The Role of Uncertainty in the Joint Output and Employment Dynamics
Online Appendix

Tsu-ting Tim Lin

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1 Introduction

This document is the online appendix for "The Role of Uncertainty in the Joint Output and Employment Dynamics." It is organized as follows. Section 2 describes the model in detail. Section 3 derives the marginal product of effort. Section 4 describes the data used in this paper. Section 5 conducts robustness checks.

2 Detailed Model Description

This section describes the model used to examine the role of uncertainty in jobless recoveries. The basic building blocks of this model are: (1) a search-and-matching labor market; (2) households; (3) firms; and (4) a government.

Households make consumption and investment decisions. I follow Merz (1995) and Andolfatto (1996) in assuming that each household consists of an infinite number of members, some of whom are employed and some are not. There is perfect risk-sharing among household members so each member consumes the same amount as the others. Moreover, while the extensive margin is supplied inelastically, I assume that employed workers incur disutility from exerting effort.[1] Employed workers receive wage payment while unemployed workers receive unemployment insurance from the government, which levies a lump-sum tax to finance the program. In addition to labor income, households receive rental income from supplying firms with capital as well as firms' profits in the form of dividend payments.

Firms make production decisions. The inputs are capital and labor. Firms rent capital from a competitive market taking the rental rate as given. They post vacancies to attract workers in order to expand the extensive margin of the labor input. Relationships are formed when a vacancy is matched up with a job seeker. Firms can expand their production through an intensive labor margin I refer to as effort.[2] The effort and wage schedule (wage depends on effort exerted) are negotiated between a firm and its workers. Firms are owned by households; any profits go to the households as dividend payments.

I now provide the details of my model, starting with the labor market.

[1] A number of recent works have also included an intensive margin of adjustment within a search model. For example, Cooper et al. (2007) studies a multi-worker firm model with variable intensive margin of adjustment to account for both aggregate and establishment level labor flows. Krause et al. (2008) estimate a full New Keynesian model with search friction and variable intensive margin in order to examine inflation dynamics. Barnichon (2010b) uses the intensive margin to allow for a positive endogenous correlation between output and measured labor productivity following a positive aggregate demand shock. Cacciatore et al. (2017) estimate the model with cost intensive margin adjustment and examined the contribution of hours per worker to total hours. Trapeznikova (2017) calibrates her model using a matched employer-employee panel of Danish firms and simulates two labor market policies aimed at promoting job creation. Dossche et al. (2018) study a multi-worker model with an intensive margin of labor adjustment in order to explain the business cycle variation of hours per worker.

[2] While it may be intuitive to consider effort as equivalent to hours per worker, it is important to keep in mind that the intensive margin represents a broader, and often unobservable, measure of effort on the part of the workers.

2.1 Labor Market

There is a unit mass of workers in the economy. At the beginning of each period, ρ_0 fraction of employed workers from the previous period are separated from their jobs. Let n_{t-1} be the number workers who were employed in period $t-1$. The total number of job seekers in period t is then

$$u_t = 1 - (1-\rho_0)n_{t-1}.$$

Let v_t be the aggregate number of vacancies posted by the firms in the economy and m_t the number of matches formed. I follow the literature in assuming a Cobb-Douglas matching function:

$$m_t = m_0 u_t^{\mu} v_t^{1-\mu},$$

where m_0 is the scale parameter and $\mu \in (0,1)$ is the match elasticity with respect to job seekers.

With all the ingredients in place, the law of motion for aggregate employment can be written as:

$$n_t = (1-\rho_0)n_{t-1} + m_t.$$

Note that given the quarterly timing, I allow a worker who is exogenously separated at the beginning of a period to—(1) join the pool of job seekers; (2) form a match with an employer; and (3) produce output—all within the same quarter. This implies the relevant unemployment statistics of the model that is comparable to data is

$$u_t^m = 1 - n_t,$$

where u_t^m denotes measured unemployment. This corresponds to the number of workers who are not producing output at time t.

Lastly, the job finding rate for a job seeker can be defined as:

$$s_t = \frac{m_t}{u_t};$$

and likewise the vacancy fill rate:

$$q_t = \frac{m_t}{v_t}.$$

2.2 Households

The economy consists of a continuum of households, each has an infinite number of identical members. I abstract from labor participation choice—every member of a household is either employed or is looking for work. Those who are employed receive wage income $w_t h_t$, the per-effort wage rate times the effort exerted. Those who are not employed receive unemployment insurance b from the government. I assume that workers incur disutility from exerting effort once they are employed. Each household member's utility is additively separable in consumption and leisure, and there is perfect risk-sharing among members of the household, yielding the same consumption for everyone in the household.

Let c_t denote consumption and h_t the intensive labor margin. Conditional on n_t, the number of employed members, households' objective function can be written as:

$$\mathbb{E}_t \sum_{s=0}^{\infty} \beta^s \left(\frac{c_{t+s}^{1-\gamma} - 1}{1-\gamma} - \kappa_h \frac{h_{t+s}^{1+\phi}}{1+\phi} n_{t+s} \right), \tag{1}$$

where β is the discount factor; γ is the coefficient of relative risk aversion; κ_h is the scale parameter for disutility of work; and $\frac{1}{\phi}$ is the intertemporal elasticity of substitution of leisure.

