partial \mathcal{J}_t^j(N_{jt})}{\partial N_{jt}}$ . The multiplier  $mc_{jt}$  on the constraint that demand equals production is the contribution of an additional unit of output to the firm's revenue and is equal to the firm's real marginal cost.

The first condition is the optimal price setting condition, which in a symmetric equilibrium with  $P_{jt} = P_t$  reduces to

$$mc_{jt} = \frac{\epsilon_t - 1}{\epsilon_t}.$$

That is, stochastic marginal cost is the inverse of the markup, variations of which directly affect a firm production decisions. Combining the next two conditions yields the job creation condition:

$$\frac{c'(V_t)}{q(\theta_t)} = (1 - \rho)E_t\beta_{t+1} \left[ \varphi_{jt+1}\alpha\frac{Y_{jt+1}}{N_{jt+1}} - W_{jt+1}H_{jt+1} + \frac{c'(V_{t+1})}{q(\theta_{t+1})} \right]. \quad (2)$$

The left hand side is the investment into new jobs, the right hand side the expected benefit when filled. Intuitively, firms expand employment up the point where the benefit from employing an additional worker (the right-hand side) is equal to the cost of posting a vacancy (the left-hand side). In a symmetric equilibrium,  $V_{jt} = V_t$ .<sup>6</sup>

### 3.4 Wage Bargaining and Hours Choice

We assume that worker and firm bargain at the individual level over the joint surplus of their match, and that they split it according to the Nash bargaining solution. Bargaining takes place both over hours per worker and the wage, to maximize the Nash product:

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

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<sup>6</sup>In the derivations we assume that firms take wages as given when choosing employment (and vacancies). Strictly speaking, large firms' employment adjustment should take into account that employment potentially affects wages if they depend on the marginal product of labor. This will indeed be the case under the Nash bargaining assumed below. In fact, Rotemberg (2006) takes this 'intra-firm bargaining' effect into account. Here, we consciously deviate for two reasons. One is merely computational convenience. The other is that intra-firm bargaining is not likely to significantly affect business cycle dynamics, as shown in Krause and Lubik (2007b).



where the two terms are the marginal contribution of a worker to the household's welfare, and to the present value of profits of the firm, respectively.<sup>7</sup> The parameter  $\eta$  reflects the bargaining power of the worker.

The two resulting optimality conditions are the wage equation

$$W_t H_t = \eta \left[ mc_t \alpha \frac{Y_t}{N_t} + c'(v_t) \theta_t \right] + (1 - \eta) \left[ b + \chi_t \frac{H_t^{1+\mu}}{1 + \mu} C_t^\sigma \right], \quad (3)$$

and the hours supply equation

$$H_t = \left( mc_t \alpha^2 \frac{Y_t}{N_t} C_t^\sigma \chi_t^{-1} \right)^{\frac{1}{1+\mu}}.$$

The first equation is familiar from the equilibrium unemployment literature, see Mortensen and Pissarides (1994), and Pissarides (2000). It captures total wage payments to the worker as a weighted average of the marginal revenue product and the cost of replacing the worker, and of the outside option of the worker, which consists of unemployment benefits and the marginal disutility of labor. The bargaining weight determines how close the wage is to either the marginal product or to the outside option of the worker.

The second condition determines the amount of hours worked by equalizing the marginal product of hours and the worker's marginal rate of substitution between leisure and consumption:

$$mrs_t = \chi_t H_t^\mu C_t^\sigma = mc_t \alpha^2 \frac{Y_t}{N_t} = mpl_t.$$

Thus, hours are chosen as in a competitive labor market, maximizing the joint welfare of worker and firm. However, the choice of hours is independent of the wage. The condition helps understand the driving forces of hours variation in the search model. A higher marginal utility of wealth and a higher labor productivity increase hours supply, whereas it declines whenever the disutility of labor or the intertemporal preference increase.

