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The Cyclical Behavior of Unemployment and Wages under Information Frictions*

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Abstract

I propose a new mechanism for sluggish wages based on workers' noisy information about the state of the economy. Wages do not respond immediately to a positive aggregate shock because workers do not (yet) have enough information to demand higher wages. This increases firms' incentives to post more vacancies, which makes unemployment volatile and sensitive to aggregate shocks. The model is robust to two major criticisms of existing theories of sluggish wages and volatile unemployment: flexibility of wages for new hires and pro-cyclicality of the opportunity cost of employment. Calibrated to U.S. data, the model explains 70% of unemployment volatility.

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1 Introduction

Search and matching models are an appealing way to study fluctuations in the labor market, as they define unemployment in a manner that is consistent with statistical agencies' convention and describe in an attractive way the functioning of the labor market, how firms and workers are matched, and how wages are negotiated. However, Shimer (2005) points out that the volatility of unemployment predicted by the standard search and matching model is low. One approach to resolving this "Shimer Puzzle" has emphasized the amplifying effects of sluggish wages. This approach has been criticized in recent years on the basis that, empirically, wages for new hires (from unemployment and other jobs) exhibit little rigidity (Pissarides, 2009) while the opportunity cost of employment is pro-cyclical (Karabarbounis & Chodorow-Reich, 2016). In this paper, I propose a new mechanism that predicts sluggish wages based on workers' noisy information about the state of the economy. This new mechanism is robust to the aforementioned critiques and generates business cycle dynamics for unemployment and wages that are consistent with the empirical evidence.

In my model, wages for new hires are flexible, but wages do not adjust immediately to the true state of the economy because workers learn slowly about aggregate shocks. This delayed adjustment increases firms' incentives to expand employment, making unemployment volatile and sensitive to aggregate shocks. My model is able to explain 70% of overall unemployment volatility and generates wage semi-elasticities with respect to the unemployment rate of around -3% for new hires, as reported by Pissarides (2009).

The model is in many respects similar to a standard RBC model with search and matching in the labor market. I introduce heterogeneous firms and assume that they differ in their permanent total factor productivity (TFP) levels, which are public information. In equilibrium, the most productive firms are larger and pay higher wages. To distinguish between new hires coming from unemployment and job changers, I assume that workers search on the job for better-paid jobs. The only source of aggregate uncertainty is aggregate TFP, which is not directly observed by workers. Instead, workers form expectations based on a public and noisy signal they receive each period. Thus, TFP shocks are only partially perceived by workers, who slowly learn about aggregate conditions as time goes by. This information friction affects the decisions of households and workers including those related to consumption and saving. Firms and workers negotiate wages each period. Workers negotiate wages based on their beliefs about the aggregate state of the economy. Hence, after a positive productivity shock, wages remain relatively constant because workers do not immediately possess the proper information to demand higher wages, which generates sluggish wages within jobs.

The persistence in wages within jobs increases firms' incentives to hire workers in an expansion, as they get to keep a larger fraction of the match surplus. However, in equilibrium, the high-paying/most-productive firms hire proportionally more new workers than the low-paying/less-productive firms in response to a positive productivity shock, as documented by Kahn and McEntarfer (2014); Haltiwanger, Hyatt and McEntarfer (2015); and Moscarini and Postel-Vinay (2008, 2012). This differential employment response occurs because there is a significant increase in job-to-job flows, which reduces the average duration of a match for less productive firms and therefore the value of an additional worker. Hence, in an expansion, high-paying firms have to increase their wages the most in order to attract all workers they demand. As a result, even though wages within jobs adjust slowly to the true state of the economy, the average wage for new hires exhibits a large response to productivity shocks on impact because a new hire faces more and better-paying job opportunities in an expansion than in a recession.

I calibrate my model using U.S. data for the period 1979 to 2015. To address the cyclicality of wages for job stayers versus new hires, I use the Current Population Survey (CPS) and IPUMS-CPS (Flood, King, Ruggles, & Warren, 2015) microdata to compute the average wage for all workers, job changers, and new hires from unemployment controlling for individual characteristics (e.g. Solon, Barsky, & Parker, 1994; Haefke, Sonntag, & van Rens, 2013; Muller, 2012).[1] These series show that job changers earn a lower wage than the average worker in the economy but a larger wage than new hires from unemployment, suggesting that unemployed workers are more likely to find a job at low paying job and move up the job ladder. However, I find low wage semi-elasticities with respect to the unemployment rate using these wage series: -0.3% for all workers, -0.6% for job changers, and -1.7% for new employees. Only the latter semi-elasticity is statistically significant.

The model calibrated to the U.S. economy is able to generate a large volatility in labor market quantities (unemployment, vacancies, vacancy-unemployment ratio), and relatively low volatility in wages and consumption, as in the data. Also, the model

[1] Henceforth, I will refer to new hires from unemployment as "new employees."

generates wage semi-elasticities with respect to the unemployment rate of around -3% for new hires, and -1% for all workers, which are similar to the estimate of Pissarides (2009) and larger than the estimates of Hagedorn and Manovskii (2013) and Gertler, Huckfeldt, and Trigari (2014). Even though most of the wage cyclicality in my model is driven by the differential growth rate between high and low-paying firms, I show that my model generates differential net job flows that are consistent with the empirical evidence presented by Haltiwanger et al. (2015). These moments (volatility, wage semi-elasticities, differential growth rates) are not a target in my calibration.

I present a simple test to the main prediction of this paper: Wages should increase when workers are more optimistic about economic conditions. Using the University of Michigan Surveys of Consumers, I show that wage growth is positively correlated with workers' expectations at monthly and quarterly frequencies. However, this relationship is only statistically significant at quarterly frequencies. I estimate that a 1 standard deviation increase in my measure of workers expectations is associated with a 0.4, 0.6 and 0.5 percent increase in the average wage for all workers, new employees, and job changers, respectively.

This work builds on the literature that addresses the Shimer puzzle (Shimer, 2005; Constain & Reiter, 2008) by studying the amplifying effects of sluggish wages on job creation. This literature is large and includes, for example: Hall (2005); Hall and Milgrom (2008); Christiano, Eichenbaum and Trabandt (2016); Gertler and Trigari (2009); Kennan (2009); Menzio (2005); and Venkateswaran (2013). My paper differs in at least three aspects with respect to this literature. First, I propose a new mechanism for sticky wages based on workers who face information frictions regarding aggregate variables. This mechanism, does not rely on any assumption about the persistence of aggregate shocks (Menzio, 2005) or the distribution of firms (Kennan, 2009). In contrast to Venkateswaran (2013), what drives sticky wages in my model is the fact that workers are willing to work for wages that do not adjust to the true state of the economy. That is, it is not enough to explain why firms offer wages that are very persistent —workers need to be willing to accept them.

Second, my model is able to generate significant unemployment volatility in spite of the procyclicality of the Flow Opportunity Cost of Employment (FOCE) (Chodorow-Reich & Karabarbounis, 2014; Brugemann & Moscarini, 2010).[2] Given that households

[2]FOCE is defined as the forgone value of unemployment benefits plus the forgone value of non-

make consumption and saving decisions based on the same information friction, investment (capital accumulation) absorbs most of the shock in the initial periods, which prevents consumption and the FOCE from increasing. Hence, even though the FOCE eventually rises, it takes time because workers (not firms) have information frictions regarding aggregate variables.

Third, this paper looks at the distributional implications of productivity shocks. I show that high-wage firms expand employment the most during an expansion and how this mechanism generates different wage dynamics across firms and groups of workers. Even though the information friction is the same for all agents, wages at high-paying firms are more sensitive to the business cycle than wages at low-paying firms. As a consequence of this differential employment and wage growth, the average wage for new hires is more sensitive to the business cycle than the average wage for all workers.

This paper is also related to the literature about information frictions. My model is close in spirit to Lucas (1972), in which agents' inability to distinguish between aggregate and idiosyncratic shocks generates money non-neutrality. Following Angeletos and La'O (2012), the information friction presented in this paper has both a nominal and a real part, as it affects not only price (wage) decisions but also real allocations (saving, consumption). Paying limited attention to aggregate shocks is a standard result in the rational inattention literature that started with Sims (2003). For example, Mackowiak and Wiederhold (2009) present a model in which agents optimally decide to receive a noisy signal about aggregate conditions, as I assume in this paper, because acquiring information is costly. Similarly, Acharya (2014) and Reis (2006a, 2006b) show that agents optimally decide to update their information set sporadically when they face a cost of acquiring and processing information. On the empirical side, Coibion and Gorodnichenko (2012) find that the behavior of forecast errors is more consistent with a model in which agents receive noisy signals about aggregate conditions, as I assume in this paper. In addition, Carroll (2003) formulates and finds evidence in favor of a model in which consumers have a larger degree of information rigidity than other agents. Similarly, Roberts (1998) finds evidence of non-rational expectations in survey data, and Branch (2004) argues that surveys reject the rational expectation hypothesis not because agents use an *ad hoc* expectation rule, but rather because agents optimally decide not to use a more complicated expectation (predictor) function.

working activities in term of consumption.

Finally, this paper is related to the literature that studies the cyclicality of wages over the business cycle. Pissarides (2009) argues that vacancy decisions depend only on the wage for new hires, which seem to exhibit little rigidity, and points out that the wage semi-elasticity with respect to the unemployment rate for new hires is around -3%, compared with a semi-elasticity of -1% for job stayers. The Pissarides critique has been recently challenged by Gertler et al. (2014) and Hagedorn and Manovskii (2013) based on the cyclicality of the match quality. However, whether wages for new hires are more procyclical than wages for existing workers is still an open question and is beyond the scope of this paper. Nevertheless, I use CPS and IPUMS-CPS microdata in order to construct the average wage for all workers and new hires (adjusted for individual characteristics) and assess the predictions of my model. It is worth noting that in my model, wages for new hires are flexible and I show that my model is able to reproduce a wage semi-elasticity with respect to the unemployment rate of around -3% for new hires, and -1% for all workers, which is not a target in my calibration. Hence, this paper points out that wage flexibility for new hires does not imply that wages adjust immediately to the true state of the economy.

The rest of this paper is organized as follows. I present my model in section 2, and section 3 presents quantitative analysis. I discuss some alternative issues and test the main implication of my model using survey data in section 4. Finally, section 5 concludes.

2 Theoretical Framework

The model presented in this section is, in many aspects, similar to a standard real business cycle model with search and matching in the labor market as in Andolfatto (1996) and Merz (1995). I introduce job changers in this model by assuming that there is a distribution of productivity across firms that induces a distribution of wages in the economy. Hence, employed workers search on the job for better paying jobs. The main difference of my model with respect to the relevant literature is that workers face information frictions about aggregate conditions. As in Lucas (1972), workers form expectations about current aggregate economic conditions based on noisy signals.

2.1 Household

There is a representative household made up of a continuum of members with mass normalized to 1.[3] The household is the owner of all firms in the economy, and it supplies capital and labor to firms. Capital is supplied in a perfectly competitive market at the rental rate r, while labor supply is subject to search frictions. I assume complete consumption insurance, which implies that workers seek to maximize income for the household. Consumption and savings decisions are made at the household level, but household members make their decisions based on the same information set $\mathcal{I}_h$. Throughout this paper, $E_{\mathcal{I}_h}[x]$ is the expected value of x conditional on the information set $\mathcal{I}_h$, and $E[x]$ is the expectation conditional on perfect information.

2.1.1 Consumption and Saving

Consumption and savings decision are made at the household level to maximize the life-time utility function

$$\mathbb{U}(\omega, \Omega) = \frac{c^{1-\sigma}}{1-\sigma} - \Psi \frac{\tilde{h}^{1+\eta}}{1+\eta} + \beta E\left[\mathbb{U}(\omega', \Omega')\right] \tag{1}$$

subject to the budget constraint (2), the aggregation of labor (3), and a perceived law of motion for the economy (4):

$$c + k' \leq (r + 1 - \delta_k)k + \int_0^1 w_j h_j dj + \int_0^1 \pi_j dj + b \cdot u - T \tag{2}$$

$$\tilde{h} = \left(\int_0^1 h_j^{1+\xi} dj\right)^{\frac{1}{1+\xi}} \tag{3}$$

$$\Omega' = \lambda^h(\Omega) \tag{4}$$

where $'$ denotes next period's value. $\omega = \{k, \{h_j\}_{j=0}^1, \mathcal{I}_h\}$ is the vector of state variables for the representative household, and Ω is a vector that summarizes the aggregate state of the economy. c is consumption, k is capital, w_j is the wage paid by firm j, and π_j stands for firm j's profits. $u = \int_0^1 (1 - h_j) dj$ is the total number of unemployed workers, and b is unemployment compensation, which is financed by *lump sum* taxes

[3] For expositional purposes, I derive in this section the value of employment and unemployment based on the model assumptions. For a detailed derivation of these value functions as in Merz (1995) and Andolfatto (1996), see appendix E.

$(T = b \cdot u)$. Parameter ξ in (3) governs the elasticity of substitution between h_x and h_y for all $x \neq y$. The household and its members form expectations based on their information set $\mathcal{I}_h$ and on a perceived law of motion for the economy $(\lambda^h(\cdot))$. Hence, the first order condition for consumption:

$$c^{-\sigma} = \beta E_{\mathcal{I}_h}\left[(1-\delta+r')c'^{-\sigma}\right] \tag{5}$$

It is worth noting that the consumption decision is also affected by information frictions because the expectation in equation (5) is conditional on the information set $\mathcal{I}_h$. To the extent that aggregate shocks are partially perceived, the household will respond to productivity innovations by accumulating capital in an attempt to smooth consumption through time. As a result, the marginal disutility of labor (in terms of consumption) does not increase, which prevents wages from going up. This mechanism will be clear in section 2.5.

2.1.2 Workers

A worker can be employed or unemployed at each point in time. Unemployed workers receive unemployment compensation b and are matched with a firm with probability q. Conditional on a match, a worker is matched with firm j with probability $\left(\frac{v_j}{v}\right)$, where v is the total number of vacancies in the economy and v_j stands for firm j's vacancies. Hence, the value of unemployment $U(\omega, \Omega)$ is given by:

$$U(\omega,\Omega) = b + E\left\{Q\left((1-q)U(\omega',\Omega') + q\int_0^1 W_x(\omega',\Omega')\frac{v_x}{v}dx\right)\right\} \tag{6}$$

where $Q = \beta\left(\frac{c'}{c}\right)^{-\sigma}$ is the stochastic discount factor between this period and the next period and $W_j(\omega,\Omega)$ is the value of employment at firm j. Meanwhile, employed workers are separated from their job with exogenous probability δ_h, in which case they have to spend at least one period in unemployment before they can be matched with another firm. I assume that employed workers can search on the job and are matched with another firm with probability $\bar{i}q$. However, I assume that employed workers only change jobs if they find a firm that offers an equal or better continuation value. Throughout this paper, I refer to jobs that deliver an equal or greater continuation value as *better* jobs. Hence, denoting $W_j(\omega,\Omega)$ as the value of employment at firm j, the net value of employment is given by:

$$
\begin{aligned}
(W_j(\omega,\Omega)-U(\omega,\Omega)) = \quad & w_j - z_j \\
& + E\{Q((1-\delta_h)(1-\bar{i}qF_j)(W_j(\omega',\Omega')-U(\omega',\Omega')) \\
& + (1-\delta_h)\bar{i}qF_j(\tilde{W}_j(\omega',\Omega')-U(\omega',\Omega')) \\
& - q\left(\bar{W}(\omega',\Omega')-U(\omega',\Omega')\right))\}
\end{aligned} \tag{7}
$$

where:

$$
z_j = b + \Psi \frac{\tilde{h}^{\eta-\xi}}{c^{-\sigma}} h_j^{\xi} \tag{8}
$$

$$
F_j = \int_j^1 \frac{v_x}{v} dx \tag{9}
$$

$$
\tilde{W}_j(\omega',\Omega') = \int_j^1 W_x(\omega',\Omega') \left(\frac{v_x}{\int_j^1 v_y dy} \right) dx \tag{10}
$$

$$
\bar{W}(\omega',\Omega') = \int_0^1 W_x(\omega',\Omega') \frac{v_x}{v} dx \tag{11}
$$

The first line in equation (7) is the net flow income of a worker employed at firm j. The second term (z_j) is the FOCE, which is defined as the forgone value of unemployment benefits plus the forgone value of non-working activities (derived from the household's utility function (1)). The second line in equation (7) says that with probability $(1-\delta_h)(1-\bar{i}qF_j)$ a worker is not exogenously separated from firm j and is not matched with a better job, where F_j is the probability of finding a weakly better job than j. The third line captures that with probability $(1-\delta_h)\bar{i}qF_j$ a worker is not exogenously separated from firm j and is matched with a better job, $\tilde{W}_j(\omega',\Omega')$ is the expected value of the new job for job changers leaving firm j. Finally, the fourth line in (7) is the worker's outside option for next period. If unemployed, a worker finds a job with probability q and receives, on expectation, a continuation value equal to $\bar{W}(\omega',\Omega')$.