Households own the stock of physical capital k_t and make investment decision i_t. The capital law of motion is:

$$k_{t+1} = (1-\delta)k_t + \left[1 - \mathcal{S}\left(\frac{i_t}{i_{t-1}}\right)\right] i_t, \tag{2}$$

where δ is the capital depreciation rate and $\mathcal{S}(\cdot)$ is the investment adjustment cost function.

Further, a household chooses the level of capital utilization μ_t; it then pays utilization cost $\Psi(\mu_t)$ and receives rental income r_t for each unit of utilization-adjusted capital good it rents to firms in a competitive market.

Households maximize their objective function (1) subject to a sequence of the capital law of motion (2) and a sequence of budget constraints:

$$c_{t+s} + i_{t+s} + \Psi(\mu_{t+s}) \leq w_{t+s}h_{t+s}n_{t+s} + (1 - n_{t+s})b + r_{t+s}\mu_{t+s}k_{t+s} + \Pi_{t+s} - T_{t+s},$$

where Π_{t+s} is the dividend payments from firms and T_{t+s} is the lump-sum tax levied by the government to finance the unemployment insurance.

For the purpose of wage and effort setting that will be discussed below, it is useful to write down the surplus of an employed worker to a household. Let λ_t denote the Lagrange multiplier on the budget constraint and U_t and W_t denote the value of an unemployed worker and employed worker, respectively. The value of an unemployment worker, in units of consumption good, is:

$$U_t = b + \beta\mathbb{E}_t \frac{\lambda_{t+1}}{\lambda_t} \left[s_{t+1}W_{t+1} + (1 - s_{t+1})U_{t+1} \right]; \tag{3}$$

and the value of an employed worker is:

$$W_t = w_t h_t - \frac{\kappa_h \frac{h_t^{1+\phi}}{1+\phi}}{\lambda_t} + \beta\mathbb{E}_t \frac{\lambda_{t+1}}{\lambda_t} \left[(1 - \rho_0 + \rho_0 s_{t+1})W_{t+1} + \rho_0(1 - s_{t+1})U_{t+1} \right]. \tag{4}$$

Equation (3) says the value of an unemployed worker is the unemployment insurance she receives plus the continuation value weighted by the probability of finding a job in the next period. Equation (4) says the value of an employed worker is the wage payment she receives, less the disutility of effort, plus the continuation value weighted by the probability that she continues to have a job the next period.[3] The surplus of an employed worker, $M_t = W_t - U_t$ is then:

$$M_t = w_t h_t - \frac{\kappa_h \frac{h_t^{1+\phi}}{1+\phi}}{\lambda_t} - b + \beta\mathbb{E}_t \frac{\lambda_{t+1}}{\lambda_t}(1 - \rho_0)(1 - s_{t+1})M_{t+1}. \tag{5}$$

2.3 Firms

Let $h_{j,t}$ be the effort each worker exerted in production for firm j in period t, $n_{j,t}$ the number of workers, and $\tilde{k}_{j,t}$ the units of utilization-adjusted capital employed by firm j. I assume that a firm chooses the same effort for all of its workers; output is then:

$$y_{j,t} = a_t \tilde{k}_{j,t}^{\alpha} \left(h_{j,t}^{\vartheta} n_{j,t} \right)^{1-\alpha}. \tag{6}$$

$\alpha \in (0, 1)$ measures the diminishing returns on capital, and $\vartheta \in (0, 1]$ is the additional diminishing return on the intensive margin. (Or, in the case of $\vartheta = 1$, constant returns.) ϑ captures the notion that the worker becomes less and less effective the more and more effort is required of them.

The productivity process, a_t, follows an autoregressive process:

$$\log a_t = \rho_a \log a_{t-1} + \sigma_{a,t-1}\varepsilon_{a,t}, \tag{7}$$

where ρ_a is the persistence parameter and the innovations $\varepsilon_{a,t}$ are *i.i.d.* $\mathcal{N}(0, 1)$.

The standard deviation of the innovations above, $\sigma_{a,t}$, itself follows an autoregressive process:

$$\log \sigma_{a,t} = \rho_\sigma \log \sigma_{a,t-1} + (1 - \rho_\sigma) \log \bar{\sigma} + \eta^\sigma \varepsilon_{\sigma,t}, \tag{8}$$

[3] To be more precise, with probability $1 - \rho_0$ the worker will survive the exogenous separation shock; with probability $\rho_0 s_{t+1}$ she will lose her job exogenously but will find a new job in period $t+1$; and with probability $1 - [(1 - \rho_0) + \rho_0 s_{t+1}] = \rho_0(1 - s_{t+1})$ she will be unemployed.

where ρ_σ is the persistence parameter, $\bar{\sigma}$ is the non-stochastic mean of σ_t, η^σ is the standard deviation of the innovations, and $\varepsilon_{\sigma,t}$ is *i.i.d.* $\mathcal{N}(0,1)$. Note the timing assumption is such that firms know in advance the distribution of next period's innovations. This means that when an uncertainty shock hits today, agents realize that the innovation to productivity next period will come from a wider distribution. This represents the notion of uncertainty as firms make their decisions today.[4]

Firms acquire utilization-adjusted capital goods $\tilde{k}_{j,t}$ for production from a competitive market at rental rate r_t. Firms post vacancies to attract new workers. For firm j that begins period t with $n_{j,t-1}$ units of labor and posts $v_{j,t}$ vacancies, its employment law of motion is:

$$n_{j,t} = (1-\rho_0)n_{j,t-1} + q_t v_{j,t},$$

where q_t is the economy-wide vacancy fill rate which is taken as given. The cost of employment adjustment is $\frac{\kappa_v}{2}\left(\frac{q_t v_{j,t}}{n_{j,t}}\right)^2 n_{j,t}$.[5]