We assume a symmetric equilibrium throughout, which entails identical choices for all variables. Defining aggregates as the averages of firm specific variables, we have that  $N_t = N_{jt} = \int_0^1 N_{jt} dj$ , and  $V_t = V_{jt} = \int_0^1 V_{jt} dj$ . Furthermore, as  $P_{jt} = P_t$ ,  $Y_{jt} = Y_t$ , for all  $t$  and  $j$ . Thus, all firms produce the same amounts of output, employ equal amounts of labor, and, in particular, face the same marginal costs  $mc_t$ . Similarly, for all households  $T_t = T_{it} = \int_0^1 T_{it} di$ . The model is closed by specifying the government budget constraint  $(1 - N_t)b = T_t$ . Finally, using the household budget constraint, firms profits, and the government budget constraint, the resulting aggregate income identity is  $Y_t = C_t + I_t + c(V_t)$ .

## 4 Calibration and Simulation

We analyse the model with respect to its implications for the dynamics of hours in two steps. First, we calibrate the model to typical values in the search and matching literature. We then simulate the model conditional on specific shock processes and study the business cycle dynamics. This section also includes a robustness analysis with respect to key labor market parameters and to model specification. In the following section we then take a more formal empirical approach and estimate the model using Bayesian methods.

<sup>7</sup>From now on, we ignore household and firm indices for ease of exposition.

## 4.1 Calibration

Each period corresponds to a quarter. We set the discount factor  $\beta = 1.03^{-\frac{1}{4}}$ , which implies a 3 percent annual real interest rate. The coefficient of relative risk aversion  $\sigma = 1$ . We normalize the level of  $\chi$  in the disutility of labor to unity. There is a wide range of empirically plausible values for the parameter  $\mu$ , the inverse of the hours supply elasticity. As our baseline, we choose a quadratic disutility,  $\mu = 1$ . Estimates of labor supply elasticities often find a less elastic supply. In our case, however, this parameter captures only hours per worker and not total hours worked, the elasticity of which may be different. We therefore choose to treat  $\mu$  as a free parameter which we use to trace out its impact on the volatility of hours.

The Nash bargaining parameter  $\eta$  is set to 0.5. In the absence of any direct evidence, we impose the commonly employed value in the literature.<sup>8</sup> We set the value of the unemployment benefit  $b$  equal to 0.7, which implies a pure replacement ratio of 40%, i.e. net of the consumption-equivalent of leisure. Following the argument in Den Haan, Ramey, and Watson (2000), we choose a separation rate of  $\rho = 0.1$ . This value captures both exogenous job destruction as well as quits into unemployment or movements out of the labor force. We set the elasticity of the matching function with respect to unemployment  $\xi$ , equal to 0.5 as our benchmark value. This is in line with the upper bound of the range reported by Petrongolo and Pissarides (2001), and it implements the Hosios-condition for a socially efficient allocation. We also consider the alternative value of 0.3 in line with Shimer (2005).

The match efficiency parameter  $m = 0.4$  is chosen to yield a steady-state unemployment rate of 5.8%, which is the sample mean in the data. We set the vacancy posting elasticity  $\psi = 1$ , as it is standard in literature to assume linear vacancy creation costs. As a robustness check, we follow Rotemberg (2006) and also consider concave and convex recruiting costs. The scale parameter in the vacancy cost function is set to  $\kappa = 0.05$ , which implies that a fraction of 2.8% of output is spent on job posting activity.

We set the demand elasticity  $\epsilon = 11$ , which implies a steady state mark-up of 10%. The labor input parameter  $\alpha$  in the production function is set to 0.67, while the quarterly depreciation rate of capital is fixed at  $\delta = 0.025$ . The coefficient in the investment adjustment cost function is chosen to roughly match the relative volatility of investment. Finally, we assume that the shock processes are of order AR(1), with an autoregressive parameter of  $\rho = 0.9$ . In our baseline case, we choose the standard deviation of the technology shocks to match the volatility of U.S. GDP.