Notice that the net value of employment $(W_j(\omega,\Omega)-U(\omega,\Omega))$ is a decreasing function in z_j and therefore in consumption. An increase in consumption makes z_j go up and reduces the net value of employment. As a consequence, wages must increase when consumption increases in order to compensate workers for the decline in the value of employment. It is worth noticing that equations (7) and (8) explain why high-paying firms are more sensitive to aggregate shocks than low-paying firms in this model. Since high-paying firms are larger in equilibrium, the FOCE (z_j) is an increasing function in j and, as a consequence, so is $\frac{z_j}{p_j}$. Given that z_j is increasing in firm size, we should also expect high-paying firms to have more volatile wages than low-paying firms.[4]

Finally, notice that the expectations in equations (6) and (7) are not conditional on the household's information set $\mathcal{I}_h$ because equations these describe what a worker will *actually* receive in expectation and not what workers expect to receive. However, workers will have to form expectations about $W_j(\omega, \Omega)$ and $U(\omega, \Omega)$ to negotiate wages, as described in section 2.5.

2.2 Firms

There is a continuum of firms indexed by j with a mass normalized to 1. All firms produce a homogeneous good that is sold in a competitive market. A *priori* the only difference among firms is their (permanent) TFP level, which is denoted by a_j. Without loss of generality, I assume that $a_x \geq a_y$ for all $x \geq y$. Firms produce with capital and labor, and their output can be used for consumption or for capital accumulation. At the beginning of each period, firms rent capital and open new vacancies, v. A vacancy is matched with a worker with probability $\tilde{q}$. As is standard in the literature, a filled vacancy becomes productive in the subsequent period. However, not all matches become productive. If a vacancy is matched with a worker who is currently employed at a better job, the match is dissolved. Hence, the job filling rate for firm j ($\tilde{q}_j$) is given by $\tilde{q}_j = \tilde{q}^u + \tilde{q}^c_j$, where $\tilde{q}^u = \tilde{q} \cdot \left(\frac{u}{s}\right)$ is the probability of filling a vacancy with an unemployed worker and $\tilde{q}^c_j = \tilde{q} \cdot \left(\int_0^j \frac{(1-\delta_h)\bar{i}h_x}{s} dx\right)$ is the probability of filling a vacancy

[4] The underlying source of this differential growth is not important for the results of this paper. However, Kahn and McEntarfer (2014) find that high-paying firms do not have a more cyclical demand than low-paying firms and that high-paying firms have a larger drop in wage rigidity during recessions than low paying firms.

with a job changer. The problem for firm j is given by:

$$\Pi_j(\omega_f, \Omega) = \max_{v_j, k_j} \quad \pi_j + E\left[Q\Pi_j(\omega_f', \Omega')\right] \tag{12}$$

s.t.

$$\pi_j = e^{a_j+a} k_j^{\alpha} h_j^{1-\alpha} - w_j h_j - r k_j - \frac{\kappa}{1+\chi}(\tilde{q}_j v_j)^{1+\chi} \tag{13}$$

$$h_j' = (1-\delta_h)(1-\bar{i}qF_j)h_j + \tilde{q}_j v_j \tag{14}$$

$$\Omega' = \lambda^f(\Omega) \tag{15}$$

where a stands for aggregate TFP, which is common to all firms. $\omega_f = \{h_j\}$ is the vector of state variables for firm j, and equation (15) is the perceived law of motion for the economy. Denoting marginal labor productivity by $p_j = (1-\alpha)e^{a_j+a}k_j^{\alpha}h_j^{-\alpha}$, the first order conditions with respect to v_j and k_j are given by:

$$v_j: \quad -\kappa(\tilde{q}_j v_j)^{\chi} + E\left[Q \cdot J_j'(\omega_f', \Omega')\right] \quad \leq 0 \tag{16}$$

$$k_j: \quad p_j\left(\frac{h_j}{k_j}\right)\left(\frac{\alpha}{1-\alpha}\right) - r \quad = 0 \tag{17}$$

where $J_j(\omega_j, \Omega) = \frac{\partial \Pi_j(\omega_f, \Omega)}{\partial h_j}$ is the firm's value of an additional worker, or the continuation value of a filled vacancy:

$$J_j(\omega_f, \Omega) = p_j - w_j + E\left[Q \cdot (1-\delta_h)(1-\bar{i}qF_j) \cdot J_j(\omega_f', \Omega')\right] \tag{18}$$

Notice that even though the exogenous separation rate δ_h is the same for all firms, the *total* separation rate varies across firms. If we define $\delta_{hj} = 1-(1-\delta_h)(1-\bar{i}q_tF_j)$ as firm j's total separation rate, we can see that low-wage (less-productive) firms have higher separation rates. Therefore, labor market conditions affect the value of a new vacancy through the firm specific separation rate δ_{hj}.

2.3 Information Sets

I assume that workers (households) face information frictions in the sense that they do not perfectly know the current value of aggregate TFP (a), which is the only source of aggregate uncertainty. I assume that there is a public signal ($\hat{a}$), based on which workers form expectations. I assume that this public signal is also observed by firms, so that workers' beliefs are common knowledge. The public signal is the sum of the aggregate TFP an a noise signal denoted by n. The aggregate TFP (a) and the noise (n) are assumed to follow two independent AR(1) processes.

$$\hat{a} = a + n \tag{19}$$

$$a' = \rho_a a + e_a'; \qquad e_a \sim N(0, \varsigma_a) \tag{20}$$

$$n' = \rho_n n + e_n'; \qquad e_n \sim N(0, \varsigma_n) \tag{21}$$

To formally define the equilibrium of this economy and find the solution of this model, I assume that workers can perfectly observe the state of the economy with a lag of $\mathcal{T}$ periods where $\mathcal{T}$ is a large integer. Hence, the information set for the representative household is given by: $\mathcal{I}_h = \{\hat{a}^{\mathcal{T}}, \Omega_{-\mathcal{T}}\}$, where $\hat{a}^{\mathcal{T}}$ represents the last $\mathcal{T}$ realizations of n, and $\Omega_{-\mathcal{T}}$ is the value of the vector Ω $\mathcal{T}$ periods ago.[5]

2.4 Matching

The total number of matches in the economy $m(v, s)$ is an increasing function in the total number of vacancies ($v = \int_0^1 v_j dj$) and the total number of job searchers ($s = u + \int_0^1 (1 - \delta_h)\bar{\imath} h_j dj$), where $u = 1 - \int_0^1 h_j dj$ is the number of unemployed workers. Following the literature, $m(v, s)$ is assumed to be homogeneous of degree 1. Hence, $q = m(\theta, 1)$ and $\tilde{q} = m(1, \theta^{-1})$ where $\theta = v/s$ is labor market tightness.

2.5 Wage Negotiation

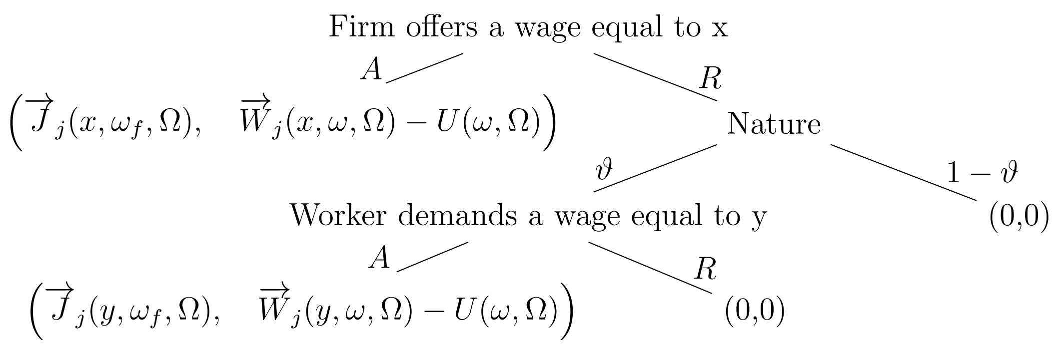
I assume that wages are completely flexible and are negotiated at the start of every period according to a simple game, through which firms and workers bargain over the match surplus, $S_j = J_j(\omega_f, \Omega) + W_j(\omega, \Omega) - U(\omega, \Omega)$. For expositional purposes, I will abuse notation slightly in this section and define functions $\overrightarrow{J}_j(w, \omega_f, \Omega)$ and $\overrightarrow{W}_j(w, \omega, \Omega)$ as the value of a filled vacancy and employment for an arbitrary wage w.

Wages in this economy are negotiated according to the following game: (1) The firm offers a wage x to the worker. (2) The worker observes the firm's offer. Upon acceptance, the game ends with payoffs of $\overrightarrow{W}_j(x, \omega, \Omega) - U(\omega, \Omega)$ to the worker and $\overrightarrow{J}_j(x, \omega_f, \Omega)$

[5] Appendix B explains this in more details.

to the firm. (3) If the worker rejects the firm's offer, the match is destroyed with exogenous probability $1-\vartheta$ (with payoffs to both agents of 0); otherwise, the worker demands a wage y. (4) The firm observes this demand. Upon acceptance, the game ends with payoffs of $\overrightarrow{W}_j(y,\omega,\Omega)-U(\omega,\Omega)$ for worker and $\overrightarrow{J}_j(y,\omega_f,\Omega)$ for firm. If the firm rejects the worker's offer, the game ends with payoffs of zero for both agents. The extensive-from representation of this game is given in Figure 1.

Figure 1: Wage Determination Game



Note: This figure shows the extensive-form representation of the wage determination game. Firms and workers bargain over the match surplus (S_j) by making wage offers/demands. Details are provided in the text.

2.5.1 Equilibrium Wage and Discussion

Even though this model assumes information frictions, an important benchmark is the case in which all agents have perfect information. In this spirit, the following lemma establishes the equilibrium of this game under perfect information, which will be used to compare the results under information frictions.

Lemma 1. *If all agents in the economy have complete and perfect information, the following strategy profiles constitute the unique sub-game perfect Nash equilibrium of this game:*

- *Worker: To accept only wage offers greater than or equal to x^* (first stage), and to demand a wage equal to y^* (second stage).*
- *Firm: To offer x^* (first stage) and to accept only wage demands that are less than or equal to y^* (second stage).*

where x^* and y^* are such that $\overrightarrow{J}_j(x^*, \omega_j, \Omega) = (1 - \vartheta) \cdot S_j$ and $\overrightarrow{J}_j(y^*, \omega_j, \Omega) = 0$.

Proof. See Appendix A.1 □

Hence, under perfect information, the solution to this game coincides with the solution to the *Nash-bargaining* game when the worker's bargaining power is equal to ϑ. Therefore, I will call ϑ the *long-term bargaining power* of workers. Now, before characterizing the solution to this game with information frictions, the following lemmas tell us that, in equilibrium, firms cannot credibly communicate the true state of the economy to the workers.

Lemma 2. *Suppose that agents are information-constrained as described in section 2.3. If there is an equilibrium in which firms' strategy is to reveal the aggregate state of the economy, the best strategy for firms is the same strategy described in Lemma 1.*

Proof. See Appendix A.2 □

Lemma 3. *If agents in the economy are information-constrained as described in section 2.3, then in equilibrium, firms do not follow a strategy in which they perfectly reveal the true state of the economy.*

Proof. See Appendix A.3 □

Lemmas 2 and 3 make clear that a solution in which firms reveal the true state of the economy is not possible. The intuition is simple: firms have incentives to lie. Firms will always be tempted to tell workers that aggregate productivity is lower than it actually is, so wages can be lower. As a consequence, workers do not rely on firms' offer to form expectations about aggregate conditions. Before defining the solution for this game with information frictions, I make the following assumption:

Assumption 1. *For all realizations of a and n, $\overrightarrow{J}_j(x^{**}, \omega_f, \Omega) \geq 0$ where x^{**} is such that $E_{\mathcal{I}_h}\left[\overrightarrow{W}_j(x^{**}, \omega, \Omega) - U(\omega, \Omega)\right] = \vartheta \cdot E_{\mathcal{I}_h}[S_j]$*

That is, if both parties agree upon a wage x^{**} such that, according to the worker's information set, a fraction ϑ of the match surplus goes to the worker, the firm still gets a positive payoff for all realizations of the true productivity and the signal.[6] Next, the following lemma presents the solution to this game.

[6] I check that this assumption holds in my calibration by simulating the economy for 1 million periods and computing, for each period, $mJ = min_j\{J_j\}$. Figure 9 in Appendix D plots mJ and shows that mJ is always positive and never close to zero.

Lemma 4. *If agents in the economy are information-constrained as described in section 2.3, the following strategy profiles constitute a Perfect Bayesian Nash equilibrium that satisfies the intuitive criterion:*

- *Worker: To accept only wage offers greater than or equal to x^{**} (first stage), and to demand a wage equal to y^{**} (second stage).*
- *Firm: to offer x^{**} (first stage), and to accept only wage demands that are less than or equal to $\tilde{y}^{**}$.*

where x^{**} and y^{**} are such that $E_{\mathcal{I}_h}\left[\overrightarrow{J}_j(x^{**}, \omega_j, \Omega)\right] = (1-\vartheta)E_{\mathcal{I}_h}[S_j]$ and $E_{\mathcal{I}_h}\left[\overrightarrow{J}_j(y^{**}, \omega_j, \Omega)\right] = 0$

Proof. See Appendix A.4 □

Notice that in equilibrium, wages are a function of what workers would have demanded if given the chance, even though they do not get to make such a wage demand in equilibrium. If firms anticipate that workers will ask for a fraction X of their perceived match surplus, they will offer a wage such that workers get $\vartheta \cdot X$ of the match surplus. Notice that this result is common in the literature. In the classic paper of Rubinstein (1982), there are no counter-offers in equilibrium because the first player to move makes an offer that takes into account what the other player would get in the second stage of the game.[7]

Regarding the solution with information frictions, Lemma 4 is an important result for this paper. Given that firms have incentives to lie about true productivity (Lemma 3), workers will only use their own information set to assess wage offers. Hence, wage demands will be based on information frictions. To the extent that aggregate TFP shocks are partially perceived, wage demands will be less sensitive to aggregate conditions because workers' expectations are smoother than aggregate shocks.

2.6 Equilibrium

We can now characterize the vector that describes the aggregate state of the economy as $\Omega = \{k, \{h_j\}_{j=0}^{1}, a^{\mathcal{T}}, n^{\mathcal{T}}\}$. As before, $a^{\mathcal{T}}$ and $n^{\mathcal{T}}$ refer to the last $\mathcal{T}$ realizations of a

[7] Similarly, Hall and Milgrom (2008) and Christiano et al. (2016) assume that wages are negotiated according to an alternating wage offer game, in which there are no counter-offers in equilibrium for the same reason

and n, respectively.[8]

Definition 1. *A recursive competitive equilibrium for this economy is a list of functions* $\{\mathbb{U}(\omega,\Omega),\ W_j(\omega,\Omega),\ U(\omega,\Omega),\ \Pi_j(\omega_f,\Omega),\ J_j(\omega_f,\Omega)\}$ *[Value Functions],* $\{\{w_j(\Omega)\}_{j=0}^1,\ r(\Omega)\}$ *[Prices],* $\{h_j(\omega_f,\Omega), k_j(\omega_f,\Omega), v_j(\omega_f,\Omega), \pi_j(\omega_f,\Omega), \tilde{W}_j(\omega,\Omega), z_j(\Omega)\}_{j=0}^1, \bar{W}(\omega,\Omega),$ $c(\omega,\Omega),\ k(\omega,\Omega),\ y(\Omega),\ s(\Omega),\ v(\Omega),\ \theta(\Omega)\}$ *[Allocations],* $\{\{\tilde{q}_j(\Omega),\ \tilde{q}_j^c(\Omega),\ F_j(\Omega)\}_{j=0}^1,$ $q(\Omega),\ q^u(\Omega)\}$*[Probabilities], and* $\{\lambda,\ \lambda^f,\ \lambda^c\}$*[Law of motion] such that given a law of motion for* $\{\hat{a},\ a,\ n\}$*[Exogenous variables]:*

(1) *The representative household optimize:* $c(\omega,\Omega)$ *and* $k'(\omega,\Omega)$ *satisfy optimality condition (5) and the household's budget constraint (2).*

(2) *Firms optimize:* $v_j(\omega_f,\Omega)$*,* $k_j(\omega_f,\Omega)$*, and* $h_j(\omega_f,\Omega)$ *satisfy optimality conditions (16), (17) and the law of motion for* h_j *(69) for all* j*.*

(3) *Wages are a solution to wage bargaining game 2.5.*

(4) *Value functions are consistent with equations (1), (7), (6), (12), and (18).*

(5) *At each point in time, workers' beliefs are determined by their information set* $\mathcal{I}_h$*, their perceived law of motion for the economy (4), and Bayes' rule.*

(6) *The decision rules of households and firms imply a law of motion for the economy such that:* $\lambda^f = \lambda^h = \lambda$*.*

(7) *Probabilities:* $\tilde{q}_j = \tilde{q}^u + \tilde{q}_j^c$*,* $\tilde{q}^u = \tilde{q}\,(u/s)$*,* $\tilde{q}_j^c = \tilde{q}(\int_0^j (1-\delta_h)\bar{i}(h_x/s)dx)$*,* $F_j = \int_j^1 (v_x/v)dx$*, and* $q = m(v,s)/s$*.*

(8) *Allocations:* $\pi_j(\omega_f,\Omega)$*,* $z_j(\Omega)$*,* $\tilde{W}_j(\omega,\Omega)$*,* $\bar{W}(\omega,\Omega)$ *and* $\theta(\Omega)$ *are consistent with equations (13), (8), (10), (11), and* $\theta(\Omega) = (v(\Omega)/s(\Omega))$*.*

(9) *Aggregation:* $y = \int e^{a_j+a} k_j^{\alpha} h_j^{1-\alpha} dj$*,* $s = u + \int \bar{i} h_j dj$*,* $u = 1 - \int h_j dj$*,* $v = \int v_j dj$*, and* $k = \int k_j dj$*.*

Appendix F presents the equations that describe the equilibrium of this economy, and the computation of this model is explained in Appendix B.