Given that households own the firms, firms discount the future using households' stochastic discount factor. Firm j chooses $v_{j,t}$ and $\tilde{k}_{j,t}$ to maximize the present value of its lifetime profits subject to employment law of motion. I assume firms and workers jointly determine wage and the intensive margin through a process I will describe later. Firm j's problem can be written as:

$$V_{j,t} = \max_{\{v_{j,t},\tilde{k}_{j,t}\}} \left\{ y_{j,t} - w_{j,t}h_{j,t}n_{j,t} - r_t\tilde{k}_{j,t} - \frac{\kappa_v}{2}\left(\frac{q_t v_{j,t}}{n_{j,t}}\right)^2 n_{j,t} + \beta\mathbb{E}_t\frac{\lambda_{t+1}}{\lambda_t}V_{j,t+1} \right\}, \tag{9}$$

subject to

$$n_{j,t} = (1-\rho_0)n_{j,t-1} + q_t v_{j,t}.$$

Let $J_{j,t}$ be the Lagrangian multiplier for employment, the first order conditions for the firm's problem are:

$$v_{j,t}: \quad \kappa_v\frac{q_t v_{j,t}}{n_{j,t}} = J_{j,t} \tag{10}$$

$$\tilde{k}_{j,t}: \quad r_t = \alpha\frac{y_{j,t}}{\tilde{k}_{j,t}}. \tag{11}$$

Condition (10) equates the marginal cost of hiring a new employee to the value of adding another worker, $J_{j,t}$, which I will describe in more detail in the following section. Condition (11) is the standard capital optimality condition.

Given that all the firms are identical, I will omit the j subscript below.

2.4 Effort and Wage Setting

Due to labor market friction, employer-employee matches create a positive surplus to be shared between the parties. In this model, firms and their workers jointly determine effort h_t and wages w_t.

2.4.1 Effort

In terms of effort, I assume that h_t is set at the level such that the marginal product equals the marginal disutility of the household. More specifically:

$$(1-\alpha)\vartheta\frac{y_t}{h_t} = \frac{\kappa_h h_t^\phi}{\lambda_t}n_t, \tag{12}$$

where the left hand side of the expression is the marginal product of labor at the intensive margin; and the right hand side is the household's marginal disutility of effort.

[4]See Bachmann and Bayer (2013), Fernández-Villaverde et al. (2011), and Fernández-Villaverde et al. (2013) for similar treatments of time-varying volatility.

[5]Quadratic adjustment cost is utilized here because it incentivizes firms to make gradual adjustments to their labor force. Relative to the standard per-vacancy adjustment cost, this assumptions improves the model's ability to generate jobless recoveries, though it is not crucial. Merz and Yashiv (2007), Gertler et al. (2008), and Galí and van Rens (2010) are a sample of recent literature that also utilize convex adjustment costs.

2.4.2 Wages

I assume the firm bargains with its existing workforce collectively, and that all workers with the same productivity receives the same wage.[6]

With the effort schedule specified above, the value of an additional worker to the firm can be derived by taking the derivative of firm's objective function (9) with respect to n_t subject to (12) and employment law of motion. It is:

$$J_t = (1-\xi_F)(1-\alpha)\frac{y_t}{n_t} - w_t h_t + \frac{\kappa_v}{2}\left(\frac{q_t v_t}{n_t}\right)^2 + (1-\rho_0)\beta\mathbb{E}_t\frac{\lambda_{t+1}}{\lambda_t}J_{t+1}, \tag{13}$$

where $\xi_F = \frac{\alpha\vartheta}{1+\phi-\vartheta(1-\alpha)}$ captures the endogenous effect of an additional worker on the effort choice—a firm recognizes when it hires an additional worker, it can reduce effort among all its existing workers. (See appendix 3 for the derivation of ξ_F.) Expression (13) tells us that the value of a worker to the firm equals her marginal product, less the wage payment, plus hiring cost savings and the continuation value weighted by the probability the match survives the exogenous separation shock next period.

Before I proceed further, it is worth noting that workers would be willing to stay in a match with a firm as long as their surplus, M_t, is positive; likewise, a firm is willing to stay in a relationship with a worker if J_t is positive. Using equations (5) and (13), this implies the lower bound of wage bill for a worker is

$$w_t^{lb}h_t = \frac{\kappa_h\frac{h_t^{1+\phi}}{1+\phi}}{\lambda_t} + b + \beta\mathbb{E}_t\frac{\lambda_{t+1}}{\lambda_t}(1-\rho_0)(1-s_{t+1})\left(w_{t+1}^{lb}h_{t+1} - w_{t+1}h_{t+1}\right).$$ [7]

Similarly, the upper bound of the wages is

$$w_t^{ub}h_t = (1-\xi_F)(1-\alpha)\frac{y_t}{n_t} + \frac{\kappa_v}{2}\left(\frac{q_t v_t}{n_t}\right)^2 + (1-\rho_0)\beta\mathbb{E}_t\frac{\lambda_{t+1}}{\lambda_t}\left(w_{t+1}^{ub}h_{t+1} - w_{t+1}h_{t+1}\right).$$

In the context of this model, the Nash rent-sharing outcome that is standard in the literature is equivalent to:

$$w_t^N = \eta w_t^{ub} + (1-\eta)w_t^{lb},$$

where $\eta \in [0,1]$ is the worker's share of the total surplus.