## 4.2 Baseline Results

We report results from the simulation of the baseline calibration in Table 3. The standard deviations of the model variables are relative to that of GDP. Two sets of results stand out: first, the model's inability to replicate the observed volatility of unemployment, vacancies, and labor market tightness, which are off by an order of magnitude compared to the data; second, the counterfactual observation that movements in total hours worked are almost exclusively explained by movements in hours per worker. However, the model is

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<sup>8</sup> $\eta$  can in principle be chosen such as to match the volatility of wages. This is effectively what estimation of the full model will accomplish. For purposes of the calibration analysis, however, we decide to keep the number of potentially free parameters to a minimum.

able to match the standard deviation of hours in the data (30% of GDP) exactly, whereas total hours variation falls significantly short. The apparent reason for this is the lack of employment volatility. This feature of the search and matching model has come to be associated with Shimer (2005). Replicating the hours facts thus requires finding a solution to the vacancy-unemployment volatility puzzle that does not worsen the performance of the model especially in the hours per worker dimension. We pursue this avenue by simulation the baseline version under alternative shock processes, and then by varying the calibration.

The model does quite well in replicating some key correlations in the data. Unemployment and vacancies comove negatively in the simulations, although not to the high degree seen in the data. The correlation of hours per worker with selected labor market variables roughly matches those in the data, especially with respect to the wage and employment. The almost perfect correlation with total hours reflects the lack of unemployment volatility detailed above.

We now proceed to simulate the model under alternative shock processes. Standard deviations of the innovations are chosen such as to match the observed standard deviation of GDP over the sample period. We mainly concentrate on stochastic variations in the elasticity parameter of differentiated products  $\varepsilon_t$  which can be interpreted as a demand or mark-up shock. For instance, Rotemberg (2006) has suggested this type of demand shock as a solution to the Shimer-puzzle. The simulation results show that demand shocks more than double the relative standard deviations of tightness and its components, while preserving the key correlations in the data, albeit at a higher level. This offers support to the argument that mark-up shocks are an important driving force of business cycle dynamics.

However, they do not resolve the hours worked facts. While the model now captures the volatility of total hours, this comes almost entirely through variations in the intensive margin (which still explain 95% of total variation). Similarly, real wages are now twice as volatile as in the baseline. We conclude that mark-up shocks alone cannot explain the behavior of hours over the business cycle as they simply scale up the effects of technology shocks.<sup>9</sup> This also comes with the caveat that the required volatility to match output fluctuations is almost two orders of magnitude higher than that of productivity shocks.

In the next step, we look at the effects of preference shocks, that is variations in the discount factor  $\beta_t = \beta\zeta_t$  and in the disutility of working  $\chi_t$ . We again scale the standard deviation of the shocks to match output volatility. The implications of the two preference shocks are similar. Neither can match the tightness volatility nor the relative contribution of hours per worker. Moreover, both shocks lead to negative comovement between hours and the wage. A labor disutility shock raises the worker's outside option for which he has to be compensated in the bargaining process. This drives up the wage and in turn lowers firms' incentives to post vacancies. At the same time, the disutility shock has a direct negative impact on the optimal hours choice so that a negative correlation results. A shock to the discount factor works through a different channel. It raises the marginal value of capital, which leads to fewer vacancy postings and a substitution away from labor input. Hours rise on account of the higher marginal product and a fall in consumption.

Finally, we simulate the model with investment specific shocks  $\varphi_t$  only. Primiceri et al. (2006) have argued that these shocks are crucial driving forces for aggregate dynamics in an estimated New Keynesian DSGE model. We find that this is not quite the case in our real

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<sup>9</sup>This conclusion is likely to be different in a nominal model with price stickiness.

model with labor market frictions, at least as far as the labor market facts are concerned. While this shock helps in matching the volatility of investment, it is at odds with the tightness and hours facts. Similarly to both preference shocks, variations in the investment disturbance imply negative comovement between hours and wages. Interestingly, this shock comes closest in capturing the Beveridge-curve and the comovement between hours and output.