3 Quantitative Analysis

I assess the model's predictions using quarterly data for the United States for the period 1979 to 2015. I present business cycle statistics for the quarterly time series (seasonally adjusted) of unemployment, vacancies, output, consumption, investment, aggregate

[8]Section Appendix B describe the solution method in more detail.

TFP, and real wages (deflated by CPI and constructed using the CPS microdata) for new employees, job changers, and all workers. I take the quarterly average of series that are available monthly. Following Shimer (2005), all variables are HP-filtered in logs with a smoothing parameter of 10^5.[9] Data source and details are presented in Appendixes I and J.

Table 1: Business Cycle Statistics: U.S. Economy 1979:Q1 to 2015:Q4

		u	v	v/u	y	c	Inv	w^a	w^u	w^c	a
Standard deviation		0.19	0.19	0.38	0.02	0.02	0.10	0.02	0.03	0.02	0.02
Autocorrelation		0.97	0.96	0.97	0.95	0.96	0.94	0.9	0.69	0.65	0.91
Correlation Matrix	u	1	-0.92	-0.98	-0.80	-0.63	-0.82	-0.22	-0.21	-0.13	-0.47
	v		1	0.98	0.76	0.56	0.85	0.06	0.01	0.01	0.50
	v/u			1	0.79	0.6	0.86	0.14	0.11	0.07	0.49
	y				1	0.91	0.82	0.54	0.40	0.49	0.81
	c					1	0.61	0.62	0.47	0.55	0.76
	Inv						1	0.22	0.07	0.25	0.67
	w^a							1	0.79	0.78	0.51
	w^u								1	0.71	0.32
	w^c									1	0.45
	a										1

Note: Statistics for the U.S. economy are based on: u: Unemployment level. v: Help-wanted index (Barnichon, 2010). v/u: Vancancy-unemployment ratio. y: Real GDP. c: Consumption of non-durable goods and services. Inv: Real private domestic investment. w^a: Average wage in the economy. w^u: Average wage for new employees. w^c: Average wage for job changers. a: Solow residual. All series are seasonally adjusted, logged, and detrended via the HP filter with a smoothing parameter of 100,000.
Calculations based on: U.S. Bureau of Labor Statistics, Unemployment level [UNEMPLOY] and Consumer Price Index for All Urban Consumers [CPIAUCSL], U.S. Bureau of Economic Analysis, Real Gross Domestic Product [GDPC1], Personal Consumption Expenditures: Nondurable Goods [PCNDG96] and Services [PCESVC96], Real Gross Private Domestic Investment [GPDIC96], all retrieved from FRED, Federal Reserve Bank of St. Louis, https://fred.stlouisfed.org/. Barnichon (2010), Current Population Survery (CPS), IPUMS-CPS (Flood et al., 2015), and Federal Reserve Bank of San Francisco.

Table 1 presents unconditional business cycle statistics for the U.S. economy. As has been previously documented in the literature, unemployment is one of the most volatile series (e.g. Shimer, 2005; Costain & Reiter, 2008). Unemployment is 10 times more volatile than TFP, and 8 times more volatile than output, in contrast to consumption,

[9]In general my results are not very sensitive to this parameter.

whose standard deviation is almost as large as that of TFP. Vacancies and the vacancy-unemployment ratio are also highly volatile as their standard deviations are 19.5% and 37.5%, respectively, in comparison with 2.3% and 1.6% for output and TFP, respectively. Investment also fluctuates a lot over the business cycle. Even though it is not as volatile as unemployment or vacancies, the standard deviation of investment is 4.5 times larger than that of output. In contrast, wages are not very volatile. The standard deviations of the average wage of all workers (w^a), new hires from unemployment (w^u), and job changers (w^c) are 2.1%, 3.4% and 2.4% respectively. Also, it is noteworthy that wages are the less persistent and less correlated series with unemployment and output.

3.1 Parameterization

I calibrate this model to a monthly frequency and compute quarterly averages of the model generated series in order to compare my model results with the U.S. data. I take the values for the intertemporal elasticity of substitution (σ), the inverse of the Frisch elasticity (η), and the output elasticity of labor (α) from previous literature and set these parameters equal to 1, 0.5, and 0.33, respectively. I set ϑ equal to 0.5, which implies equal bargaining power for workers and firms in steady state. The unemployment benefit b is set to 0.041 following the evidence presented by Chodorow-Reich and Karabarbounis (2014). I set δ and β so that the annual depreciation rate is equal to 10% and the annual interest rate is equal to 5% in steady state.

Following den Han, Ramey and Watson (2000), I assume the following matching function: $m(s,v) = \frac{sv}{\left(s^l+v^l\right)^{\frac{1}{l}}}$, where l is such that the job-finding rate (q) is equal to 0.27 in steady state, which implies an average duration of unemployment equal to 15 weeks. The exogenous separation rate δ_h is set such that the unemployment rate is equal to 5.5% in steady state.

I discretize the firm productivity distribution (a_j) into 101 points, and I calibrate it such that marginal labor productivity (p_j) is distributed according to a truncated normal between $\left[\underline{p}, \infty\right)$ with a mode equal to 1 and standard deviation equal to 0.6, as reported by Long, Dziczek, Luria, and Wiarda (2008). In order to guarantee a positive match surplus in equilibrium for all firms, I set $\underline{p}$ equal to 0.4, which is 10 times larger than b.

I calibrate the disutility of labor parameter Ψ such that the average of the ratio

$\frac{z_j}{p_j}$ across firms is equal to 0.72, which is consistent with the value found by Hall and Milgrom (2008). The value for $\bar{i}$ is calibrated such that the number of job changers per month in steady state is equal to 2.5% of the total population (Fallick & Fleischman, 2004).

Table 2: Parameter Values

Externally Calibrated

Parameter	Value	Description
σ	1	Intertemporal elasticity of substitution
ξ	0.5	Inverse of Frisch elasticity
α	0.33	Labor share in production function
ρ_a	$0.95^{1/3}$	Persistence of productivity shocks
ϑ	0.5	Workers' bargaining power in steady state

Internally Calibrated

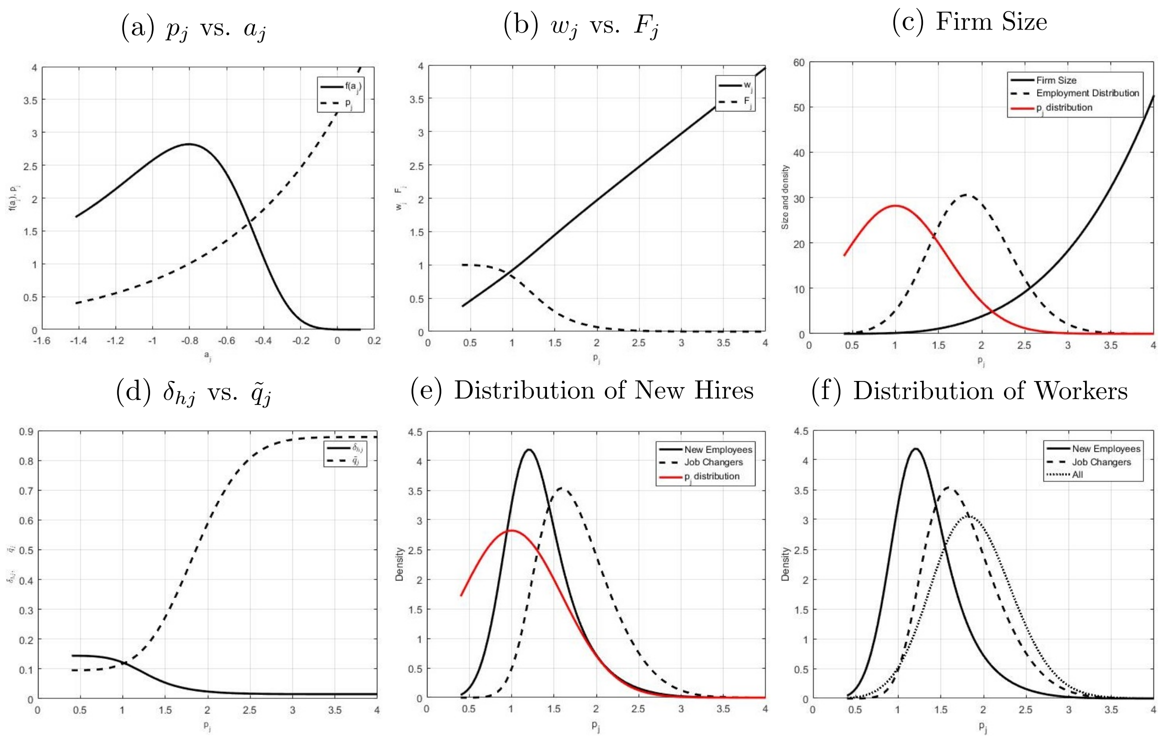
Parameter	Value	Description
ς_n	$2 \cdot \varsigma_a$	Standard deviation of noise shocks.
ρ_n	0.841	Persistence of noise shocks.
δ_h	0.015	Exogenous separation rate.
Ψ	1.158	Desutility of labor parameter.
b	0.041	Unemployment benefits.
l	1.3806	Matching function parameter.
$\bar{i}$	0.485	Relative search intensity of employed workers.
β	0.996	Discount factor.
ξ	0.2922	Elasticity of substitution between jobs.
χ	0.3225	Hiring cost function convexity.
δ_k	0.0087	Capital depreciation rate.

Note: This table summarizes the parameterization of the model. Details are reported in section 3.1.

I use parameters ξ and χ to target some moments of the wage and size distribution across firms for the United States. Kahn and McEntarfer (2014) present the average monthly earnings across firms for each wage quintile, which are reproduced in Table 9 in Appendix C. According to this table, a worker employed at a firm in the highest wage quintile earns, on average, 3.61 times more than a worker employed at a firm in the lowest wage quintile. I calibrate ξ to match this moment. On the other hand, based on the firm size distribution reported by the Business Dynamics Statistics from 1977 to 2014, I calibrate parameter χ to target the average size of firms with 100 to 249 employees as a fraction of the average size of the smallest firms.[10]

Finally, the persistence of aggregate TFP is set equal to $0.95^{1/3}$ and the standard deviation calibrated to match the standard deviation of TFP presented in Table 1. Following Coibion and Gorodnichenko (2012), $\frac{\varsigma_n}{\varsigma_a}$ is set to 2 and ρ_n is calibrated such that the perception error has a quarterly persistence of 0.8.[11] Table 2 summarizes the aforementioned calibration parameters.

Figure 2: Firm and Employment Distribution in Steady State



Note: This figure plots the distributions of employment and productivity across firms in steady state along with the separation rate, job filling rate, and wage associated with each firm.

[10]Table 10 in Appendix C presents these statistics. Given that average size increases drastically at the high end of the distribution, I do not target the average size of the largest firms

[11]Perception error IS defined as aggregate TFP - perceived aggregate TFP.

3.2 Model Results

3.2.1 Steady State

Figure 2 illustrates the properties of this model in steady state. Panel 2a plots the distribution of idiosyncratic TFP across firms ($f(a_j)$) and the marginal labor productivity associated with each a_j. Panel 2b shows the wage rate (w_j) and the probability of finding a better job conditional on a match for employed workers (F_j). Panel 2c shows the average firm size as a function of the firm's labor productivity p (solid black line), and the distributions of employment (dashed line). Panel 2d plots the separation rate (δ_{hj}) and the job filling rate ($\tilde{q}_j$) associated with each level of labor productivity. Panels 2e and 2f, plot the distribution of new employees (solid black lines) and job changers (dashed black lines) along with the labor productivity distribution (red line in panel 2e) and the distribution of all workers (dotted black line in Panel 2f).

Based on Figure 2, we can see that workers employed at the most productive firms earn higher wages and face a lower probability of finding a better job (F_j). On the other hand, high-productive firms are larger, retain a larger fraction of their workers and fill vacancies faster than low-productive firms (Panels 2c and 2d). As a consequence, the distribution of employment is shifted to the right in comparison with the distribution of the labor productivity (Panel 2c), and unemployed workers are more likely to find a job at a low paying firm and then move up the job ladder.

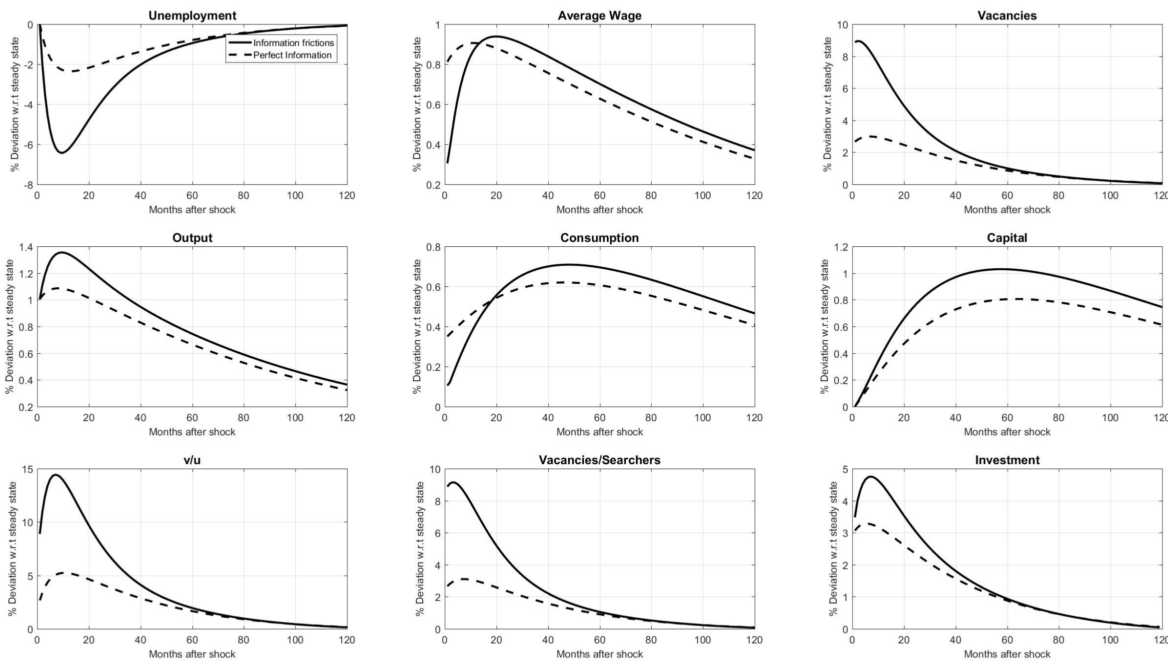
Table 3: Average Wages in Steady State

	All workers	Job Stayers	New Hires	Job Changers	New Employees
Model	1.00	1.01	0.85	0.94	0.70
Data	1.00	1.01	0.90	0.98	0.89

Notes: All wages are expressed as a fraction of the average wage for all workers in the economy. The first row of this table reports the average wage for different groups of workers in steady in the model. The second row presents data average for the period 1979-2015. The average wage for new hires and job stayers are weighted averages of the average wage of all workers, job changers and new employees.

Table 3 reports the average wage for different types of workers as a fraction of the average wage for all workers in the model and in the data. According to the model results, the average wage for job stayers is higher than the average wage for any other group, while the average wage for new employees is the lowest. High-paying firms are larger and a great share of their hires come from other firms, while low-paying firms rely more on the pool of unemployment to fill a vacancy. This story has been documented by Moscarini and Posterl-Vinay (2008) and Haltiwanger et al. (2005) and is also consistent with the data reported in the second row.[12] Even though the model does a good job matching the wage and size distribution in the economy, the average wage for new employees is significantly lower in my model than in the data.

Figure 3: Impulse Response Function to a 1% Increase in Aggregate Productivity



Note: This figure plots model Impulse Response Functions (IRFs) to a 1% increase in aggregate TFP. Solid black lines are the IRFs for a model in which workers face information frictions, and dashedlines are the IRFs generated by a model in which all agents have perfect information.

3.2.2 Impulse Response Functions

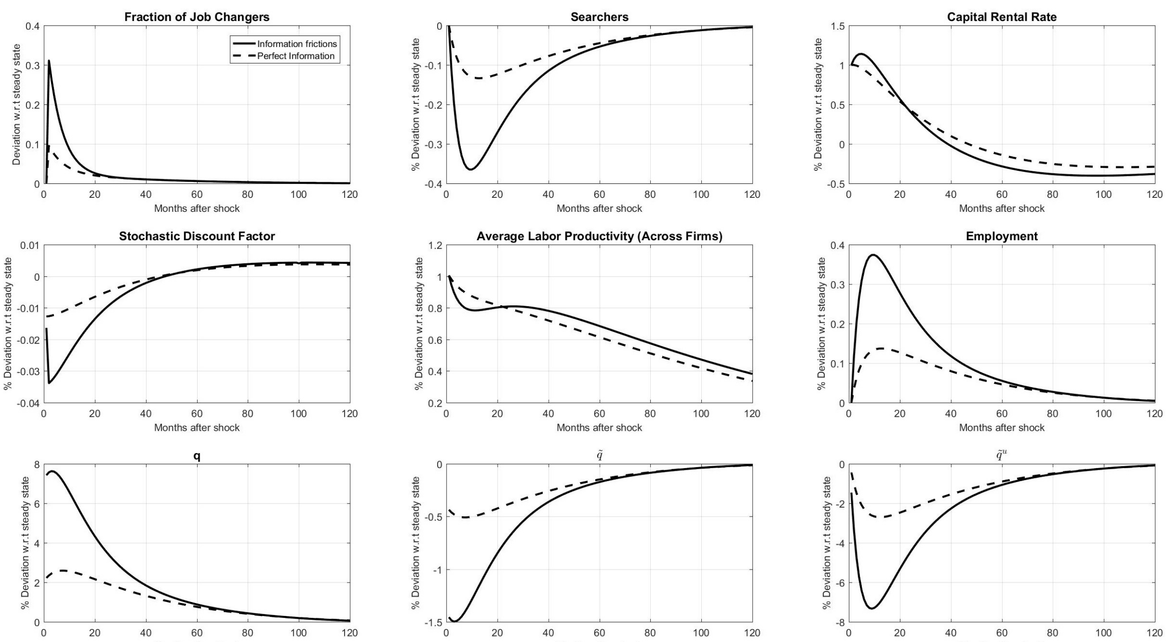
Next, Figures 3 and 4 plot the Impulse Response Functions (IRFs) of the aggregate variables of this model to a 1% increase in aggregate TFP (solid black lines). To decipher the role of information frictions, I simultaneously plot the IRFs generated by a calibrated model in which agents have perfect information (dashed lines). In

[12] Appendix I reports additional graphs.

addition, Figure 5 plots the IRFs for firms located at the 20th, 40th, 50th, 60th, and 80th percentiles of the wage distribution weighted by employment.