Shimer (2005) and Hall (2005) have argued that period-by-period Nash rent-sharing wage shown above is too volatile relative to the data, which results in a muted response of employment to productivity shocks. Hall (2005) further points out that any wage within the bargaining set, defined as any wage between w_t^{lb} and w_t^{ub} should be considered a legitimate solution to the wage bargaining process between a firm and its employees. In order to allow the model to generate a more realistic employment response to productivity shocks, I adopt the following wage rule:

$$w_t = \tau w_{t-1} + (1-\tau)w_t^N, \tag{14}$$

where $\tau \in [0,1]$ indexes the degree of wage rigidity; I constrain $w_t \in \left[w_t^{lb}, w_t^{ub}\right]$.[8]

[6]In a multi-worker firm model such as the one examined here, there exists an intra-firm bargaining framework first highlighted by Stole and Zwiebel (1996b) and Stole and Zwiebel (1996a) where a firm bargains with its workers individually. Stole and Zwiebel show that, under diminishing marginal returns and intra-firm bargaining, firms over-hire strategically to reduce the wage rate they pay to their workers. This intra-firm bargaining framework has been expanded by Cahuc and Wasmer (2001) and Cahuc et al. (2008) to general equilibrium search models, and more recently by Elsby and Michaels (2013) in a search model with endogenous job destruction. However, given that Krause and Lubik (2013) have shown that intra-frim bargaining has a small business cycle effect, I choose a wage-setting mechanism that does not include this game theoretical aspect. Cooper et al. (2007), Krause et al. (2008), Gertler and Trigari (2009), and Cacciatore et al. (2017), among others, also abstract from intra-firm bargaining considerations.

[7]One can derive the expression for $w_t^{lb}h_t$ and the expression for $w_t^{ub}h_t$ by setting $M_t = 0$ and $J_t = 0$ and by noting $M_t = w_t h_t - w_t^{lb}h_t$, and $J_t = w_t^{ub}h_t - w_t h_t$.

[8]See Hall (2005) for a discussion of this particular adaptive wage determination process. This paper is one of many in the recent literature that departs from period-by-period Nash rent-sharing wage; see, for example, Gertler et al. (2008), Shimer (2012b), Blanchard and Galí (2010), and Galí and van Rens (2010).

2.5 Government and Resource Constraint

Government levies a lump-sum tax T_t from the households to finance unemployment insurance $(1-n_t)b$. Let x^* denote the non-stochastic steady-state value of variable x, I assume the unemployment insurance b satisfies the condition:

$$b + \frac{\kappa_h \frac{{h^*}^{1+\phi}}{1+\phi}}{\lambda^*} = \bar{b}(1-\alpha)\frac{y^*}{n^*},$$

that is, the unemployment insurance is set such that the opportunity cost of employment, b and the utility gained from supplying no effort, equals a constant fraction of the marginal product of labor in the steady-state.

Lastly, to close the model, the resource constraint is

$$y_t = c_t + \frac{\kappa_v}{2}\left(\frac{q_t v_t}{n_t}\right)^2 n_t + \Psi(\mu_t) + i_t.$$

3 Marginal Product of Labor

For convenience, the effort condition is rewritten here:

$$(1-\alpha)\vartheta\frac{y_t}{h_t} = \frac{\kappa_h h_t^{\phi}}{\lambda_t} n_t.$$

Substitute the production function (6) for y_t and rearrange, we get:

$$h_t^{1+\phi-\vartheta(1-\alpha)} = (1-\alpha)\frac{\lambda_t}{\kappa_h}\vartheta a_t k_t^{\alpha} n_t^{-\alpha}.$$

Implicitly differentiate:

$$[1+\phi-\vartheta(1-\alpha)]\, h_t^{1+\phi-\vartheta(1-\alpha)-1}\partial h_t = -\alpha(1-\alpha)\vartheta\frac{\lambda_t}{\kappa_h} a_t k_t^{\alpha} n_t^{-\alpha-1}\partial n_t.$$

Rearrange, substitute the production function back, and use the effort condition we get:

$$\frac{\partial h_t}{\partial n_t} = \frac{-\alpha}{1+\phi-\vartheta(1-\alpha)}\frac{h_t}{n_t}.$$

This expression gives us the reduction in effort when an additional worker joins the firm.

The marginal value of labor is

$$\begin{aligned}\frac{dy_t}{dn_t} &= \frac{\partial y_t}{\partial n_t} + \frac{\partial y_t}{\partial h_t}\frac{\partial h_t}{\partial n_t} \\ &= (1-\alpha)\frac{y_t}{n_t}\left[1+\vartheta\frac{n_t}{h_t}\frac{\partial h_t}{\partial n_t}\right] \\ &= (1-\alpha)\frac{y_t}{n_t}\left[1-\frac{\alpha\vartheta}{1+\phi-\vartheta(1-\alpha)}\right].\end{aligned}$$

Defining $\xi_F \equiv \frac{\alpha\vartheta}{1+\phi-\vartheta(1-\alpha)}$ gives us equation (13).

4 Data Sources

This section describes the data used in this paper. Note the time frame, 1969Q1 to 2016Q4 is chosen to match the starting date of the Survey of Professional Forecasters and the end date of the vacancy series by Barnichon (2010a).