We summarize the preceding analysis by observing that the inability of the model to match salient labor market facts is pervasive. On top of the excess smoothness of unemployment and vacancies identified by Shimer (2005), we document that the model cannot replicate the dynamics of hours, in particular the small contribution of the intensive margin to total hours variation. We find that this is independent of the underlying driving processes, although shocks to the mark-up generate modest amplification. Disturbances to ‘wedges’ or rates of transformation, such as preference or investment-specific shocks do not help either and counterfactually imply negative comovement between hours and wages, which we regard as a criterion to select among competing explanations. We conclude that shocks alone cannot reconcile the search and matching labor market framework with hours adjustment along both extensive and intensive margins with the respective stylized facts. In the next section we assess the robustness of this claim with respect to alternative parameterizations.

## 4.3 Robustness

### 4.3.1 Parameters

There is a substantial degree of disagreement in the literature in how to calibrate the search and matching framework. We therefore vary selected labor market parameters within empirically plausible ranges. Our main target is to replicate the volatility and comovement pattern of hours. A second concern is to improve upon the behavior of tightness. We report the results from the parameter robustness exercise in Table 4.

First, we vary the labor supply elasticity in both directions. When  $\mu$  becomes large, i.e. hours supply becomes less elastic, the relative contribution of hours variation to total hours declines, but at the same time the overall volatility of labor market variables drops, too. When hours supply is perfectly inelastic, the model essentially replicates the findings of other RBC models with search and matching frictions without the intensive margin. On the other hand, when hours react perfectly elastically ( $\mu = 0$ ) the model takes a long step towards replicating the labor market volatilities. However, this comes at the cost of making hours comove negatively, and counterfactually, with other labor variables. With hours supply perfectly elastic, firms make extensive use of the intensive margin to adjust labor input, which also comes at a lower wage cost since workers are more willing to substitute out of leisure. Once workers are enticed to work, the substitution in and out of hours becomes secondary.

In the second exercise, we vary the the size of the unemployment benefit  $b$ . The results are qualitatively similar as in the previous robustness check. When  $b$ , and therefore the replacement ratio, is high, the model comes much closer than the baseline calibration in replicating the volatility facts. This point has been noticed before by Hagedorn and Manovskii (2008) who argue the case for this specific calibration based on a more inclusive view of the empirical value of a worker’s outside option. While this calibration offers a so-

lution to the Shimer-puzzle, it also leads, as before, to negative comovement between hours and other aggregate variables. A lower benefit value replicates the correct comovement pattern, but reduces volatilities across the board.

Finally, when we increase the worker bargaining share to  $\eta = 0.99$ , which implies that workers appropriate all of the surplus and are being paid their marginal product the variability increases, but is still some way off what is observed in the data. The model again has problems with the comovement, most notably the correlation between hours per worker and employment.

### 4.3.2 Some Intuition

We have demonstrated in the previous section that a search and matching model with employment adjustment along the intensive margin has difficulty replicating the cyclical fluctuations of hours. We can gain some intuition for this result from the optimal choice of hours. Essentially, our results are driven by the fact that hiring operates with lag in the baseline specification; that is, workers matched to a firm become productive only in the following period (see Eq. (1)). Variations along the hours margin, on the other hand, have an immediate impact on total hours worked. Consequently, firms predominantly choose adjustment along the intensive margin, the importance of which is diminished only in calibrations when the wage response is too strong and deters hours adjustment.