Because TFP shocks are partially perceived by workers, wages are less sensitive to aggregate productivity innovations, and firms have more incentives to expand employment (Figure 4). In particular, the assumed information friction has two reinforcing effects on wages. First, workers' expectations are highly sluggish. Hence, in a boom, workers do not demand a large increase in wages because they do not have enough information to conclude that the economy has entered an expansionary path. Second, given workers' beliefs, consumption does not change significantly on impact, which curbs the increase of the flow of opportunity cost of employment (z_j) from increasing and makes wages even less responsive.

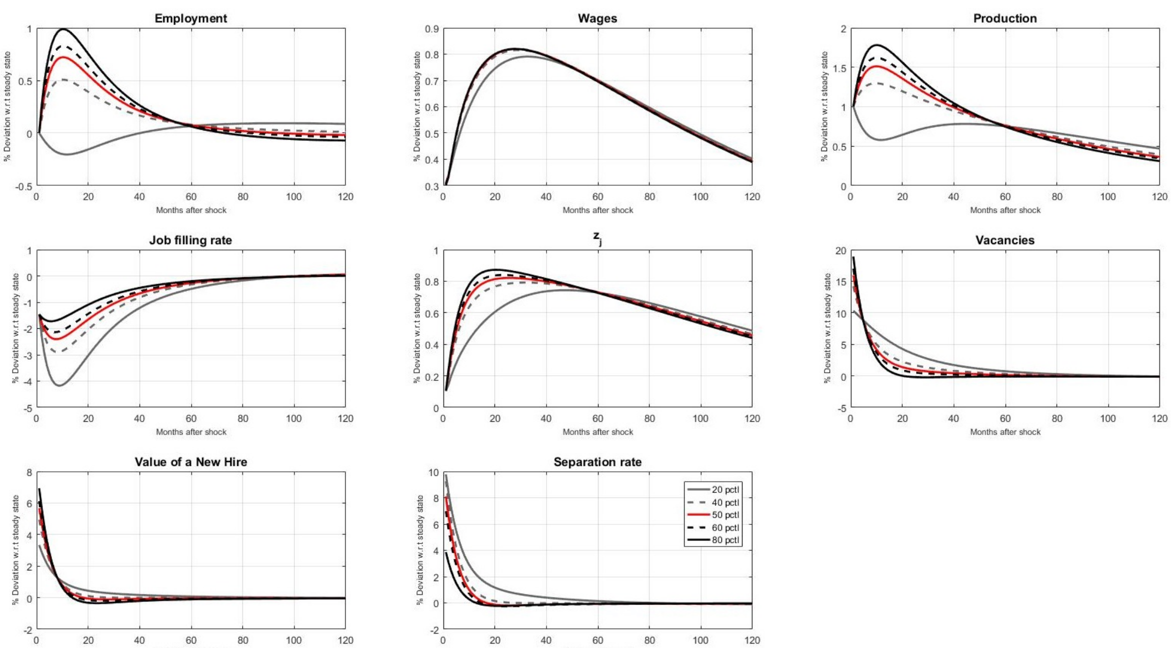
Figure 4: Impulse Response Function to a 1% Increase in Aggregate Productivity



Note: This figure plots model Impulse Response Functions (IRFs) to a 1% increase in aggregate TFP. Solid black lines are the IRFs of a model in which workers face information frictions, and dashed lines are the IRFs generated by a model in which all agents have perfect information. q, $\tilde{q}$, and $\tilde{q}^u$ denote the job finding rate, the probability that a vacancy is matched with a worker, and the job filling rate (from unemployment), respectively.

However, the most productive firms experience a larger expansion in employment as a consequence of a positive aggregate TFP innovation. Notice that the value of a new hire is affected by two countervailing effects. On the one hand, the productivity increase, combined with sluggish real wages, tends to increase the value of an additional worker for firms in an expansion. On the other hand, the expansion in overall employment increases the flow of job changers, which rises the separation rate and reduces the the value of an additional worker, as firms expect the match to not last as long. Given that the separation rate increases the less for high-paying firms, they expand employment the most. As a result, the differential employment growth rate between high and low paying firms is positive and procyclical, which is consistent with the empirical evidence (e.g. Kahn & McEntarfer, 2014; Haltiwanger et al., 2015). Similarly, since low-paying firms rely more on hiring from the pool of unemployment, they experience a larger decline in $\tilde{q}_j$ than high-paying firms because of the decline in unemployment.

Figure 5: Distributional Dynamics to a 1% Increase in Aggregate Productivity



Note: This figure plots the Impulse Response Functions (IRFs) for a model with information frictions for different firms to a 1% increase in aggregate TFP. Solid gray lines are the IRFs for firms at the 20th percentile of wage distribution weighted by employment. The dashed-gray lines are the IRFs for firms at the 40th percentile. The solid red lines are the IRF for the median firm. The dashed black lines are the IRF for firms at the 60th percentile, and the solid black lines are the IRFs for firms at the 80th percentile. z_j denotes the flow opportunity cost of employment for firm j.

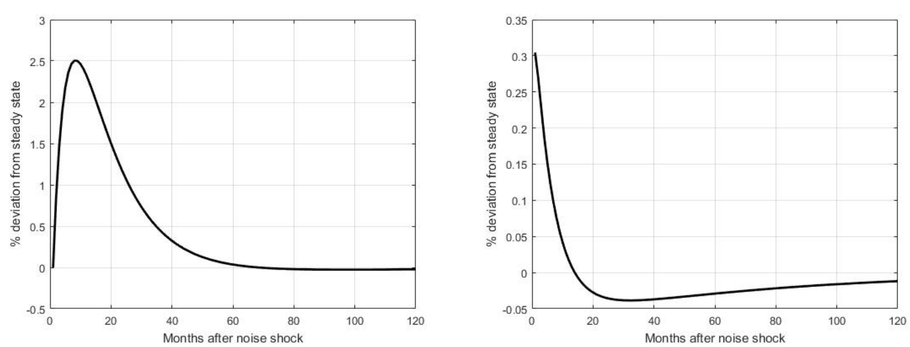
This differential growth rate in employment implies a larger increase in the FOCE

(z_j), and as a consequence in wages, for high-paying firms. Because workers can perfectly distinguish among firms and they know that highly-productive firms are more sensitive to the business cycle, employees at the most productive firms demand higher wage in expansions than employees at less-productive firms. Hence, the differential employment growth rate occurs despite the larger adjustment in wages for high-paying firms, as documented by Kahn and McEntarfer (2014).

Noise shocks, however, do not only reduce wage demands through workers' perceived productivity. Workers will partially attribute noise shocks to TFP innovations, resulting in higher wage demands and unemployment as shown in Figure 6. Since workers know that the demanding higher wages in response to noise shocks is not optimal, wage demands will tend to be even lower in response to productivity shocks. In other words, wage demands weight the positive effects of a positive TFP shock and the negative effects of a positive noise shock.

Figure 6: Unemployment and Wage Responses to a 1% Increase in Noise Shock

(a) Unemployment (b) Average Wage



Note: This figure plots the Impulse Response Functions to a 1% increase in the signal noise (n). Lines represent % deviation with respect to its steady state value.

3.2.3 Simulated Business Cycles Statistics

Table 4 reports the theoretical business cycle statistics predicted by a model in which workers face information frictions, and Table 5 does the same for the model with full information.[13] In comparison with the U.S. data, my model with information frictions

[13]The model was used to generate artificial series of the same length and frequency as in my data. These series were used to compute, in the same way, the same business cycle statistics reported in

does a good job predicting a high volatility for labor market variables and a low volatility for wages and consumption. This is in part because of the amplifying effect of the information friction. The volatility of u, v, and v/u are three times larger in the model with information frictions than in the model with full information, but the volatility of consumption and wages is just slightly larger in the former. The autocorrelation predicted by my model are close to the data, and my model is able to display a lower autocorrelation for the average wage of new employees and job changers. Even though the information friction tends to reduce the correlation between the average wage of the economy with other economy variables, those correlations continue to be significantly larger than in the data. Similarly, the correlations between the average wage for new employees and all variables of the economy have a different sign as in the data.

Table 4: Simulated Business Cycle
Workers Face Information Frictions

		u	v	v/u	y	c	Inv	w^a	w^u	w^c	a
Standard deviation		0.14	0.18	0.31	0.03	0.01	0.09	0.02	0.02	0.01	0.02
Autocorrelation		0.93	0.87	0.91	0.93	0.97	0.92	0.94	0.76	0.74	0.89
Correlation Matrix	u	1	-0.89	-0.97	-0.83	-0.24	-0.91	-0.56	0.47	0.08	-0.72
	v		1	0.98	0.78	0.07	0.90	0.39	-0.21	0.11	0.75
	v/u			1	0.83	0.15	0.93	0.48	-0.34	0.03	0.76
	y				1	0.61	0.94	0.86	-0.01	0.40	0.96
	c					1	0.32	0.83	0.21	0.45	0.50
	Inv						1	0.69	-0.13	0.26	0.93
	w^a							1	0.08	0.44	0.80
	w^u								1	0.87	0.18
	w^c									1	0.54
	a										1

Note: Statistics for the simulated economy under information frictions: *u:* Unemployment level. *v:* Vacancies *v/u:* Vancancy-unemployment ratio. *y:* Output. *c:* Consumption. *Inv:* Investment. *w^a:* Average wage in the economy. *w^u:* Average wage for new employees. *w^c:* Average wage for job changers. *a:* Aggregate TFP. All series are seasonally adjusted, logged, and detrended with the HP filter with a smoothing parameter of 100,000.

Table 1. This exercise was repeated 10,000 times. Then, each statistic reported in Tables 4 and 5 is the average of that moment across the 10,000 simulations.

Table 5: Simulated Business Cycle
Model with Full Information

		u	v	v/u	y	c	Inv	w^a	w^u	w^c	a
Standard deviation		0.04	0.06	0.10	0.02	0.01	0.06	0.02	0.01	0.01	0.02
Autocorrelation		0.95	0.92	0.95	0.92	0.96	0.91	0.92	0.77	0.82	0.89
Correlation Matrix	u	1	-0.93	-0.98	-0.93	-0.76	-0.92	-0.9	-0.7	-0.74	-0.9
	v		1	0.99	0.96	0.71	1.00	0.92	0.87	0.88	0.99
	v/u			1	0.96	0.74	0.98	0.93	0.81	0.83	0.97
	y				1	0.87	0.96	0.98	0.9	0.91	0.98
	c					1	0.69	0.88	0.74	0.77	0.75
	Inv						1	0.92	0.88	0.88	0.99
	w^a							1	0.87	0.89	0.94
	w^u								1	0.96	0.93
	w^c									1	0.92
	a										1

Note: Statistics for the simulated economy under perfect information: u: Unemployment level. v: Vacancies v/u: Vancancy-unemployment ratio. y: Output. c: Consumption. Inv: Investment. w^a: Average wage in the economy. w^u: Average wage for new employees. w^c: Average wage for job changers. a: Aggregate TFP. All series are seasonally adjusted, logged, and detrended with the HP filter with a smoothing parameter of 100,000.

3.2.4 Wages and Employment Composition

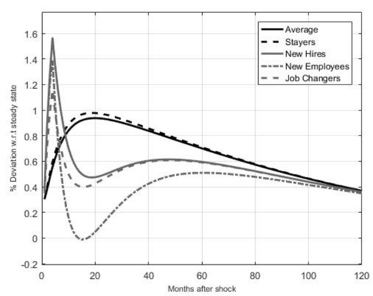
The left panels of Figure 7 plot the IRF to a 1% increase in aggregate TFP for average wages for each type of worker in the model with information frictions (panel 7a) and in the model with full information (panel 7c). Notice that the average wage for new hires, job changers, and new employees has a larger response, soon after the TFP shock. However, these wage differences are driven primarily by heterogeneity across firms. To see the importance of this heterogeneity, the right panels of Figure 7 plot the average wage for all groups of workers when wages are adjusted for this composition effect following Horrace and Oaxaga (2001).[14] By comparing the left and right panels of Figure 7, we can infer that the initial increase in the wages of new hires, job changers and new employees is due almost entirely to the large increase in employment at high-

[14]The composition adjusted wage for group G is defined as the average wage for a fixed composition of workers, which is given by the distribution of workers in steady state.

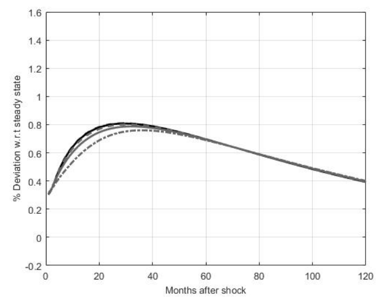
paying firms. [15]

Figure 7: Wages Responses to a 1% Increase in Aggregate Productivity

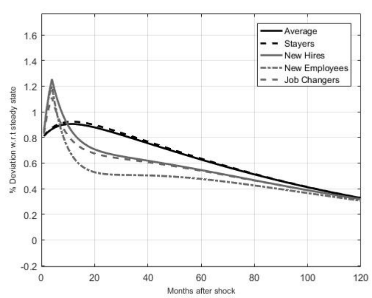
(a) Information Frictions Model
Simple Average



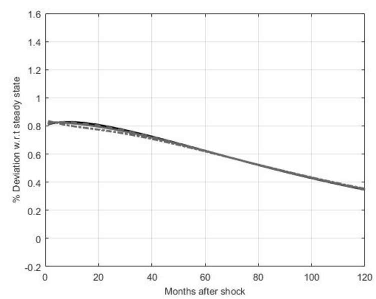
(b) Information Frictions Model
Composition Adjusted



(c) Full Information Model
Simple Average



(d) Full Information Model
Composition Adjusted



Note: This figure plots the evolution of the average wage for different groups of workers in response to a 1% increase in aggregate productivity. Panels 7a and 7c plot the evolution of average wages not adjusted for composition effects. Panels 7b and 7d plot the evolution of average wages adjusted for composition effects as proposed by Horrace and Oaxaga (2001).

How does the wage flexibility in my model compare with the data? and How large is the reallocation of workers from low to high paying firms in my model? These questions are answered in Tables 6 and 7. On the one hand, Pissarides (2009) argues that the wage semi-elasticity with respect to the unemployment rate for new hires is around -3% compared with -1% for job stayers, indicating a larger wage flexibility for new hires than usually assumed and questioning the importance of wage stickiness to explain

[15] Actually, in the model with information frictions, the average wage response for new employees is lower than the average wage response for job changers, which is slightly lower than the average wage response for job stayers. This is because unemployed workers are more likely to find a job at a low paying firms and then to move up the job ladder (Figure 2f), and low paying firms increase their wages less in booms (Figure 5).

the unemployment volatility. I compute this wage semi-elasticity using the wage series constructed from microdata and model simulated series by fitting the following equation consistent with Pissarides (2009):

$$log(w_t^G/w_{t-1}^G) = \alpha_0 + \beta_u \cdot (ur_t - ur_{t-1}) + e_t \tag{22}$$

where w_t^G is the average wage for group G. α_0 is a constant, ur_t is the unemployment rate at time t, and e_t is an error term. Table 6 reports the estimated values for β_u using U.S. data in column 1. My estimates are smaller than reported by Pissarides (2009), and only the semi-elasticity for new employees is statistically significant at 10%. Columns 2 and 3 in Table 6 present the theoretical values for β_u in the model with full information and with information frictions respectively.[16] The model with full information predicts a wage semi-elasticity of -1% for all workers but positive and large semi-elasticities for new employees and job changers. This is because, the largest wage responses are on impact, but the largest unemployment response is not. In contrast, the model with information frictions generates negative wage semi-elasticities for all groups of workers (-2.93% for job changers, -2.65 for new employees, and -1.12% for all workers). In the model with information frictions, the largest wage responses are not on impact, and we observe a significant change in the average wage for new hires because high-paying firms expand employment the most in booms (Figure 7), which induces a higher correlation between changes in unemployment and wages for new hires.