4.1 Output and Employment

Output and employment are U.S. real GDP and nonfarm payroll. The corresponding FRED series names are GDPC1 and PAYEMS, respectively.

4.2 Vacancy

The vacancy data is based on Barnichon (2010a) and downloaded from https://sites.google.com/site/regisbarnichon/data. I average monthly numbers to generate the quarterly data.

4.3 Job Finding Rate

The job finding rate is computed using the algorithm in Shimer (2012a) at a monthly frequency. I then compute the quarterly averages.

4.4 Productivity

The data productivity in this paper refers to the total factor productivity series computed by Fernald (2014) and is downloaded from https://www.frbsf.org/economic-research/indicators-data/total-factor-productivity-t

4.5 Proxies for Uncertainty

There are three proxies for uncertainty used in this paper. The first is the corporate profit forecast dispersion. It comes from the Survey of Professional Forecasters conducted by the Federal Reserve Bank of Philadelphia. The measure of dispersion I used in this paper is the log difference between the 75th and the 25th percentile forecasts.

The second measure is the corporate bond spread. It is computed by subtracting the 10-year Treasury, constant maturity (FRED series GS10), from Baa bond yield (FRED series BAA). Monthly data is averaged at a quarterly frequency.

The third measure is the consumer uncertainty in Leduc and Liu (2016). It finds the sum of people who cited 'uncertain future' as reason that it is a bad time to purchase a vehicle and people who cited same reason to purchase household durables. I then divide it by the total number of people who answered these questions.

5 Robustness

5.1 Fitering Schemes

5.2 Different Filtering Scheme

The model evaluation procedure is carried out with data filtered using HP 10^5 (as in Shimer (2005)) and band-pass filter with smoothing parameter 6 and 32 (typical for quarterly data, see Christiano and Fitzgerald (2003)). Figures 1 and 2 are analogous to Figure **??** and show the behaviors of simulated output and employment with and without uncertainty shocks. The full model is able to match both output and employment regardless of the filtering scheme. The counterfactual employment series without uncertainty fails to generate jobless recoveries as in the case of HP 1,600. Figure 3 shows the uncertainty processes under these three filtering schemes. The volatility series under HP 1,600 is the blue line; HP 10^5 is green dashed line; band-pass filter is magenta dotted line. The scale understandably are different, especially with HP 10^5. This is because a larger HP filtering parameter makes the underlying trend closer to a straight line, which implies more of the variation in output and employment is left in the cyclical component, resulting in larger responses in the uncertainty series in order to explain the data. More importantly, however, as can be seen in Figure 3, the dynamics of the model-implied uncertainty does not change dramatically when different filtering scheme is used. The correlation coefficient between the baseline filter and the HP 10^5 and band-pass filter are 0.874 and 0.916, respectively.

[Figure 1 about here.]

[Figure 2 about here.]

[Figure 3 about here.]

6 Capital Market Friction

Since the capital market features—utilization and adjustment cost—are not standard features of the search-and-matching model, I explore an alternative specification as in (Gertler et al., 2008)—$\nu_k = 0.695$ (utilization adjustment curvature) and $\eta_k = 2.425$ (capital adjustment cost). The model continue to be able to replicate the dynamics of output and employment. The resulting volatility series is shown in Figure 4. The correlation coefficient between the two volatility series is 0.920.

[Figure 4 about here.]

References

Andolfatto, D., 1996. Business cycles and labor-market search. American Economic Review 86, 112–132.

Bachmann, R., Bayer, C., 2013. 'wait-and-see' business cycles? Journal of Monetary Economics 60, 704–719. URL: http://www.sciencedirect.com/science/article/pii/S0304393213000810, doi:http://dx.doi.org/10.1016/j.jmoneco.2013.05.005.

Barnichon, R., 2010a. Building a composite help-wanted index. Economics Letters 109, 175–178. URL: http://www.sciencedirect.com/science/article/pii/S0165176510002934, doi:https://doi.org/10.1016/j.econlet.2010.08.029.

Barnichon, R., 2010b. Productivity and unemployment over the business cycle. Journal of Monetary Economics 57, 1013–1025. URL: http://www.sciencedirect.com/science/article/pii/S0304393210001054, doi:https://doi.org/10.1016/j.jmoneco.2010.09.006.

Blanchard, O.J., Galí, J., 2010. Labor markets and monetary policy: A new-keynesian model with unemployment. American Economic Journal: Macroeconomics 2, 1–30.

Cacciatore, M., Fiori, G., Traum, N., 2017. Hours and employment over the business cycle: A bayesian approach. HEC Montréal mimeo .

Cahuc, P., Marque, F., Wasmer, E., 2008. A theory of wages and labor demand with intra-firm bargaining and matching frictions. International Economic Review 49, 943–972. URL: http://www.jstor.org/stable/20486824.

Cahuc, P., Wasmer, E., 2001. Does intrafirm bargaining matter in the large firm's matching model? Macroeconomic Dynamics 5, 742–747. doi:10.1017/S1365100501031042.

Christiano, L.J., Fitzgerald, T.J., 2003. The band pass filter. International Economic Review 44, 435–465.

Cooper, R., Haltiwanger, J., Willis, J., 2007. Implications of Search Frictions: Matching Aggregate and Establishment-level Observations. Working Paper 13115. National Bureau of Economic Research. URL: http://www.nber.org/papers/w13115, doi:10.3386/w13115.