However, this is not the full story. Inserting the wage equation (3) into the job creation condition (2), and then using the hours relationship  $\chi_t H_t^{1+\mu} C_t^\sigma = mc_t \alpha^2 Y_t / N_t$  results in a modified job creation condition adjusted for the intensive margin:

$$\frac{c'(V_t)}{q(\theta_t)} = (1-\rho)E_t\beta_{t+1} \left[ \left(1 - \frac{\alpha}{1+\mu}\right) (1-\eta) \varphi_{t+1} \alpha \frac{Y_{t+1}}{N_{t+1}} - (1-\eta)b - \eta c'(V_{t+1}) \theta_{t+1} + \frac{c'(V_{t+1})}{q(\theta_{t+1})} \right].$$

While the inclusion of hours in the model does not fundamentally change the job creation condition, it does affect the returns to posting vacancies and hence the implications for labor market dynamics. As in our baseline calibration, with curvature in the production function and somewhat elastic hours supply, the scale factor  $\frac{\alpha}{1+\mu}$  reduces the effective gross return to posting vacancies, that is, the firm's marginal revenue product, by one third. Consequently, the incentive to post vacancies decreases.

This mechanism lies behind the failure of the model to replicate the volatilities of unemployment and vacancies even compared to the standard RBC-model with search and matching frictions (e.g. Merz, 1995, Andolfatto, 1996). Intuitively, firms can adjust employment along the 'cheaper' hours margin - and they choose to do so, with has repercussions for the hiring of new workers. Only when hours supply is very inelastic, this feedback mechanism disappears, and the model approaches the standard specification.

While this explains the occurrence of the Shimer-puzzle in the model, the behavior of total hours is tied to the optimal hours choice. For simplicity of exposition, assume that  $\alpha = 1$ , so that  $Y_t = A_t N_t H_t$ . Furthermore, assume that vacancy creation costs are small,  $c'(V_t) \approx 0$ , so that  $C_t = Y_t$ . This implies:

$$H_t^{\mu+\sigma} \approx mc_t A_t^{1-\sigma} \frac{1}{\chi_t N_t^\sigma}.$$

We can make two observations from this expression. First, hours and employment have a tendency to comove negatively over the business cycle. The model will only be able to successfully replicate the observed positive correlation when this relationship is broken. In other words, the type of underlying shock matters for the specific business cycle dynamics. Second, the volatility of hours and total hours is tied to the volatility of employment and the hours supply elasticity. **Thus the hours-employment volatility puzzle is closely related to Shimer's (2005) vacancy-unemployment volatility puzzle.**

#### **4.3.3 Contemporaneous Hiring**

[To be written]

#### **4.3.4 Real wage rigidity**

[To be written]

## **5 Bayesian Estimation**

### **5.1 Priors, Data, and Shocks**

### **5.2 Posterior Estimates**

## **6 Conclusion**

## 7 Impulse Response Functions

IRFs are a great tool to understand the dynamics of the model and to get a handle on potential identification problems. These tend to manifest as similar adjustment paths of the variables of interest in response to notionally different shocks. For instance:

- The preference shock  $\zeta_t$  and the disutility shock  $\chi_t$  induce, perhaps not surprisingly, the same comovement patterns of the depicted variables, the only exception being the behavior of wages. In the former case, they decrease on impact, while they increase in the latter case. The reason is that  $\chi_t$  affects the marginal rate of substitution between consumption and leisure. In order to generate the same consumption utility, the more unwilling workers (i.e. ‘hours’) have to be induced by higher wages.<sup>10</sup> Movements in  $\zeta_t$  on the other hand affect total utility. The decrease in wage is driven by a lower surplus to share. This differential effect may depend on the specific calibration chosen. This affects our empirical analysis in two ways: first, the two utility shocks may not be separately identifiable. Second, the parameter  $\mu$  associated with the disutility of labor may not be identifiable.<sup>11</sup> On the other hand, if the initial increase in the wage under the laziness shock  $\chi_t$  is general, then this may be enough for identification.
- Similar considerations apply for the impulse responses to the technology shock  $A_t$  and the mark-up shock  $\varepsilon_t$ . The identification problem may not be as severe, however, since hours and employment comove differently. In this case, it seems almost imperative to use data on both series in order to disentangle the effects. What is surprising at first glance is that ‘supply’ and ‘demand’ shocks imply the same adjustment. On second glance, this is not surprising since (i) both shocks are expansionary, (ii) we only at quantities, and (iii) prices are fully flexible. The point to emphasize here is the differential behavior of hours and employment.
- The cleanest behavior is exhibited in response to the investment-specific shock  $\varphi_t$ .<sup>12</sup> A persistent increase in the rate of transformation between investment and capital has a similar effect as a technology shock on these variables, but the behavior of vacancies, tightness, and wages is strikingly different. The complementarity in the production function requires firms to match higher capital with higher labor input. This is initially achieved by increasing hours. Vacancy posting is below its long-run level for two periods.