On the other hand, I asses the employment flows generated by my model in Table 7. Column (1) of Table 7 reproduces the findings of Haltiwanger, et al (2015) regarding the reallocation of workers from low to high paying firms during the business cycle. As before, columns (2) and (3) report the analog theoretical moments. In particular, Table 7 reports the estimated values of β in the following specification:

$$Y_t = \gamma + \pi_t + \beta \cdot CYC_t + \epsilon_t \tag{23}$$

where Y_t is differential net job flows, net poaching flow, and net nonemployment flows

[16] Using my model, I generate artificial series of the same size and frequency as my data (148 monthly observations for the average wage of all and new employees and 88 monthly observations for the average wage of job changer). Using these artificial series, I estimate β_u by fitting equation (22). I repeat this exercise 10,000 times and get the theoretical value of β_u by taking the average across the 10,000 simulations.

Table 6: Wage Semi-Elasticities with Respect to the Unemployment Rate

	US Data	Model Simulated Data	
		Full Information	Information Frictions
All Workers	-0.27	-1.01	-1.12
	(0.27)		
New Employees	-1.66*	3.98	-2.65
	(0.99)		
Job Changers	-0.57	3.42	-2.93
	(1.21)		

Note: Each specification includes monthly dummies and a lag of the independent variable. Robust standard error in parenthesis. *, **, *** indicate statistically significance at 10%, 5%, and 1% respectively. Sample period for all and new employees is January 1979 to December 2015 and for job changers is January 1994 to December 2015.

between high and low wage firms.[17] γ is a constant, π includes seasonal dummies and a time trend, and ϵ is an error term. CYC is a cyclical variable, which can be the HP-filtered unemployment rate or the first different in the unemployment rate. According to Table 7, both models generate differential employment flows that are consistent with the empirical estimates of Haltiwanger, et al (2015) when I use the HP-filtered unemployment rate as a cyclical indicator. But both models generate little differential employment growth when the first different in the unemployment rate is used as a cyclical indicator. Given that my model does not display a larger differential employment flow than observed in the data, the wage cyclicality reported in Table 6 does not seem to be driven by an excessive reallocation of workers from low to high-paying firms.

4 Robustness and Extensions

4.1 A Simple Test Using Survey Data

In this subsection, I test the main implication of my model: Wages should increase when workers are more optimistic about economic conditions. To this end, I re-estimate equation (22) introducing a variable of workers' expectations. Hence, my empirical

[17]High wage firm indicates that the firm is in the two top quintiles of the wage distribution across firms. Low wage firm indicates that the firm is in the bottom quintile of the wage distribution.

Table 7: Differential Net Flows, Coefficient on Cyclical Variable
High Wage minus Low Wage

	Data	Model Simulated Data Full Information	 Information Frictions
		Deviation from HP Trend	
Net Job Flows	-0.269	-0.210	-0.257
Net Poaching Flows	-0.253	-0.252	-0.292
Net Nonemployment Flows	-0.016	0.042	0.035
		First Difference	
Net Job Flows	-0.557	0.007	0.018
Net Poaching Flows	-1.460	0.004	0.013
Net Nonemployment Flows	-0.903	0.003	0.005

Note: Data for the first column are from Haltiwanger, Hyatt, and McEntarfer (2015) Table 1. Each model was used to generate artificial data over a time horizon of 55 quarters, which is consistent with the sample size of Haltiwanger, et al. (2015). Each model was simulated 10,000 times. The coefficient on the cyclical variable was computed for each artificial series, and the theoretical coefficient was estimated by averaging across the 10,000 simulations.

model takes the following form:

$$\left(log(w_t^G) - log(w_{t-1}^G)\right) = \alpha_0 + \beta_u \cdot (ur_t - ur_{t-1}) + \beta_E \cdot \Delta E_t^w + e_t \tag{24}$$

Where variable ΔE_t^w is a measure of change in workers expectations. As a proxy of E_t^w, I use the Index of Consumer Sentiments (ICS) of the Surveys of Consumers conducted by the University of Michigan. The ICS is reported monthly and is intended to be a indicator of how consumers view prospects (better or worst) for their own financial situation and for the economy in the near and long term. The ICS is used in levels because it asks for expected changes instead of expected levels. Also, for an easier interpretation in my estimation, I normalize the ICS such that it has a zero mean and a standard deviation equal to one. The first three columns in Table 8 present the results of estimating equation (24) by OLS. For an easier interpretation, all values in Table

8 are expressed as semi-elasticities. By including a variable of workers expectations, all wage semi-elasticities with respect to the unemployment rate become smaller and statistically insignificant. Also, these results show that wages are positively correlated with workers' expectations, but this coefficient is only statistically significant for the average wage of all workers. A one standard deviation increase in the ICS is associated with a 0.14% increase in the average wage for all workers.

Table 8: Wage Growth vs. Expectations

	Monthly Frequency			Quarterly Frequency		
	All Workers	New Employees	Job Changers	All Workers	New Employees	Job Changers
β_u	-0.03	-1.51	-0.42	-0.31	-0.23	0.87
	(0.28)	(1.02)	(1.28)	(0.28)	(0.94)	(0.98)
β_E	0.14***	0.08	0.10	0.35***	0.63**	0.48***
	(0.05)	(0.18)	(0.21)	(0.11)	(0.27)	(0.24)
β_{ue}				-0.07	-0.12	-0.71
				(0.33)	(0.92)	(1.00)
β_y				-0.25	-0.49	-0.05
				(0.20)	(0.42)	(0.50)
R^2	0.21	0.27	0.26	0.17	0.33	0.15
N	442	426	253	146	139	83

Note: This table reports the estimated coefficient on the unemployment rate (β_u), workers' expectations (β_E), expected change in the unemployment rate over the next year (β_{ue}), and expected GDP growth for the following year (β_y) for each group of workers. Each specification includes monthly (quarterly) dummies and a lag of the independent variable. Robust standard errors in parentheses. *, **, *** indicate statistically significance at 10%, 5%, and 1% respectively. Sample period for all and new employees is January 1979 to December 2015 and for job changers is January 1994 to December 2015.

To see if wages are correlated with other agents' expectations, the last three columns of Table 8 report the results of estimating the following equation:

$$\left(log(w_t^G) - log(w_{t-1}^G)\right) = \alpha_0 + \beta_u \left(ur_t - ur_{t-1}\right) + \beta_E E_t^w + \beta_{ue} ur_t^e + \beta_y y_t^e e_t \qquad (25)$$

where ur_t^e is the expected change in the unemployment rate over the next year, and y_t^e is the expected GDP growth for the following year. ur_t^e and y_t^e are taken from the

Survey of Professional Forecasters and are available at a quarterly frequency. These results show that workers' expectations are more significantly correlated with wages at a quarterly frequency. A 1 standard deviation increase in the ICS is associated with a 0.35%, 0.63% and 0.48% increase in the average wage for all workers, new employees and job changers respectively. Also, it is worth noticing that the ICS is the only statistically significant variable in Table 8, suggesting a significant relationship between wages and workers' beliefs.

4.2 Unilateral Deviations in Equilibrium

Nothing in my model prevents firms from paying a higher wage in equilibrium. Even though higher wages increase firms' payroll, offering a higher wage can reduce the fraction of workers who are poached by other firms, and as a consequence, increase profits. When workers' bargaining power is low (high), firms incentives to offer higher wages could be large (small). However, in my calibration with a bargaining power equal to 0.5, if we allowed firms to offer higher wages, no firm has incentives to offer a higher wage in equilibrium. In Appendix G, I present this results formally following the theoretical framework of Moscarini and Postel-Vinay (2013).

4.3 Firms Face Information Frictions

Assuming that firms and workers face information frictions is not a straight forward exercise in my model. Depending on how this new friction is introduced in the benchmark model, hiring decisions and the unemployment response can become larger or smaller. However, as long as workers face information frictions regarding aggregate conditions, and assuming that the workers' information set is always a subset of the firms' information set, wages will have fewer pressures to increase in booms because the value of the outside option (the value of unemployment) is underestimated. Notice that the two equations governing the dynamics of wages and hiring decisions in this model are given by:

$$E_{\mathcal{I}_h}\left[\overrightarrow{W}_j(w_j,\omega,\Omega)\right] = \vartheta \cdot E_{\mathcal{I}_h}\left[S_j\right] + E_{\mathcal{I}_h}\left[U(\omega,\Omega)\right] \tag{26}$$

$$\kappa(\tilde{q}_j v_j)^{\chi} = E_{\mathcal{I}_j}\left[Q \cdot J_j'(\omega_f',\Omega')\right] \tag{27}$$

where $\mathcal{I}_j$ is the information set of firm j. Hence, *wages depend on workers' expectations, while hiring decisions depend on firms beliefs.* In the benchmark model, workers underestimate changes in S_j and $U(\omega, \Omega)$ reducing the volatility of wages. This rises the volatility of Jj, which increases firms' hiring decision. In Appendix H, I present three variations of my benchamark model in which firms face information frictions. I show that models with information frictions, in general, continue to display larger unemployment responses to TFP shocks than a model with full information. Also, I show that wage responses continue to display a clear hump-shaped response to TFP shocks in models with information frictions because workers take time to understand changes in the economy.

5 Conclusion

I propose a new mechanism for sluggish wages based on workers' noisy information about the state of the economy. In my model, workers receive noisy signals about the current state of the economy and learn slowly about aggregate conditions. Hence, wages do not immediately respond to a positive aggregate shock because workers do not (yet) have enough information to demand higher wages. This delayed adjustment in wages increases firms' incentives to post more vacancies, making unemployment more volatile and sensitive to aggregate shocks. My calibrated model is able to explain 70% of overall unemployment volatility.

My model is robust to two major critiques of existing theories of sluggish wages and volatile unemployment: the flexibility of wages for new hires and the cyclicality of the opportunity cost of employment. On the one hand, my model predicts a very cyclical opportunity cost of employment, as the value of non-working activities in terms of consumption increases in expansions. On the other hand, my model assumes flexible wages for new hires and generates a wage semi-elasticity with respect to the unemployment rate for new hires and all workers of around -3% and -1% respectively, which is similar to the estimate of Pissarides (2009) and larger than the estimates of Hagedorn and Manovskii (2013), Gertler et al. (2014) and my own estimations using the CPS and IPUMS-CPS (Flood et al., 2015) microdata (-0.27% for all workers, -1.66% for new employees, and -0.57% for job changers).

Consistent with recent empirical evidence (e.g. Kahn & McEntarfer, 2014; Haltiwanger et al. 2015), my model predicts that high-wage highly productive firms expand employment more than low-wage firms and also exhibit larger wage adjustments in expansions. This differential growth rate implies that the distribution of new hires shifts to the most productive and highest paying firms in response to positive productivity shocks. This has important consequences for new hires, as they find more and better paying jobs in expansions.

I use the University of Michigan Surveys of Consumers and my wage series constructed from the CPS and IPUMS-CPS microdata to test whether wages increase when workers are more optimistic about economic conditions. Even though workers' expectations and wages are positively correlated, this relationship is only statistically significant at quarterly frequencies. I estimate that a 1 standard deviation increase in my measure of workers' expectations is associated with a 0.35%, 0.63%, and 0.48% increase in the average wage for all workers, new employees and job changers respectively. Also, I find no statistically significant correlation between unemployment and output expectations from the Survey of Professional Forecasters and wages.

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A Proofs

A.1 Proof of Lemma 1

If all agents in the economy have complete and perfect information, the following strategy profiles constitute the unique sub-game perfect Nash equilibrium of this game:

- *Worker: To accept only wage offers greater than or equal to x^* (first stage), and to demand a wage equal to y^* (second stage).*

- *Firm: To offer x^* (first stage) and to accept only wage demands that are less than or equal to y^* (second stage).*

where x^* and y^* are such that $\overrightarrow{J}_j(x^*, \omega_j, \Omega) = (1 - \vartheta) \cdot S_j$ and $\overrightarrow{J}_j(y^*, \omega_j, \Omega) = 0$.

Proof. I begin at the third stage of the game (i.e. when the worker makes an offer). At this stage, the firm will accept any wage demand y as long as $\overrightarrow{J}_j(y, h_j, \Omega) \geq 0$. Hence, the worker will demand a wage y^* such that $\overrightarrow{J}_j(y^*, h_j, \Omega) = 0$ and she keeps all the match surplus. Thus, at the second stage (i.e. when the worker has to accept or reject the firm's offer), the worker knows that if she rejects this offer, her expected payoff at the third stage will be $\vartheta \cdot S_j$. Therefore, she will only accept wage offers that are greater than or equal to x^* where $\overrightarrow{W}_j(x^*, \omega, \Omega) - U = \vartheta \cdot S_j$. Finally, at the first stage of the game (i.e. when the firm makes an initial offer), the firm anticipates a payoff of zero if it makes an offer less than x^* and a payoff of $\overrightarrow{J}_j(x, h_j, \Omega)$ if $x \geq x^*$. Hence, the firm offers exactly x^* to the worker and she accepts it. □

A.2 Proof of Lemma 2

Suppose that agents are information-constrained as described in section 2.3. If there is an equilibrium in which firms' strategy is to reveal the aggregate state of the economy, the best strategy for firms is the same strategy described in Lemma 1.

Proof. As we are considering the equilibrium of the game, if firms are following a revealing strategy, workers know it and behave rationally. As a consequence, workers can perfectly infer the current state of the economy based on the firm's wage offer.

Hence, a worker knows that she will receive, in expectation, $\vartheta \cdot S_j$ if she rejects a firm's offer. Therefore, the optimal strategy for workers is the following:

- To infer the current level of the aggregate productivity based on firm's offer x: $a = x^{-1}(a)$

- To accept only wage offers greater than or equal to x^* where:

$$\overrightarrow{W}_j(x^*, \omega, \Omega) - U = \vartheta \cdot S_j$$
$$\overrightarrow{J}_j(x^*, \omega, \Omega) = 0$$

- To demand a wage equal to y^* if she has the chance such that:

$$\overrightarrow{W}_j(y^*, \omega, \Omega) - U = S_j$$

Now, given the workers' strategy, the firm anticipates a payoff of zero if it makes an offer less than x^* and a payoff of $\overrightarrow{J}_j(x, h_j, \Omega) - U$ if $x \geq x^*$. Given that $\overrightarrow{J}_j(x, h_j, \Omega)$ is strictly decreasing in x, the optimal strategy for firms, *assuming that they follow a revealing strategy* is the following:

- To offer x^*.

- To accept only wage demands that are less than or equal to y^*.

As a consequence, if there exists an equilibrium in which firms reveal the true state of the economy, in equilibrium firms offer exactly x^* and workers will accept it. In other words, workers rationally believe that if a firm extends a wage offer x, it has to be the case that $x = x^*$. □

A.3 Proof of Lemma 3

If agents in the economy are information-constrained as described in section 2.3, then in equilibrium, firms do not follow a strategy in which they perfectly reveal the true state of the economy.

Proof. Suppose not. By Lemma A.2, if there is an equilibrium in which firms reveal the true state of the economy, firms always offer $x = x^*$ and workers accept all wage offers (x) because they rationally believe that x is always equal to x^*. However, in order for these strategies to be an equilibrium, firms cannot have incentives to deviate.

Suppose that firms deviate to a strategy in which they offer $\tilde{x} = 0.5x^*$. Workers will accept this offer because they believe $\tilde{x} = x^*$, and firms will be better off because $J_j(\tilde{x}) > J_j(x^*)$. Therefore, there is not an equilibrium in which firms reveal the true state of the economy. □

A.4 Proof of Lemma 4

If agents in the economy are information-constrained as described in section 2.3, the following strategy profiles constitute a Perfect Bayesian Nash equilibrium that satisfies the intuitive criterion:

- *Worker: To accept only wage offers greater than or equal to x^{**} (first stage), and to demand a wage equal to y^{**} (second stage).*
- *Firm: to offer x^{**} (first stage), and to accept only wage demands that are less than or equal to $\tilde{y}^{**}$.*

where x^{**} and y^{**} are such that $E_{\mathcal{I}_h}\left[\overrightarrow{J}_j(x^{**}, \omega_j, \Omega)\right] = (1-\vartheta)E_{\mathcal{I}_h}[S_j]$ and $E_{\mathcal{I}_h}\left[\overrightarrow{J}_j(y^{**}, \omega_j, \Omega)\right] = 0$.

Proof. I begin at the third stage of the game (i.e. when the worker gets to make an offer). At this stage, the firm will accept any wage demand y as long as its expected value is greater than or equal to zero. Given the firm's strategy, the firm's offer does not reveal its information. Therefore, the worker will demand a wage y^{**} such that, given her information set, the firm's value is zero. Thus, at the second stage (i.e. when the worker has to accept or reject the firm's offer), the worker knows that if she rejects this offer, her expected payoff at the third stage will be $\vartheta \cdot E_{\mathcal{I}_h}[S_j]$. Therefore, she will only accept wage offers that are greater than or equal to x^{**}. Finally, at the first stage of the game (i.e. when the firm makes an offer), the firm anticipates a payoff of zero if it makes an offer less than x^{**} and a payoff of $\overrightarrow{J}_j(x, h_j, \Omega) \geq 0$ if $x \geq x^{**}$. Hence, the firm offers exactly x^{**} to the worker and she accepts it.

To prove that this equilibrium satisfies the intuitive criterion, define Θ as the set of all possible realizations of $\{a, n\}$. Then, for a given information set $\mathcal{I}_h$, define $\hat{\Theta}(w) \subseteq \Theta$ as the set of pairs $\{a, n\}$ for which a wage offer w is not equilibrium dominated for firm

j. Hence:

$$\hat{\Theta}(w > x^{**}) = \emptyset \tag{28}$$
$$\hat{\Theta}(w < x^{**}) = \Theta \tag{29}$$

Any wage offer above the equilibrium wage x^{**} is always equilibrium dominated. Given that a worker is willing to work for a wage x^{**}, offering a higher wage will only reduce the firm's profits.