Dossche, M., Lewis, V., Poilly, C., 2018. Employment, hours and the welfare effects of intra-firm bargaining. Journal of Monetary Economics .

Elsby, M., Michaels, R., 2013. Marginal jobs, heterogeneous firms, and unemployment flows. American Economic Journal: Macroeconomics 5, 1–48. URL: http://www.aeaweb.org/articles?id=10.1257/mac.5.1.1, doi:10.1257/mac.5.1.1.

Fernald, J., 2014. A quarterly, utilization-adjusted series on total factor productivity. FRBSF Working Paper .

Fernández-Villaverde, J., Guerrón-Quintana, P., Keuster, K., Rubio-Ramírez, J.F., 2013. Fiscal Volatility Shocks and Economic Activity. Working Paper 17317. National Bureau of Economic Research. URL: http://www.nber.org/papers/w17317.

Fernández-Villaverde, J., Guerrón-Quintana, P., Rubio-Ramírez, J.F., Uribe, M., 2011. Risk matters: The real effects of volatility shocks. American Economic Review 101, 2530–2561.

Galí, J., van Rens, T., 2010. The vanishing procyclicality of labor productivity. CREI Mimeo.

Gertler, M., Sala, L., Trigari, A., 2008. An estimated monetary dsge model with unemployment and staggered nominal wage bargaining. Journal of Money, Credit, and Banking 40, 1713–1764.

Gertler, M., Trigari, A., 2009. Unemployment fluctuations with staggered nash wage bargaining. Journal of Political Economy 117, 38–86.

Hall, R.E., 2005. Employment fluctuations with equilibrium wage stickiness. American Economic Review 95, 50–65. doi:10.1257/0002828053828482.

Krause, M., Lubik, T., 2013. Does Intra-Firm Bargaining Matter for Business Cycle Dynamics? Economic Quarterly , 229–250URL: https://ideas.repec.org/a/fip/fedreq/00006.html.

Krause, M.U., Lopez-Salido, D., Lubik, T.A., 2008. Inflation dynamics with search frictions: A structural econometric analysis. Journal of Monetary Economics 55, 892–916. URL: http://www.sciencedirect.com/science/article/pii/S0304393208000500, doi:https://doi.org/10.1016/j.jmoneco.2008.04.004. carnegie-Rochester Conference Series on Public Policy: Labor Markets, Macroeconomic Fluctuations, and Monetary Policy November 9-10, 2007.

Leduc, S., Liu, Z., 2016. Uncertainty shocks are aggregate demand shocks. Journal of Monetary Economics 82, 20–35. URL: http://www.sciencedirect.com/science/article/pii/S0304393216300393, doi:https://doi.org/10.1016/j.jmoneco.2016.07.002.

Merz, M., 1995. Search in the labor market and the real business cycle. Journal of Monetary Economics 36, 269–300.

Merz, M., Yashiv, E., 2007. Labor and the market value of the firm. American Economic Review 97, 1419–1431.

Shimer, R., 2005. The cyclical behavior of equilibrium unemployment and vacancies. American Economic Review 95, 25–49.

Shimer, R., 2012a. Reassessing the ins and outs of unemployment. Review of Economic Dynamics 15, 127–148. URL: http://www.sciencedirect.com/science/article/pii/S1094202512000063, doi:https://doi.org/10.1016/j.red.2012.02.001.

Shimer, R., 2012b. Wage rigidities and jobless recoveries. Journal of Monetary Economics 59, Supplement, S65–S77. URL: http://www.sciencedirect.com/science/article/pii/S0304393212001390, doi:http://dx.doi.org/10.1016/j.jmoneco.2012.10.024. supplement issue:October 15-16 2010 Research Conference on 'Directions for Macroeconomics: What did we Learn from the Economic Crises' Sponsored by the Swiss National Bank (http://www.snb.ch).

Stole, L., Zwiebel, J., 1996a. Intra-firm bargaining under non-binding contracts. The Review of Economic Studies 63, 375–410. URL: http://www.jstor.org/stable/2297888.

Stole, L., Zwiebel, J., 1996b. Organizational design and technology choice under intrafirm bargaining. The American Economic Review 86, 195–222. URL: http://www.jstor.org/stable/2118263.

Trapeznikova, I., 2017. Employment adjustment and labor utilization. International Economic Review 58, 889–922. URL: https://onlinelibrary.wiley.com/doi/abs/10.1111/iere.12239, doi:10.1111/iere.12239, arXiv:https://onlinelibrary.wiley.com/doi/pdf/10.1111/iere.12239.