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<sup>10</sup>This is somewhat neoclassical reasoning, but similar aspects would still apply in the search and matching framework.

<sup>11</sup>This is very classical reasoning, but even in a Bayesian setting, researchers may want to worry about flatness in the likelihood.

<sup>12</sup>I am starting to understand how Primiceri, Schaumburg, and Tambalotti (2006) get their mileage out of “intertemporal disturbances”.

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## A Equation System: Derivation

1. Consumption choice:

$$\begin{aligned} s_t C_t^{-\sigma} &= \lambda_t, \\ C_t^{-\sigma} &= \lambda, \\ \tilde{\zeta}_t - \sigma \tilde{C}_t &= \tilde{\lambda}_t. \end{aligned}$$

2. Capital choice:

$$\begin{aligned} \mu_t &= \beta E_t \mu_{t+1} \left[ (1 - \delta) + \varphi_{t+1} S' \left( \frac{I_{t+1}}{K_t} \right) \left( \frac{I_{t+1}}{K_t} \right)^2 \right] + \beta E_t \lambda_{t+1} r_{t+1}, \\ r &= \frac{1 - \beta(1 - \delta)}{\beta}, \\ \tilde{\mu}_t &= \beta r E_t \tilde{\lambda}_{t+1} + \beta r E_t \tilde{r}_{t+1} + \beta(1 - \delta) E_t \tilde{\mu}_{t+1} + \beta s \delta^3 E_t \tilde{I}_{t+1} - \beta s \delta^3 \tilde{K}_t. \end{aligned}$$

3. Investment choice:

$$\begin{aligned} \lambda_t &= \mu_t \varphi_t \left[ 1 - S \left( \frac{I_t}{K_{t-1}} \right) - S' \left( \frac{I_{t+1}}{K_t} \right) \frac{I_t}{K_{t-1}} \right], \\ \lambda &= \mu, \\ \tilde{\lambda}_t &= \tilde{\mu}_t - s \delta^2 \tilde{I}_t + s \delta^2 \tilde{K}_{t-1} + \tilde{\varphi}_t. \end{aligned}$$

4. Capital accumulation:

$$\begin{aligned} K_t &= (1 - \delta) K_{t-1} + \varphi_t \left[ 1 - S \left( \frac{I_t}{K_{t-1}} \right) \right] I_t, \\ \delta &= I/K, \\ \tilde{K}_t &= (1 - \delta) \tilde{K}_{t-1} + \delta \tilde{I}_t + \delta \tilde{\varphi}_t. \end{aligned}$$

## B Equation System: Canonical Form

1.

$$n\tilde{n}_t + (1-n)\tilde{u}_t = 0$$

2.

$$\tilde{\theta}_t - \tilde{v}_t + \tilde{u}_t = 0$$

3.

$$(1+\mu)\tilde{h}_t + \tilde{n}_t + \sigma\tilde{c}_t - \tilde{y}_t - \frac{1}{\varepsilon-1}\tilde{\varepsilon}_t + \tilde{\chi}_t = 0$$

4.

$$\tilde{n}_t = (1-\rho)\tilde{n}_{t-1} + \rho\xi\tilde{u}_{t-1} + \rho(1-\xi)\tilde{v}_{t-1}$$