However, wage offers below the equilibrium wage are not equilibrium dominated for any realization of $\{a, n\}$ because firm's profits will increase if a worker is willing to work for a lower wage. As a consequence, if a worker receives a wage offer below the equilibrium wage, she cannot extract more information from that offer. Regardless of the realization of a and n, offering a lower wage could always be a profitable deviation for firms. Formally:

$$Pr(a = x|\mathcal{I}_h, w < x^{**}) = Pr(a = x|\mathcal{I}_h) \quad \forall \quad x \in \Theta \tag{30}$$
$$E[a|\mathcal{I}_h, w < x^{**}] = E[a|\mathcal{I}_h] \tag{31}$$

Conditional on receiving a wage offer below the equilibrium wage, the worker's expectations do not change.

□

B Computation

To compute the solution to this model numerically, it is important to find and determine a law of motion for the economy, based on which the household forms expectations and makes decisions. This task may not be simple for a large vector Ω, given a distribution of firms and workers. Another challenge is that the vector of state variables should incorporate a set of variables that capture agents' beliefs, which could include prior beliefs about Ω or lags of the vector of state variables. This could not only increase significantly the size of the vector of state variables but also may require the computation of higher order expectations (expectations of agents' expectations).

Hence, I propose a procedure that combines the solution method for heterogeneous agent models developed by Reiter (2009) and the Kalman filter. In particular, the law of motion for the aggregate economy will be linear (Reiter method), which will allow me to form expectations using the Kalman filter. I show that I can keep track of agents' expectations by keeping track of the last $\mathcal{T}$ realizations of the aggregate shocks in the economy, where $\mathcal{T}$ is a "large" integer.[18] Hence, *to solve the model with noisy signals, you only need to include the last $\mathcal{T}$ realizations of the aggregate shocks as state variables.*[19]

In more detail, the Reiter method solves heterogeneous agent models by taking a first-order approximation of the model around the deterministic steady state of the economy.[20] Assume that the following system of equations describes the equilibrium of the economy:

$$f(\Omega, \Omega', \Upsilon, \Upsilon', \mathbb{E}) = 0 \tag{32}$$

where Υ is the vector of endogenous variables of the economy and $\mathbb{E}$ is the vector of exogenous shocks. The Reiter method then finds the solution in three steps:

1. A finite representation of the economy is provided by discretizing the distribution of agents.

[18] $\mathcal{T}$ is large enough if $\tilde{\mathcal{T}} >> \mathcal{T}$ generates almost the same results. In my calibration, I find that $\mathcal{T}$=100 was more than enough.

[19] Notice that vector Ω in the equilibrium definition in section 2.6 included the last $\mathcal{T}$ realization of the aggregate shocks.

[20] For a detailed application of the Reiter method, see Costain and Nakov (2011).

2. The deterministic steady state of the economy is found by imposing $\mathbb{E} = 0$ and finding the solution to:

$$f^* = f(\Omega^*, \Omega^*, \Upsilon^*, \Upsilon^*, 0) = 0 \tag{33}$$

3. The model is linearized numerically around the steady state, which yields the system of linear equations:

$$f_1^*(\Omega - \Omega^*) + f_2^*(\Omega' - \Omega^*) + f_3^*(\Upsilon - \Upsilon^*) + f_4^*(\Upsilon' - \Upsilon^*) + f_5^*\mathbb{E} = 0 \tag{34}$$

   where f_i^* is the partial derivative of (33) with respect to its *i-th* argument. This system is solved using a standard method such as Sims (2002) or Klein (2000).

Hence, the Reiter method induces a law of motion for the economy of the form:

$$\Omega' = \mathbb{F}\Omega + \mathbb{E} \tag{35}$$

$$\Upsilon = \mathbb{G}\Omega \tag{36}$$

where $\mathbb{F}$ and $\mathbb{G}$ are matrices of coefficients. Therefore, the law of motion for the economy is described by $\lambda = \{\mathbb{F}, \mathbb{G}\}$. The challenge for a model with information frictions comes from the fact that the law of motion λ is derived from a perceived law of motion λ^h, which in equilibrium has to be equal to the actual law of motion λ.

I exploit the linearity of the Reiter method and proceed as follows:[21]

1. Define a tolerance level.

2. Guess a linear law of motion for the economy $\lambda^{h\{1\}} = \{\mathbb{F}^{h\{1\}}, \mathbb{G}^{h\{1\}}\}$. A good initial guess may be the law of motion of the model under perfect information.

3. Let the household form expectations based on this guess and the Kalman filter, which is explained in 10.

4. Find the solution of the model using the Reiter method, which is given by a new law of motion $\lambda^{\{1\}} = \{\mathbb{F}^{\{1\}}, \mathbb{G}^{\{1\}}\}$.

[21] The linearity of the model makes the model tractable as I can compute expectations based on a linear filter. Otherwise, I would need to use non-linear filters (such as the particle filter), which would substantially increase the complexity of the problem for a large vector Ω.

5. If the maximum difference between $\lambda^{h\{1\}}$ and $\lambda^{\{1\}}$ is less than the predetermined tolerance level, stop and conclude that $\lambda^{h\{1\}} = \lambda$. Otherwise, update the household's perceived law of motion as follows:

$$\lambda^{h\{n+1\}} = d \cdot \lambda^{h\{n\}} + (1-d) \cdot \lambda^{\{n\}}; \qquad 0 < d < 1 \tag{37}$$

   where d is a fraction that determines how smoothly the guess is updated.

6. Go back to step 3.

B.1 Computing Expectations

In this subsection, I show how to compute workers expectations given a vector of state variables $\Omega = \{k, \{h_j\}_{j=0}^{1}, a^{\mathcal{T}}, n^{\mathcal{T}}\}$, and a linear law of motion for the economy as in (35) and (36). Reiter (2009) shows how to find the aggregate law of motion for the economy for heterogeneous agent models. In this subsection, I focus on how to compute workers' expectations, which is the novel part of my paper. In particular, *I show that we only need to keep track of the last $\mathcal{T}$ realization of the exogenous state variables in order to compute expectations. Therefore, we do not need to include as a state variable agents' beliefs or the realization of vector Ω, $\mathcal{T}$ periods ago.* This represents a significant gain in efficiency because the dimensionality of the problem does not significantly increase. Solving numerically this model, I found that setting $\mathcal{T} = 100$ was more than enough, meaning that a value of $\tilde{\mathcal{T}} >> \mathcal{T}$ did not represent any significant difference. However, the optimal value for $\mathcal{T}$ is a function of how informative the signal is. For example, when ρ_a and ρ_n are close, it becomes more difficult to distinguish between TFP and noise shocks. Agents' expectations take longer to converge to the true values, and a larger value of $\mathcal{T}$ is needed.

This note is based on the Kalman filter and follows the notation of Hamilton (1994). I start with some definitions. Then, I show how to compute expectations regarding the vector of state variables. I conclude by computing expectations about endogenous variables and forecasting economic conditions.

B.1.1 Preliminary Definitions

Define $e_t = [a_t \quad n_t]'$ as the vector of exogenous state variables, which evolves according to:

$$
\begin{aligned}
e_{t+1} &= \mathcal{F} e_t + \mathcal{V}_t && (38) \\
\mathcal{F} &= \begin{bmatrix} \rho_a & 0 \\ 0 & \rho_n \end{bmatrix} && (39) \\
E\left[\mathcal{V}_t \mathcal{V}_t'\right] &= \mathcal{Q} && (40) \\
&= \begin{bmatrix} \varsigma_a & 0 \\ 0 & \varsigma_n \end{bmatrix} && (41)
\end{aligned}
$$

The vector of states variables Ω can be partitioned as $\Omega_t = \begin{bmatrix} \tilde{\Omega}_t & e_t \end{bmatrix}'$ where $\tilde{\Omega}$ is the vector of endogenous predetermined state variables. Then, the dynamics for Ω and Υ (vector of non-predetermined variables) are given by:

$$
\begin{aligned}
\Omega_{t+1} &= \mathbb{F}\Omega_t + \mathbb{E}_t && (42) \\
\Upsilon_t &= \mathbb{J}\Omega_t && (43) \\
\mathbb{E}_t &= [\varnothing \quad \mathcal{V}_t] && (44) \\
\mathbb{F} &= \begin{bmatrix} \mathbb{F}_{\tilde{\Omega}} & \mathbb{F}_e \\ \varnothing & \mathcal{F} \end{bmatrix} && (45) \\
E\left[\mathbb{E}_t \mathbb{E}_t'\right] &= \mathcal{R} && (46) \\
&= \begin{bmatrix} \varnothing & \varnothing \\ \varnothing & \mathcal{Q} \end{bmatrix} && (47)
\end{aligned}
$$

Hence, assuming that vector Ω was perfectly observed at time $t - \mathcal{T}$, we only need to from expectations about e to infer agents' beliefs regarding other variables in the economy.

B.1.2 Computing Expectations about e

Forming beliefs about e is a classic signal extraction problem. In this section, I show that the expectation of e_t conditional on information available at time x, which is denoted by $e_{t|x}$ can be expressed as a linear combination of the last $\mathcal{T}-1$ shocks.

In this case, the signal is given by $\hat{a} = a + n$, and the evolution of conditional expectations ($e_{t|x}$ is given by:

$$a_t = H'e_t \tag{48}$$

$$e_{t|t} = \mathcal{F}e_{t|t-1} + B_t\left(a_t - H'\mathcal{F}e_{t|t-1}\right) \tag{49}$$

where matrices H and B_t:

$$H = \begin{bmatrix}1 & 1\end{bmatrix}' \tag{50}$$

$$B_t = P_{t|t-1}H\left(H'P_{t|t-1}H\right)^{-1} \tag{51}$$

$$P_{t|t-1} = \mathcal{F}P_{t|t}\mathcal{F}' + \mathcal{Q} \tag{52}$$

$$P_{t|t} = P_{t|t-1} - P_{t|t-1}H\left(H'P_{t|t-1}H\right)^{-1}P_{t|t-1} \tag{53}$$

$$P_{t-\mathcal{T}|t-\mathcal{T}} = \varnothing \tag{54}$$

It can be verified that:

$$e_{t|t} = e_t + \sum_{j=0}^{\mathcal{T}-1} C_{t-j}\mathcal{V}_{t-j} \tag{55}$$

$$C_t = (B_tH' - I) \tag{56}$$

$$C_{t-j} = -C_{t-j+1}\mathcal{F}\left(B_{t-j}H' - I\right) \quad 0 < j <= \mathcal{T} \tag{57}$$

B.1.3 Computing Expectations about $\tilde{\Omega}$

We can rewrite the law of motion for $\tilde{\Omega}_t$ as follows:

$$\tilde{\Omega}_t = \mathbb{F}_{\tilde{\Omega}}\tilde{\Omega}_{t-1} + \mathbb{F}_e e_{t-1} \tag{58}$$

$$= \mathbb{F}_{\tilde{\Omega}}^{\mathcal{T}}\tilde{\Omega}_{t-\mathcal{T}} + \mathbb{F}_{\tilde{\Omega}}^{\mathcal{T}-1}\mathbb{F}_e e_{t-\mathcal{T}} + \sum_{j=0}^{\mathcal{T}-2}\mathbb{F}_{\tilde{\Omega}}^{j}\mathbb{F}_e e_{t-1-j} \tag{59}$$

Given that workers perfectly know $\tilde{\Omega}_{t-\mathcal{T}}$ and $e_{t-\mathcal{T}}$, the expected value of $\tilde{\Omega}$ given information available at time t is given by:

$$\tilde{\Omega}_{t|t} = \mathbb{F}_{\tilde{\Omega}}^{\mathcal{T}} \tilde{\Omega}_{t-\mathcal{T}} + \mathbb{F}_{\tilde{\Omega}}^{\mathcal{T}-1} \mathbb{F}_e e_{t-\mathcal{T}} + \sum_{j=0}^{\mathcal{T}-2} \mathbb{F}_{\tilde{\Omega}}^{j} \mathbb{F}_e e_{t-1-j|t-1-j} \tag{60}$$

Combining, (59), (60), and (55), we get:

$$\tilde{\Omega}_{t|t} = \tilde{\Omega}_t + \sum_{j=0}^{\mathcal{T}-2} \mathbb{F}_{\tilde{\Omega}}^{j} \mathbb{F}_e \tilde{\mathcal{V}}^{t-1-j} \tag{61}$$

$$\tilde{\mathcal{V}}^{t-1-j} = \sum_{i=0}^{\mathcal{T}} C_{t-1-j-i} \mathcal{V}_{t-1-j-i} \tag{62}$$

According to (55) and (62), I only need to keep track of the last $\mathcal{T}$ realization of e instead of keeping track of the whole vector of expectations $\tilde{\Omega}_{t|t}$ and $e_{t|t}$ to compute workers expectations.[22]

B.1.4 Expectations about Υ and Forecast

It is now straight forward to define the expectations of Υ given information available at time t.

$$\Upsilon_{t|t} = \mathbb{G} \Omega_{t|t} \tag{63}$$

$$\Omega_{t|t} = \begin{bmatrix} \tilde{\Omega}_{t|t} & e_{t|t} \end{bmatrix}' \tag{64}$$

Hence, partitioning matrix $\mathbb{G} = \begin{bmatrix} \mathbb{G}_{\tilde{\Omega}} & \mathbb{G}_e \end{bmatrix}$, the forecast f periods ahead is given by:

$$\begin{bmatrix} \tilde{\Omega}_{t+f|t} \\ e_{t+f|t} \\ \Upsilon_{t+f|t} \end{bmatrix} = \begin{bmatrix} \mathbb{F}_{\tilde{\Omega}} & \mathbb{F}_e & \varnothing \\ \varnothing & \mathcal{F} & \varnothing \\ \mathbb{G}_{\tilde{\Omega}} & \mathbb{G}_e & \varnothing \end{bmatrix}^f \begin{bmatrix} \tilde{\Omega}_{t|t} \\ e_{t|t} \\ \Upsilon_{t|t} \end{bmatrix} \tag{65}$$

[22] Notice that you can also keep track of $\mathcal{V}$ directly.

C Other Tables

Table 9: Wage Distribution

Wage Quintile	Fraction of Firms	Monthly Earnings	Earnings (% of Lowest)	
			Data	Model
Lowest	20%	1,842.16	1.00	1.00
2^{sd}	20%	2,754.87	1.50	1.40
3^{rd}	20%	3,458.19	1.88	1.86
4^{th}	20%	4,354.70	2.36	2.42
Highest	20%	6,665.13	3.62	3.62
All	100%	3,815.01	2.07	2.06

Note: This table reports average monthly earnings by pay quintile. Average earnings are weighted by employment. Data source is Kahn and McEntarfer (2014).

Table 10: Firm Size Distribution

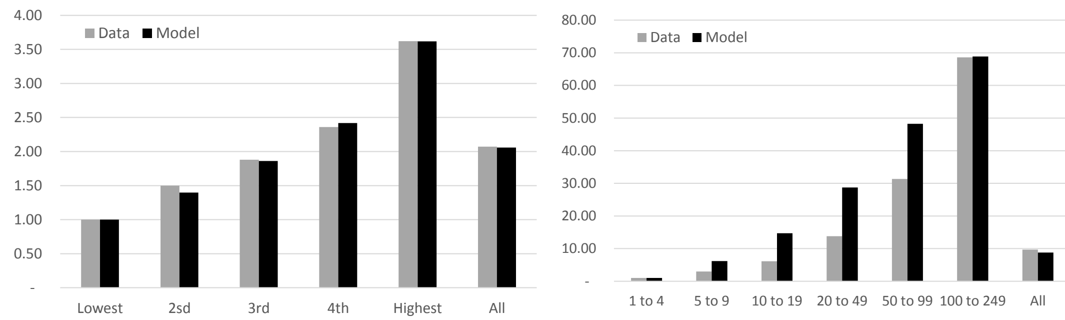
Firm Size	Fraction of Firms	Average Size	Size (% of Smallest)	
			Data	Model
1 to 4	55.1%	2.23	1.00	1.00
5 to 9	21.1%	6.66	2.99	6.21
10 to 19	12.2%	13.70	6.15	14.73
20 to 49	7.4%	30.75	13.81	28.74
50 to 99	2.3%	69.85	31.37	48.24
100 to 249	1.2%	152.78	68.62	68.87
250+	0.7%	1,648.26	740.34	117.00
All	100.0%	21.64	9.72	8.79

Note: This table reports firm size statistics for the United States. for the period 1977 to 2014. Firm size is defined as number of employees per firm. Average size is computed as total number of employees over total number of firms. Calculations based on U.S. Census Bureau, Business Dynamics Statistics, https://www.census.gov/ces/dataproducts/bds/.