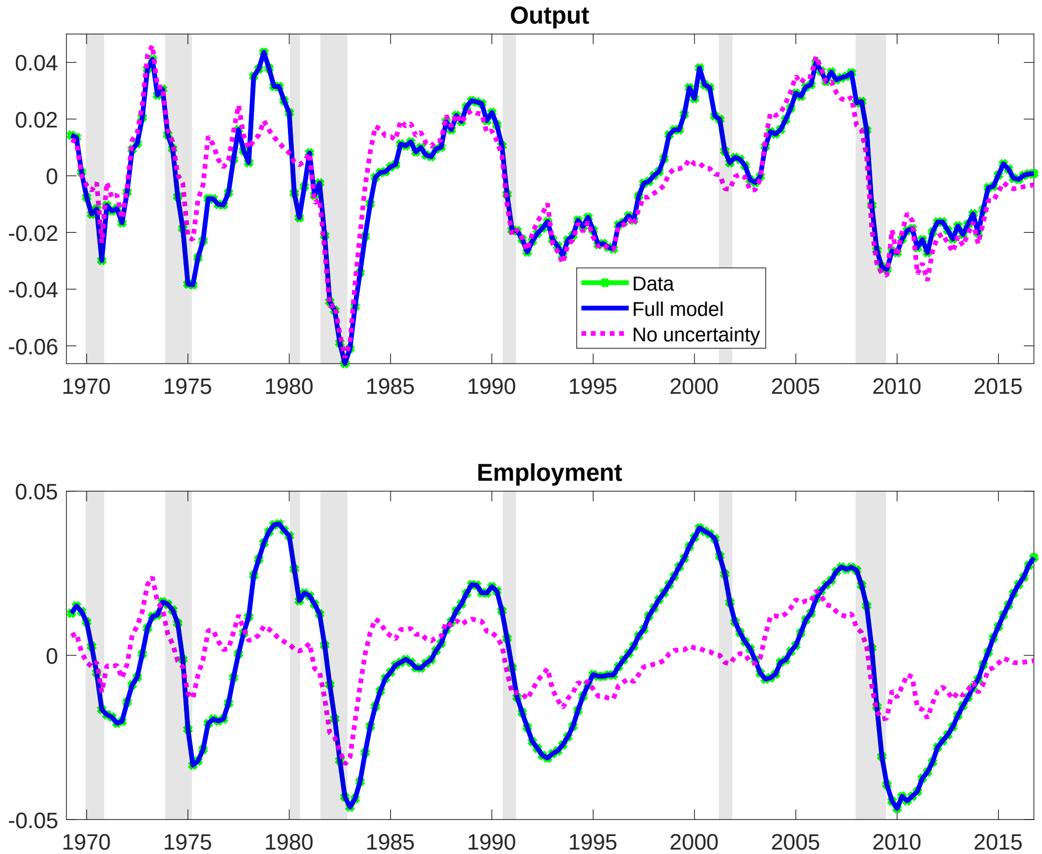

Figure 1: Model and data output and employment, HP filter 10^5

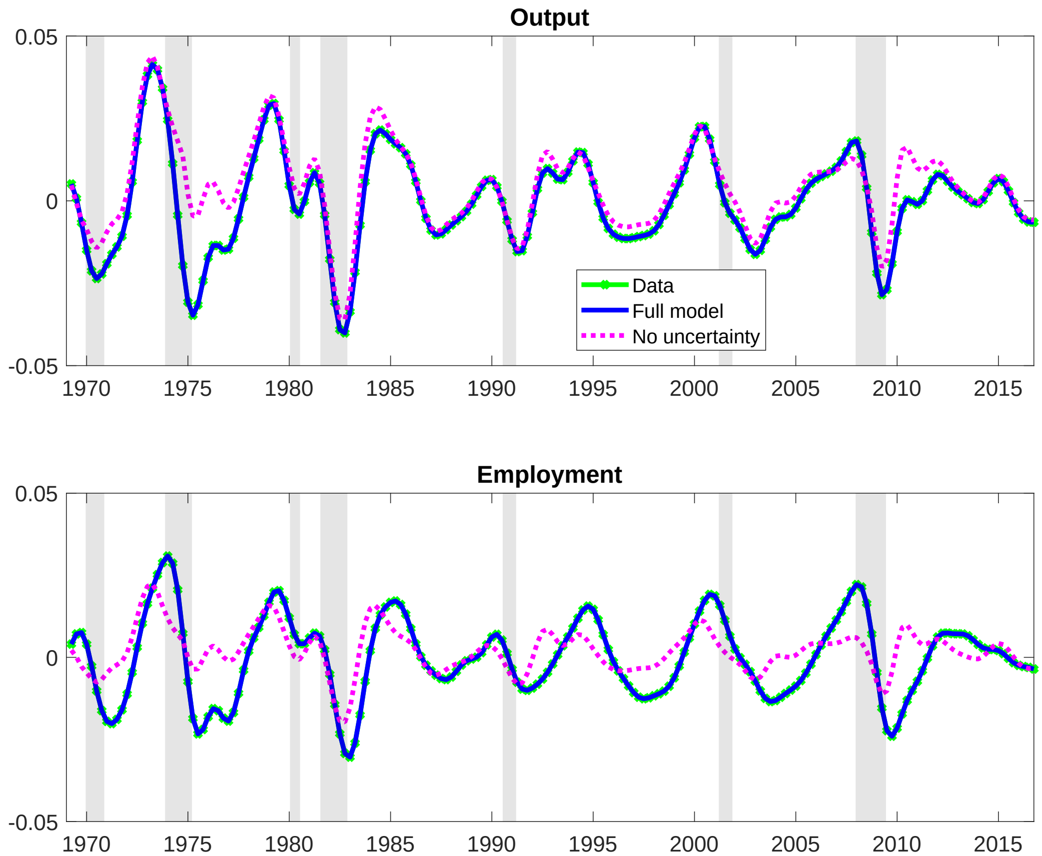

Figure 2: Model and data output and employment, band-pass filter, 6 and 32