5.

$$\tilde{y}_t - \alpha\tilde{n}_t - a\tilde{h}_t - (1-\alpha)\tilde{k}_t - \tilde{A}_t = 0$$

6.

$$\begin{aligned} -\sigma\beta(1-\rho)\tau\tilde{c}_t + \beta(1-\rho)\tau\tilde{\tau}_t &= -\sigma\beta(1-\rho)\tau\tilde{c}_{t-1} + \tau\tilde{\tau}_{t-1} + wh\tilde{w}_{t-1} + wh\tilde{h}_{t-1} - \alpha\frac{y}{n}\frac{\varepsilon-1}{\varepsilon}\tilde{y}_{t-1} \\ + \alpha\frac{y}{n}\frac{\varepsilon-1}{\varepsilon}\tilde{n}_{t-1} - \alpha\frac{y}{n}\frac{1}{\varepsilon}\tilde{\varepsilon}_{t-1} &+ \beta(1-\rho)\tau(1-\rho_\zeta)\tilde{\zeta}_{t-1} - \sigma\beta(1-\rho)\tau\eta_t^c + \beta(1-\rho)\tau\eta_t^\tau \end{aligned}$$

7.

$$\begin{aligned} \eta\kappa(\psi-1)v^{\psi-1}\theta\tilde{v}_t + \eta\kappa v^{\psi-1}\theta\tilde{\theta}_t - wh\tilde{w}_t + \eta\frac{\varepsilon-1}{\varepsilon}\alpha\frac{y}{n}\tilde{y}_t - \eta\frac{\varepsilon-1}{\varepsilon}\alpha\frac{y}{n}\tilde{n}_t + \sigma(1-\eta)\frac{h^{1+\mu}}{1+\mu}c^\sigma\tilde{c}_t \\ + [(1-\eta)h^{1+\mu}c^\sigma - wh]\tilde{h}_t + \eta\frac{\alpha y}{\varepsilon n}\tilde{\varepsilon}_t + (1-\eta)\frac{h^{1+\mu}}{1+\mu}c^\sigma\tilde{\chi}_t = 0 \end{aligned}$$

8.

$$-\sigma\tilde{c}_t + \tilde{\tau}_t = (\psi-1)\tilde{v}_{t-1} + \xi\tilde{\theta}_{t-1} - \sigma\tilde{c}_{t-1} + (1-\rho_\zeta)\tilde{\zeta}_{t-1} - \sigma\eta_t^c + \eta_t^\tau$$

9.

$$\begin{aligned} \beta(1-\delta)\tilde{\mu}_t + \beta s\delta^3\tilde{I}_t - \sigma\beta\frac{\varepsilon-1}{\varepsilon}(1-\alpha)\frac{y}{k}\tilde{c}_t + \beta\frac{\varepsilon-1}{\varepsilon}(1-\alpha)\frac{y}{k}\tilde{y}_t - \beta\left[s\delta^3 + \frac{\varepsilon-1}{\varepsilon}(1-\alpha)\frac{y}{k}\right]\tilde{k}_t \\ = \tilde{\mu}_{t-1} - \beta\frac{\varepsilon-1}{\varepsilon}(1-\alpha)\frac{y}{k}\rho_\zeta\tilde{\zeta}_{t-1} - \beta\frac{1}{\varepsilon}(1-\alpha)\frac{y}{k}\rho_\varepsilon\tilde{\varepsilon}_{t-1} \\ + \beta(1-\delta)\eta_t^\mu + \beta s\delta^3\eta_t^I - \sigma\beta\frac{\varepsilon-1}{\varepsilon}(1-\alpha)\frac{y}{k}\eta_t^c + \beta\frac{\varepsilon-1}{\varepsilon}(1-\alpha)\frac{y}{k}\eta_t^y \end{aligned}$$

10.