D Other Figures

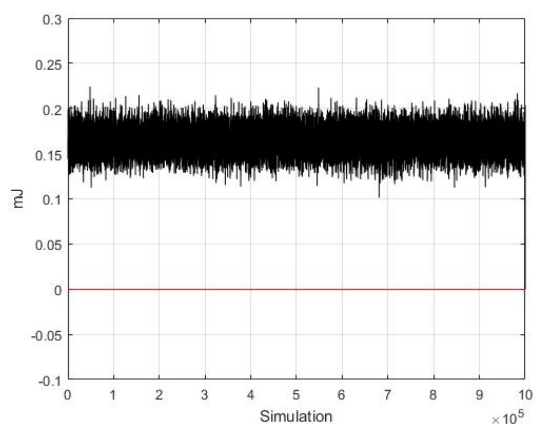
Figure 8: Wage and Size Distribution in Steady State: Model vs. Data

(a) Wage Distribution (b) Size Distribution



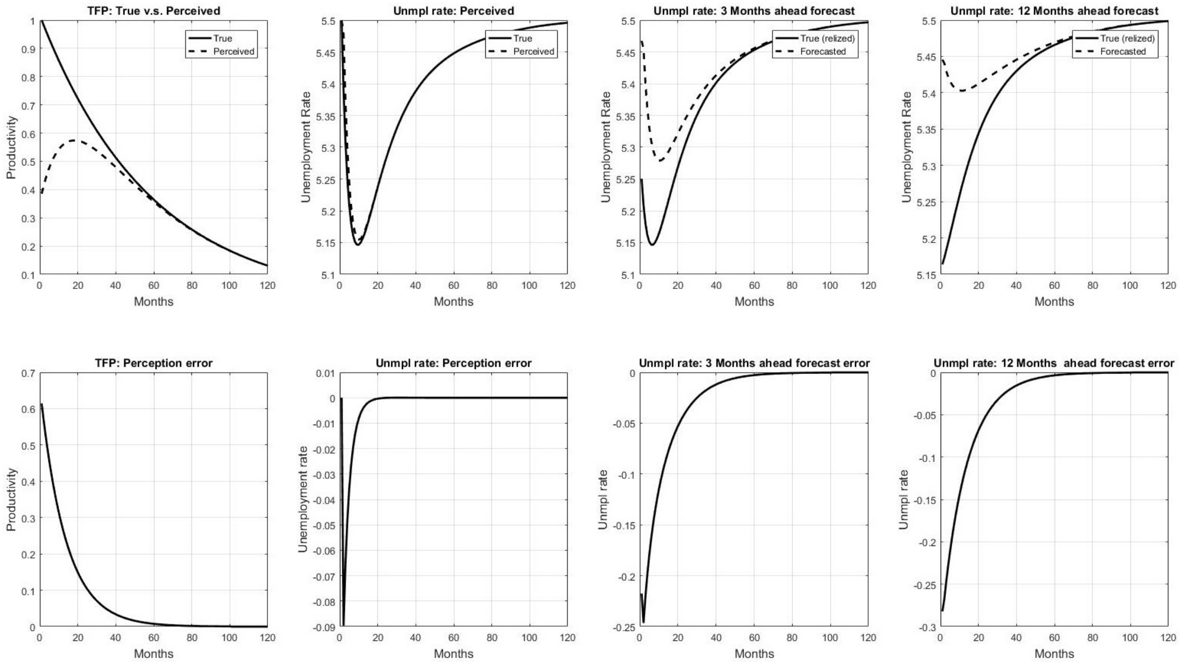
Note: This figure plots the distributions of employment (panel 8b) and wages (panel 8a). Gray bars plot the model distribution in steady state, while the black bars represent the distribution for the United States. Firms with more than 250 employees are excluded in panel 8b to preserve the scale. Calculations based on Kahn and McEntarfer (2014) and U.S. Census Bureau, Business Dynamics Statistics, https://www.census.gov/ces/dataproducts/bds/.

Figure 9: Simulated $mJ = min_j\{J_j\}$



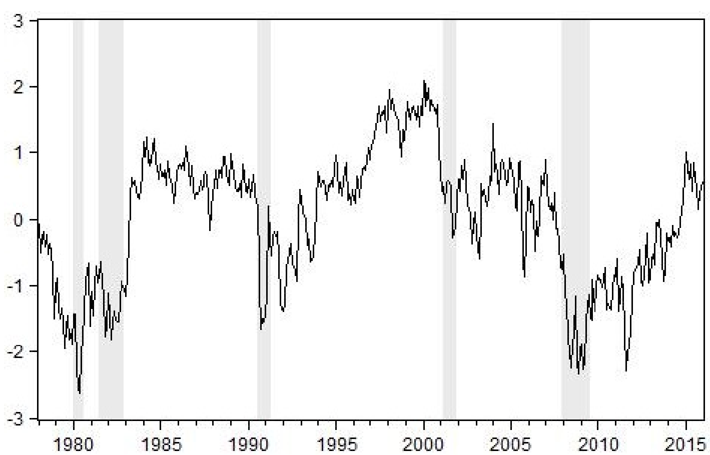
Note: This figure plots the evolution of $mJ = min_j\{J_j\}$ indicating that Assumption 1 is never violated.

Figure 10: Evolution of Workers' Beliefs
Dynamics in Response to a 1% Increase in Aggregate TFP



Note: This figure plots the evolution of workers' beliefs and expectations in response to a 1% increase in aggregate productivity. In the top panels, solid black lines represent the true evolution of each variable, and dashed black lines depict workers' expectations about those variables. The bottom panels plot the difference between the true realization and the workers' expectations.

Figure 11: Index of Consumer Sentiment



Note: This Figure plots the Index of Consumer Sentiment (ICS) from the University of Michigan Surveys of Consumers. The ICS is re-scaled such that it has a 0 mean and a standard deviation equal to 1. Shadow areas represent NBER recession dates. The sample period is January 1979 to December 2015. Data source is University of Michigan, Surveys of Consumers, https://data.sca.isr.umich.edu.

E Detailed Household's Problem

This appendix presents the household's problem in recursive form and the complete derivation of the employment and unemployment functions. The household's utility function is given by:

$$\mathbb{U}(\omega,\Omega)=\frac{c^{1-\sigma}}{1-\sigma}-\Psi\frac{\tilde{h}^{1+\eta}}{1+\eta}+\beta E\left[\mathbb{U}\left(\omega',\Omega'\right)\right] \tag{66}$$

Hence, the household's problem is:

$$\max_{c,k',\{h'_j\}_{j=0}^{1}} E_{\mathcal{I}_h}\left\{\mathbb{U}(\omega,\Omega)\right\} \tag{67}$$

subject to the budget constraint, the law of motion of labor, and the perceived law of motion of the economy:

$$c+k'=(r+1-\delta_k)k+\int_0^1 w_jh_jdj+\int_0^1 \pi_jdj+b\cdot u-T \tag{68}$$

$$h'_j=(1-\delta_h)(1-q\bar{i}F_j)h_j+q\left(\frac{v_j}{v}\right)u+\int_0^j q\bar{i}\left(\frac{v_j}{v}\right)(1-\delta_h)h_xdx \tag{69}$$

$$\tilde{h}=\left(\int_0^1 h_j^{1+\xi}dj\right)^{\frac{1}{1+\xi}} \tag{70}$$

$$u=\int_0^1(1-h_j)dj \tag{71}$$

$$\Omega'=\lambda^h(\Omega) \tag{72}$$

where $E_{\mathcal{I}_h}[\cdot]$ is the expectation conditional on the household information set $\mathcal{I}_h$. $\omega=\{k,\{h_j\},\mathcal{I}_h\}$ is the vector of state variables for household, and Ω is a vector that summarizes the aggregate state of the economy. Letting ϕ_c and ϕ_j denote the Lagrange multipliers for equations (68) and (69), the first order conditions are given by:

$$
\begin{aligned}
c:\quad & E_{\mathcal{I}_h}\left\{c^{-\sigma}-\phi_c\right\} && = 0 && (73)\\
k':\quad & E_{\mathcal{I}_h}\left\{-\phi_c+\beta\phi_c'(r'+1-\delta_k)\right\} && = 0 && (74)\\
h_j':\quad & E_{\mathcal{I}_h}\{-\phi_j - E\{\beta\Psi\tilde{h}'^{\eta-\xi}h_j'^{\xi}+\beta\phi_c'\left(w_j'-b\right) && && \\
& +(1-\delta_h)(1-q'\bar{i}F_j')\beta\phi_j' - q'\int_0^1 \beta\phi_x'\left(\frac{v_x'}{v'}\right)dx && && \\
& +(1-\delta_h)q'\bar{i}\int_j^1 \beta\phi_x'\left(\frac{v_x'}{v}\right)dx\}\} && = 0 && (75)
\end{aligned}
$$

Hence, combining (73) and (75) and lagging one period:

$$
\begin{aligned}
E_{\mathcal{I}_h}\{(W_j(\omega,\Omega)-U(\omega,\Omega))\} = & E_{\mathcal{I}_h}\{w_j - z_j \\
& + E\{Q((1-\delta_h)(1-q\bar{i}F_j)(W_j(\omega',\Omega')-U(\omega',\Omega')) \\
& + (1-\delta_h)q\bar{i}F_j(\tilde{W}_j(\omega',\Omega')-U(\omega',\Omega')) \\
& - q\left(\bar{W}(\omega',\Omega')-U(\omega',\Omega')\right))\}\} \qquad (76)
\end{aligned}
$$

where:

$$
(W_j(\omega',\Omega')-U(\omega',\Omega')) = \frac{\phi_j}{\beta\phi_c'} \qquad (77)
$$

Also from the first order conditions, we can verify that the optimality conditions for c is given by:

$$
c^{-\sigma} = \beta E_{\mathcal{I}_h}\left[(1-\delta+r')c'^{-\sigma}\right] \qquad (78)
$$

F Recursive Competitive Equilibrium (Equations)

This appendix presents the equations that characterize the recursive competitive equilibrium.

$$c^{-\sigma} = \beta E_{\mathcal{I}_h}\left[(1-\delta+r')c'^{-\sigma}\right] \tag{79}$$

$$\kappa_v(\tilde{q}_j v_j) = E\left[\cdot Q \cdot J_j'(\omega_f', \Omega')\right] \tag{80}$$

$$r = \quad p_j \left(\frac{h_j}{k_j}\right)\left(\frac{\alpha}{1-\alpha}\right) \tag{81}$$

$$h_j' = (1-\delta_h)(1-\bar{i}qF_j)h_j + \tilde{q}_j v_j \tag{82}$$

$$c + k' = (r+1-\delta_k)k + \int_0^1 \left[w_j h_j + \pi_j\right] dj \tag{83}$$

$$z_j = b + \Psi c^{\sigma} \tilde{h}_j^{\eta} h_j^{\xi} \tag{84}$$

$$\pi_j = y_j - w_j h_j - r k_j - \kappa(\tilde{q}_j v_j) \tag{85}$$

$$Q = \beta\left(\frac{c'}{c}\right)^{-\sigma} \tag{86}$$

$$\theta = \left(\frac{v}{s}\right) \tag{87}$$

$$y_j = e^{a_j + a} k_j^{\alpha} h_j^{1-\alpha} \tag{88}$$

$$F_j = \int_j^1 \frac{v_x}{v} dx \tag{89}$$

$$\tilde{q}_j = \tilde{q}^u + \tilde{q}_j^c \tag{90}$$

$$\tilde{q}^u = \tilde{q} \cdot \left(\frac{u}{s}\right) \tag{91}$$

$$\tilde{q}_j^c = \tilde{q} \cdot \left(\int_0^j \frac{(1-\delta_h)\bar{i}h_x}{s} dx\right) \tag{92}$$

$$q = m(v,s)/s \tag{93}$$

$$v = \int_0^1 v_j(\omega_f, \Omega) dj \tag{94}$$

$$y = \int_0^1 y_j(\omega_f, \Omega) dj \tag{95}$$

$$s = u + \int_0^1 \bar{i} h_j(\omega_f, \Omega) dj \tag{96}$$

$$u = \int_0^1 (1 - h_j(\omega_f, \Omega)) dj \tag{97}$$

$$k = \int_0^1 k_j(\omega_f, \Omega) dj \tag{98}$$

$$\vartheta \cdot E_{\mathcal{I}_h}[S_j] = E_{\mathcal{I}_h}\left[\overrightarrow{W}_j(w_j, \omega, \Omega) - U(\omega, \Omega)\right] \tag{99}$$

$$\mathbb{U}(\omega, \Omega) = \frac{c^{1-\sigma}}{1-\sigma} - \Psi \frac{\tilde{h}^{1+\eta}}{1+\eta} + \beta E\left[\mathbb{U}(\omega', \Omega')\right] \tag{100}$$

$$\tilde{h} = \left(\int_0^1 h_j^{1+\xi} dj\right)^{\frac{1}{1+\xi}} \tag{101}$$

$$U(\omega, \Omega) = b + E\left\{Q\left((1-q) \cdot U(\omega', \Omega') + q \cdot \int_0^1 W_x(\omega', \Omega') \frac{v_x}{v} dx\right)\right\} \tag{102}$$

$$\begin{aligned}
(W_j(\omega, \Omega) - U(\omega, \Omega)) &= w_j - z_j \\
&+ E\{Q((1-\delta_h)(1 - q\bar{i}F_j)(W_j(\omega', \Omega') - U(\omega', \Omega')) \\
&+ (1-\delta_h) q\bar{i}F_j(\tilde{W}_j(\omega', \Omega') - U(\omega', \Omega')) \\
&- q\left(\bar{W}(\omega', \Omega') - U(\omega', \Omega')\right))\}
\end{aligned} \tag{103}$$

$$\tilde{W}_j(\omega', \Omega') = \int_j^1 W_x(\omega', \Omega') \frac{v_x}{v_t} \cdot F_j^{-1} dx \tag{104}$$

$$\bar{W}(\omega', \Omega') = \int_0^1 W_x(\omega', \Omega') \frac{v_x}{v} dx \tag{105}$$

$$\Pi_j(\omega_f, \Omega) = \pi_j + E\left[Q \Pi_j(\omega_f', , \Omega')\right] \tag{106}$$

$$J_j(\omega_f, \Omega) = p_j - w_j + E\left[Q \cdot (1-\delta_h)(1 - \bar{i}qF_j) \cdot J_j(\omega_f', \Omega')\right] \tag{107}$$

$$S_j = J_j(\omega_f, \Omega) + W_j(\omega, \Omega) - U(\omega, \Omega) \tag{108}$$

$$\hat{a} = a + n \tag{109}$$

$$a' = \rho_a \cdot a + e'_a \tag{110}$$

$$n' = \rho_n \cdot n + e'_n \tag{111}$$

G Unilateral Deviations in Equilibrium (Details)

Nothing in my model prevents firms from paying a higher wage in equilibrium. Even though higher wages increase firms' payroll, offering a higher wage can reduce the fraction of workers who are poached by other firms, and as a consequence, increase profits. When workers' bargaining power is low, firms incentives to offer higher wages could be large. However, in my calibration with a bargaining power equal to 0.5, no firm has incentives to offer a higher wage. Suppose that firm j is considering offering a higher wage to its employees in order to reduce its separation rate and increase its profits. Hence, following Moscarini and Postel-Vinay (2013), the problem for firm j would be given by:

$$\Pi_j(\omega_f, \bar{W}, \Omega) = \max_{v_j, k_j, w_j, W'_j} e^{a_j + a} k_j^{\alpha} h_j^{1-\alpha} - w_j h_j - r k_j - \frac{\kappa}{1+\chi} (\tilde{q}_j v_j)^{1+\chi} + E\left[Q \Pi_j(\omega'_f, W'_j, \Omega') \right] \tag{112}$$

s.t.

$$h'_j = (1 - \delta_h)(1 - \bar{i} q F(W'_j)) h_j + \tilde{q}(W'_j) v_j \tag{113}$$

$$E_{\mathcal{I}_h}[W_j] \geq \vartheta \cdot E_{\mathcal{I}_h}[S_j] \tag{114}$$

$$E_{\mathcal{I}_h}\left[W'_j\right] \geq \vartheta \cdot E_{\mathcal{I}_h}\left[S'_j\right] \tag{115}$$

$$E_{\mathcal{I}_h}[W_j] \geq \bar{W} \tag{116}$$

$$\Omega' = \lambda^f(\Omega) \tag{117}$$

$$v_j, \quad k_j \geq 0 \tag{118}$$

where restrictions (114) and (115) imply that the wage offer cannot be lower than what workers would get otherwise, and restriction (116) implies that the continuation value for workers cannot be lower than what was promised at the end of the last period. Given that the optimality conditions for k_j and v_j do not change, let me concentrate on W'_j. Given that $E_{\mathcal{I}_h}[W_j] = max\{\vartheta \cdot E_{\mathcal{I}_h}[S_j], \bar{W}\}$, the optimality condition for W'_j is:

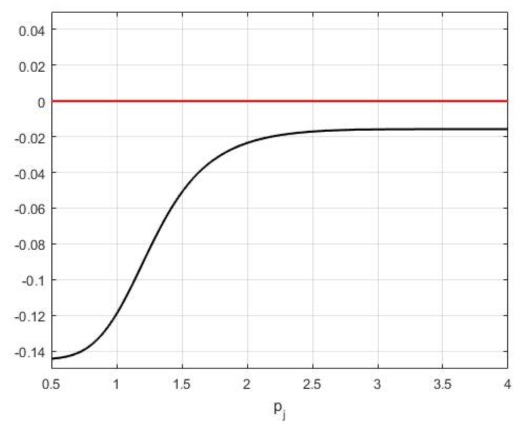
$$E\left[-Q\tilde{q}(W'_j) v_j + Q J'(\omega_f, W'_j, \Omega) h_j (1 - \delta_h) \bar{i} q \frac{\partial F(W'_j)}{\partial W'_j} \right] \leq 0 \tag{119}$$

equation (119) holds with equality if $W'_j > \vartheta \cdot E_{\mathcal{I}_h}\left[S'_j\right]$. If firm j increase its wage in one unit, its wage bill will increase by $\tilde{q}(W_j')v_j$ next period, but it will retain an additional fraction $(1-\delta_h)\bar{i}q\frac{\partial F(W_j')}{\partial W_j'}$ of its current employees, each one of which will increase firm's profits by $J'(\omega_f, W_j', \Omega)$.[23] Hence, in equilibrium, equation (115) holds with equality if:

$$\underline{\Pi}_j = E\left[-Q\tilde{q}_j\frac{v_j}{h_j} + QJ'(\omega_f,\Omega)(1-\delta_h)\bar{i}q\frac{\partial F(W_j')}{\partial W_j'}\right] \leq 0 \tag{120}$$

Figure 12 shows that $\underline{\Pi}_j$ is negative for all firms in steady state. Hence, for this particular calibration, firms do not have incentives to unilaterally deviate in equilibrium.