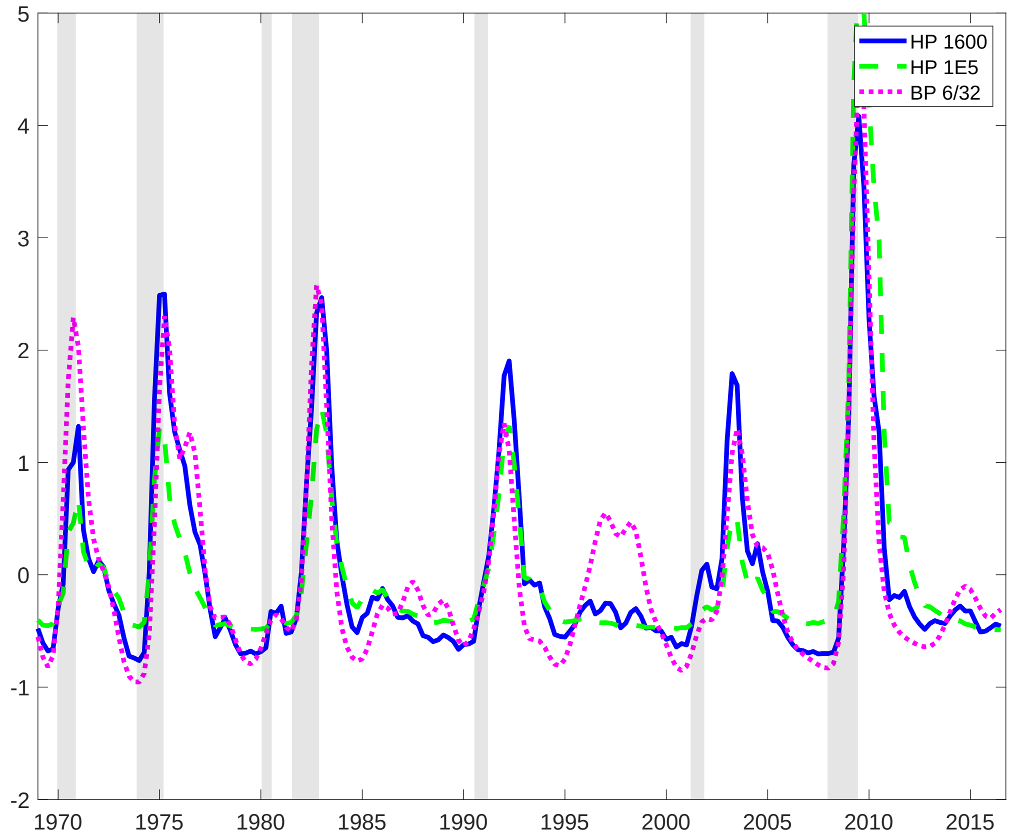

Figure 3: Uncertainty under different filtering schemes, including HP 1,600, HP 10^5, and band-pass filter 6 and 32.

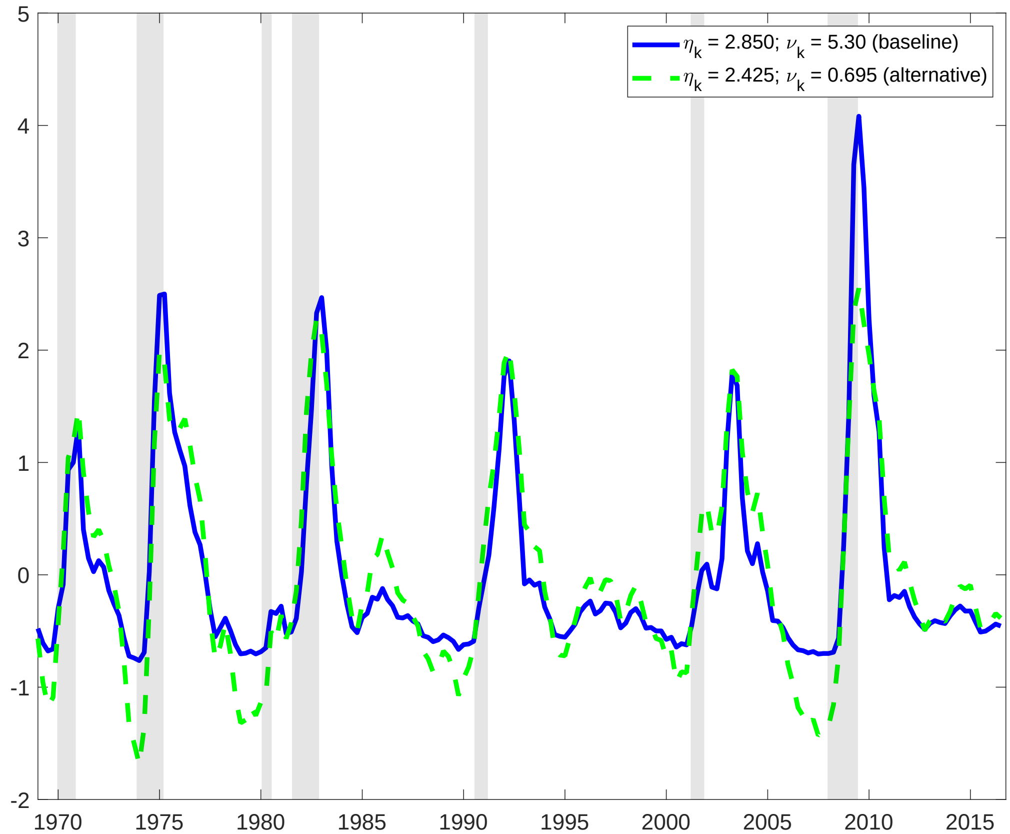

Figure 4: Uncertainty under an alternative ν_k and η_k.