$$-\sigma\tilde{c}_t - \tilde{\mu}_t + s\delta^2\tilde{I}_t - s\delta^2\tilde{k}_t - \tilde{\varphi}_t + \tilde{\zeta}_t = 0$$

11.

$$\tilde{k}_t = (1-\delta)\tilde{k}_{t-1} + \delta\tilde{I}_{t-1} + \delta\tilde{\varphi}_{t-1}$$

12.

$$c\tilde{c}_t + I\tilde{I}_t - y\tilde{y}_t + \psi\kappa v^\psi \tilde{v}_t = 0$$

13.

$$\tilde{A}_t = \rho_A \tilde{A}_{t-1} + \epsilon_{A,t}$$

14.

$$\tilde{\chi}_t = \rho_\chi \tilde{\chi}_{t-1} + \epsilon_{\chi,t}$$

15.

$$\tilde{\varepsilon}_t = \rho_\varepsilon \tilde{\varepsilon}_{t-1} + \epsilon_{\varepsilon,t}$$

16.

$$\tilde{\zeta}_t = \rho_\zeta \tilde{\zeta}_{t-1} + \epsilon_{\zeta,t}$$

17.

$$\tilde{\varphi}_t = \rho_\varphi \tilde{\varphi}_{t-1} + \epsilon_{\varphi,t}$$

Table 1: Measures of Hours Worked

	Standard Deviation (%)			Correlation
	Total Hours	Employment	Hours	(N,H)
Data Set 1	1.55	1.28	0.42	0.53
Data Set 2	1.19	0.74	0.61	0.57
Data Set 3				

Table 2: Business Cycle Statistics

Standard Deviation (%)				
	U	V	V/U	W
	7.71	9.36	16.76	0.67
Correlation				
	(U,V)	(H,W)	(H,TH)	(H,Y)
	-0.93	0.72	0.71	0.72

Table 3: Business Cycle Statistics

	Standard Deviation (rel. to GDP)							Correlation			
	U	V	$\theta$	H	TH	W	I	(U,V)	(H,N)	(H,W)	(H,Y)
Data	7.71	9.36	16.76	0.30	1.10	0.67	4.86	-0.93	0.53	0.72	0.72
Tech.	0.39	0.46	0.75	0.30	0.32	0.76	3.14	-0.54	0.63	0.70	0.84
Demand	0.97	1.14	1.85	1.17	1.22	1.37	3.99	-0.52	0.79	0.92	0.94
Leisure	0.39	0.46	0.75	1.26	1.28	0.42	3.13	-0.56	0.79	-0.76	0.97
Discount	0.40	0.47	0.81	0.73	0.93	0.73	7.36	-0.73	0.58	-0.29	0.74
Inv.	0.28	0.32	0.60	0.85	0.86	0.82	6.83	-0.92	0.30	-0.42	0.65

Table 4: Business Cycle Statistics: Robustness

	Standard Deviation (rel. to GDP)							Correlation			
	U	V	$\theta$	H	TH	W	I	(U,V)	(H,N)	(H,W)	(H,Y)
Data	7.71	9.36	16.76	0.30	1.10	0.67	4.86	-0.93	0.53	0.72	0.72
Labor Supply											
$\mu = 5$	0.04	0.05	0.09	0.09	0.09	1.05	3.03	-0.99	0.58	0.69	0.78
$\mu = 0$	0.81	5.28	5.60	0.55	0.64	0.49	3.24	-0.31	-0.62	-0.76	-0.27
Benefit											
$b = 0.95$	1.92	4.45	5.90	0.25	0.57	0.41	2.85	-0.64	-0.57	-0.53	-0.35
$b = 0.40$	0.05	0.06	0.11	0.30	0.30	0.89	3.15	-0.97	0.60	0.62	0.81
Bargaining											
$\eta = 0.99$	0.26	1.20	1.40	0.26	0.38	0.64	2.97	-0.68	-0.11	0.32	0.43