Figure 12: $\underline{\Pi}_j$ For All Firms in Steady State



Note: This figure plots the value of $\underline{\Pi}_j$ for each firm in steady state (y axis) as a function of marginal labor productivity for each firm in steady state (x axis).

[23]Moscarini and Postel-Vinay (2013) show that the wage bill effect (the first term in equation (119)) does not depend on the firm's initial size (h_j). This is because firms are indifferent about the timing of wages paid to deliver a utility label $W_j = max\{\vartheta \cdot S_j, \bar{W}\}$, since workers and firms share the same discount factor.

H Firms Face Information Frictions

Assuming that firms and workers face information frictions is not a straight forward exercise in my model. Depending on how this new friction is introduced in the benchmark model, hiring decisions and the unemployment response can become larger or smaller. However, as long as workers face information frictions regarding aggregate conditions, and assuming that the workers' information set is always a subset of the firms' information set, wages will have fewer pressures to increase in booms because the value of the outside option (the value of unemployment) is underestimated. Notice that the two equations governing the dynamics of wages and hiring decisions in this model are given by:

$$E_{\mathcal{I}_h}\left[\overrightarrow{W}_j(w_j,\omega,\Omega)\right] = \vartheta \cdot E_{\mathcal{I}_h}\left[S_j\right] + E_{\mathcal{I}_h}\left[U(\omega,\Omega)\right] \tag{121}$$

$$\kappa(\tilde{q}_j v_j)^{\chi} = E_{\mathcal{I}_j}\left[Q \cdot J_j'(\omega_f',\Omega')\right] \tag{122}$$

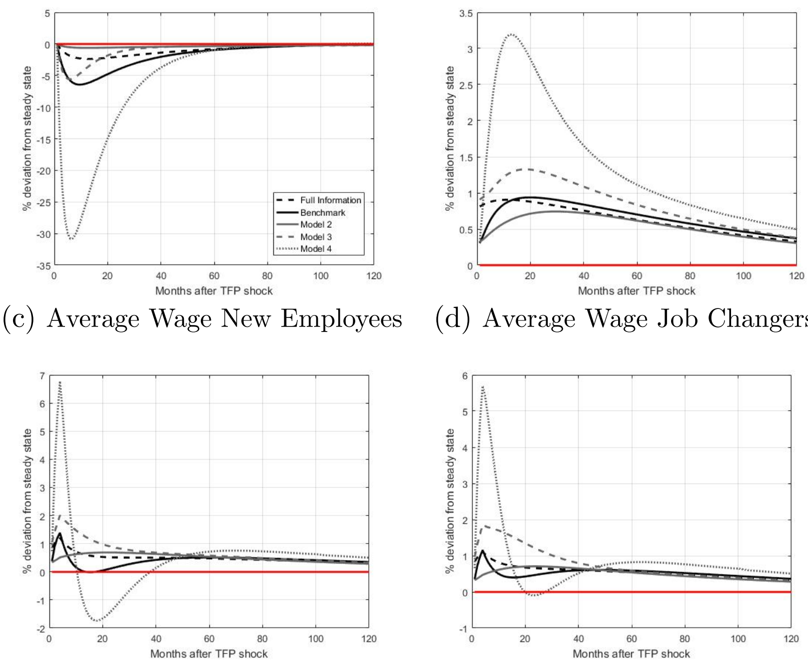
where $\mathcal{I}_j$ is the information set of firm j. Hence, *wages depend on workers' expectations, while hiring decisions depend on firms beliefs.*In the benchmark model, workers underestimate changes in S_j and $U(\omega,\Omega)$ reducing the volatility of wages. This rises the volatility of Jj, which increases firms' hiring decision. Now let me consider the following three variations of my benchmark model:

Model 2: Firms and workers have the same information set. Aggregate productivity (a) is never observed, and all agents have to form expectations based on the public and aggregate signal $\hat{a}$.

Model 3: Firms and workers have the same information set. Employers and workers at firm j observe their overall productivity ($a_j + a$) at all times but cannot decompose unexpected changes into aggregate and idiosyncratic shocks.

Model 4: Workers' information set is as described in section 2.3. Firms observe their overall productivity ($a_j + a$) at all times but cannot decompose unexpected changes into aggregate and idiosyncratic shocks. Firms also observe aggregate public signal $\hat{a}$.

Figure 13: Impulse Response Functions to a 1% Increase in Aggregate Productivity Comparing Different Information Structures



(a) Unemployment (b) Average Wage All Workers

(c) Average Wage New Employees (d) Average Wage Job Changers

Note: This figure plots the Impulse Response Function of unemployment and wages to a 1% increase in aggregate TFP. Solid black lines are the IRFs of a model in wihch workers face information frictions and firms have perfect information. Dashed black lines are the IRFs generated by a model in which all agents have perfect information. Models 2 (solid gray lines), 3 (dashed gray lines), and 4 (dotted gray lines) assume that firms and workers face information frictions as described in section 4.3.

In Models 2 and 4, wages will continue to be very sluggish because workers underestimate the responses of S_j and $U(\omega, \Omega)$ to TFP shocks. However, in Model 3, workers' expectations about S_j will tend to be more volatile than in the benchmark model while changes in $U(\omega, \Omega)$ will continue to be undervalued. Hence, wages will tend to be more procyclical in Model 3 than in my bench mark model.

When looking at hiring decision in each one of these models, we should observe a lower hiring response to TFP shocks in Model 2 than in my benchmark model, as firms' expectations about $J_j(\omega_j, \Omega)$ do not significantly change. Nonetheless, hiring responses in Model 3 should be larger than in Model 2 as firms' expectations regarding the value of an additional worker (equation (122)) become more volatile. In Model 3, firms anticipate a larger productivity in the future but do not expect a significant increase in their separation rate and wages in response to TFP shocks, which makes

Table 11: Wage Semi-Elasticities with Respect to the Unemployment Rate
Model Simulated Data

	Benchmark	Model 2	Model 3	Model 4
All Workers	-1.12	0.32	-0.02	-0.72
New Employees	-2.65	3.49	-4.77	-7.15
Job Changers	-2.93	1.69	-6.05	-8.81

Note: This table reports the theoretical wage semi-elasticities with respect to the unemployment rate based on equation (24). In the benchmark model only workers face information frictions. In models 2, 3, and 4 firms and workers face information frictions as described in this Appendix.

firms hire more workers in booms. Finally, hiring responses in Model 4 should be even larger than in Model 3. In Model 4, in response to a positive TFP shocks, firms expect a lower change in wages than in model 3 because workers' expectations about S_j are lower in Model 4 than in Model 3.

Even though hiring decisions in my benchmark model should be larger than in Model 2 but lower than in Model 4, the relationship between Model 3 and my benchmark model is not clear. In Model 3, firms expect a lower increase in their separation rate but a larger increase in their wages than in my benchmark model. However, both models should display larger unemployment responses than a model with perfect information.

Figure 13 plots the IRFs for unemployment and wages generated by these models. For these responses, I assumed that the persistence of idiosyncratic productivity shocks is equal to ρ_a.

As expected, Models 2 and 4 generate smaller and larger unemployment responses, respectively, than the benchmark model. However, for this particular calibration, Model 3 displays smaller unemployment responses to TFP shocks than my benchmark model. In Models 3 and 4, unemployment peaks earlier and is less persistent than in other models because firms overreact to aggregate shocks, and they compensate for these overreactions in later periods when they have amassed more information. For example, in response to a positive TFP shock, firms post a lot of vacancies on impact, but they reduce the number of vacancies (post less) as they learn about aggregate conditions and realize that the value of an additional worker is not as high as they had thought.

In contrast, wage responses are larger in Models 3 and 4, but lower in Model 2, than in the benchmark model. As long as workers have more information (Model 3) or

Table 12: Differential Net Job Flows, Coefficient on Cyclical Variable. High Wage minus Low Wage. Model Simulated Data

	Benchmark	Model 2	Model 3	Model 4
	Deviation from HP Trend			
Net Job Flows	-0.257	-0.696	-0.728	-0.538
Net Poaching Flows	-0.292	-0.502	-0.652	-0.503
Net Nonemployment Flows	0.035	-0.036	-0.075	-0.034
	First Difference			
Net Job Flows	0.018	-0.035	0.009	0.012
Net Poaching Flows	0.013	-0.030	0.007	0.009
Net Nonemployment Flows	0.005	-0.005	0.002	0.003

Note: This table reports the theoretical differential net job flows as discuss in the paper. In the benchmark model only workers face information frictions. In models 2, 3 and 4 firms and workers face information frictions as described in this Appendix.

unemployment is more sensitive to the business cycle (Model 4), workers will demand higher wages in response to TFP shocks. It is worth pointing out that all models with information frictions display hump-shaped wage responses because workers demand higher wages as they learn that the economy is in an expansion and that the value of the outside option is greater than they thought. However, these models tend to generate larger wage semi-elasticities (Table 11) and differential growth rates (Table 12) than my benchmark model (and the data).

I Data Source

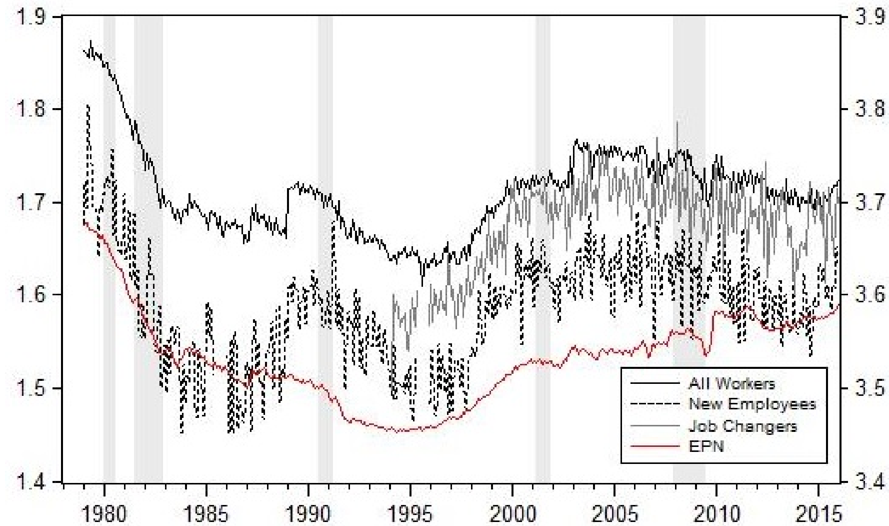
I assess the model's predictions using quarterly data for the United States for the period 1979 to 2015. I present business cycle statistics for the quarterly time series (seasonally adjusted) of unemployment, vacancies, output, consumption, investment, aggregate TFP, and real wages (deflated by CPI) for new employees, job changers, and all workers. I take the quarterly average of series that are available monthly. Following Shimer (2005), all variables are HP-filtered in logs with a smoothing parameter of 10^5.[24]

Unemployment is the total number of unemployed people from the CPS. Vacancies are the composite help-wanted index computed by Barnichon (2010). Output is real gross domestic product. Aggregate productivity is measured as the Solow residual, which is available and updated on the Federal Reserve Bank of San Francisco's website. Consumption consists of non-durable goods and services. Finally, investment is real gross private domestic investment. I include investment as a variable of interest because the effect of the information friction on investment plays an important role in my model.

Given the debate about the cyclicality of wages, I use the CPS and IPUMS-CPS (Flood et al., 2015) microdata to construct the average hourly wage for three group of workers: all workers, new employees, and job changers. In order to compute these wages, I follow Muller (2012) and Haefke et al. (2013) who also used the CPS microdata to construct similar series. The series presented in this paper are the coefficients of time fixed effects in Mincer equations controlling for education, a fourth order polynominal in experience, gender, race, marital status, state, 10 occupation dummies and 14 industry dummies. Since 1994, the CPS has asked individuals whether they still work at the same job as in the previous month, making it possible to identify job changers. However, it is not possible to identify job-to-job transitions prior to that year. Hence, the sample period for the average wage for job changers is 1994-2015. Figure 14 plots these wage series along with the average hourly earnings of production and nonsupervisory employees (red line) for comparison.

[24] In general my results are not very sensitive to this parameter.

Figure 14: Average (Log) Real Hourly Wages



Note: This figure plots the average log real hourly wages for all workers (solid black line), new employees (dashed-black lines), and job changers (solid gray line). These series are the coefficient of time fixed effect in a Mincer equation using CPS and IPUMS-CPS microdata. Details of these series are provided in Appendix J. The red line (left axis) is the log real average hourly earnings of production and nonsupervisory employees. All wages are deflated by CPI. Shadow areas represent NBER recession dates. The sample period is January 1979 to December 2015.
Calculations based on: U.S. Bureau of Labor Statistics, Nonfarm Business Sector: Compensation Per Hour [COMPNFB], U.S. Bureau of Labor Statistics, Consumer Price Index for All Urban Consumers. All Items [CPIAUCSL], all retrieved from FRED, Federal Reserve Bank of St. Louis, https://fred.stlouisfed.org/. CPS and IPUMS-CPS (Flood et al., 2015).

Based on the series reported in Figure 14, we can see that, on average, new hires from unemployment and job changers earn a wage that is 12.6% and 3.7% lower than the average worker, respectively, suggesting that workers who were previously unemployed usually get employed at low paying jobs and move up the job ladder. Notice that these differences in wages cannot be explained by education, experience, gender, race, marital status, state, occupation, or industry, as those variables were included in the Mincer equation.

J Wages from CPS and IPUMS-CPS

I use the Current Population Survey (CPS) and IPUMS-CPS (Flood, Kind, Ruggles & Warren, 2015) microdata to construct wage series adjusted for workers characteristics. The CPS is the main labor force survey for the United State, and it is the primary source of labor force statistics such as the national unemployment rate. The CPS consists of a rotating panel where households and their members are surveyed for four consecutive months, not surveyed for the following eight months, and interviewed again for another four consecutive months. The CPS includes individual information such as employment status, sex, education, race, and state. However, individual earnings and hours worked are collected only in the fourth and eighth interviews. In addition, since 1994, individuals have been asked if they still work in the same job reported in the previous month, making it possible to identify job changers. IPUMS-CPS is a project from the University of Minnesota that integrates, disseminates and harmonizes CPS microdata. IPUMS-CPS is free and includes, among many other variables, harmonized series for education, occupation and industry and a unique person and household ID, which makes it easier to link individuals across samples and facilitates data analysis.

Following Muller (2012) and Haefke, Sonntag and van Rens (2013), my empirical model is based on the following MINCER equation for the wage of individual i at time t (w_{it}):

$$log(w_{it}) = x_{it}'\beta_x + \left(\sum_{j=1}^{T} \alpha_j^a \cdot D_j + \alpha_j^{nhu} \cdot D_j \cdot D_{it,nhu} + \alpha_j^{nhc} \cdot D_j \cdot D_{it,nhc}\right) + e_{it} \tag{123}$$

x_{it} is a vector of individual characteristics, and β_x, $\{\alpha_j^a,\ \alpha_j^{nhu},\ \alpha_j^{nhc}\}_{j=1}^T$ are coefficients. D_j is a time dummy equal to 1 if $j = t$ and 0 otherwise. $D_{it,nhu}$ is a dummy variable equal to 1 if worker i spent time in unemployment during the past three months and 0 otherwise. $D_{it,nhc}$ is a dummy variable equal to 1 if worker i was previously employed at another firm during the past three months and has not been unemployed while switching jobs. Hence, the average (log) wage for all workers (w^a), new employees (w^u)

and job changers (w^c) are given by:

$$w_t^a = \alpha_t \tag{124}$$

$$w_t^u = \alpha_t + \alpha_t^{nhu} \tag{125}$$

$$w_t^c = \alpha_t + \alpha_t^{nhc} \tag{126}$$

The hourly wage rate is constructed by dividing weekly earnings by weekly hours. Following Schmitt (2003), top-coded weekly earnings are imputed assuming a log-normal cross-sectional distribution for earnings. Following Haefke et al. (2013) I drop hourly wage rates below the 0.25th and above the 99.75th percentiles each month. In order to uniquely identify workers in the CPS files, I use the IMPUMS-CPS ID variables: CPSID and CPSIDP.[25]

Vector x_{it} includes a fourth order polynomial in experience, gender, race, marital status, state, 10 occupation dummies, and 14 industry dummies. For occupation, industry and education, I use harmonized variables OCC1950, IND1950, and EDUC provided by IPUMS-CPS. Experience is defined as age minus years of education minus 6. Following the literature, individual i's weight is the product of the individual's weight reported by the BLS and hours worked.

Due to sample design, it is not possible to match individuals between July 1985 and December 1985 and between June 1995 and November 1995. Hence, with the exception of the average wage for all workers, wage series have a missing value in those months. To compute business cycle statistics for these wage series, I compute the quarterly average wage and impute the missing quarters using the average wage for all workers.

[25]I follow IPUMS-CPS recommendations, and I drop a few observations for which changes in sex or race are reported and for individuals whose age changes more than 2 years between samples