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Financial Constraints, Wage Rigidity, and the Labor Market

By TOBIAS FÖLL, UNIVERSITY OF COLOGNE*

This paper studies the effects of combining financial frictions with wage rigidity in a search and matching model of the labor market. Financial frictions, in the form of a borrowing constraint, increase the costs of hiring for firms. This amplifies the impact of real wage rigidity in times of tight credit conditions, as rigid wages keep firms' borrowing needs high. Combining financial frictions and wage rigidity enables the model to match three empirical observations that existing search and matching models struggle to explain jointly: the cyclical component of the unemployment rate is positively skewed, the number of hires tends to increase in recessions, and the correlation between vacancies and unemployment is highly negative. The analysis is also informative about the role of financial frictions for explaining business cycle fluctuations in labor market variables. With increasing wage rigidity, financial frictions become less important.

JEL: E24; E27; E32; E44; J63; J64

Keywords: Financial Frictions; Unemployment; Labor markets; Search and matching; Rigid wages

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I. Introduction

During the 2008 financial crisis, the unemployment rate in the U.S. doubled from 5.0% to 10.0% within only 18 months. From 2010 onwards, the unemployment rate decreased again and reached its pre-crisis level 60 months later at the end of 2015. The increase in the unemployment rate happened four times faster than the subsequent decrease. This asymmetric pattern is not a new observation.¹ Still, existing models of the labor market have trouble explaining these dynamics while being consistent with other aspects of the data. Even the search and matching model, which is commonly used to study labor market flows, is not in line with the behavior of the unemployment rate.

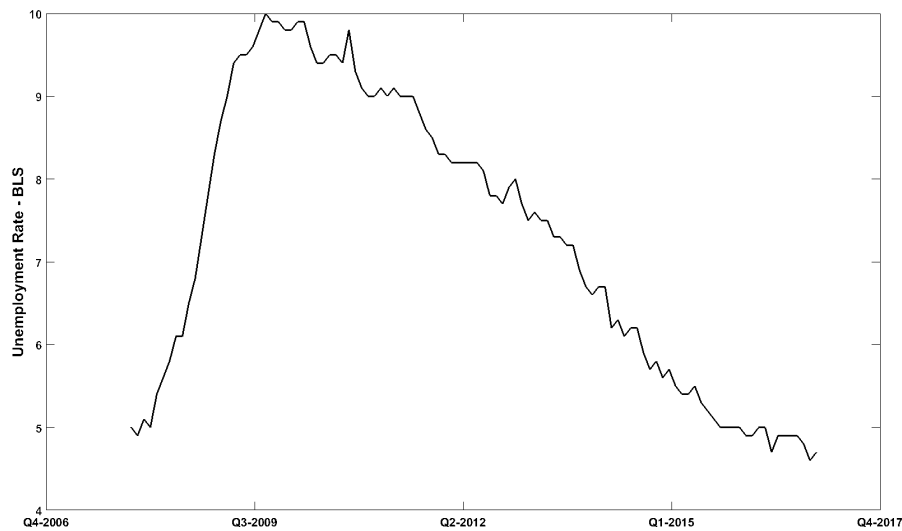


FIGURE 1. UNEMPLOYMENT RATE IN THE U.S. 2008-2016

Evidence suggests that the increase in unemployment in the 2008 recession was preceded by a tightening of credit conditions.² In the Euro Area Bank Lending Survey, the percentage of banks that expected to tighten their collateral requirements by the end of the year doubled from 25% to 50% between 2007 and 2008. A study by Campello et al. (2008) documents that financially constrained firms are more likely to cut hiring and bypass investment opportunities. All these observations highlight the importance of understanding the effects that financial conditions have on macroeconomic aggregates.

¹Studies including Neftci (1984), Sichel (1993), McKay and Reis (2008) document the skewness of the unemployment rate over the business cycle.

²See Garín (2015) for a detailed discussion

This paper combines a dynamic stochastic general equilibrium model that features financial frictions with wage rigidity. I follow Garín (2015) in introducing financial frictions in the style of Kiyotaki and Moore (1997). Due to costly contract enforcement, a firm’s ability to borrow is constrained by its holdings of collateralizable assets. Exogenous fluctuations in the liquidation value of the collateral e.g. in collateral requirements are meant to capture uncertainty in the credit conditions. Wage rigidity is modeled as a sticky wage norm similar to the one presented in Hall (2005).

The model features two agents, households and capitalists. Households supply labor and funds. Capitalists own the firms and derive utility from the consumption of dividends. Due to a cash flow mismatch, firms are required to finance their working capital requirements by taking on intra-period loans. The loan is constrained to be less than a fraction of the value of the collateralizable asset - the capital stock.

On the labor market, firms pay vacancy posting costs in order to hire additional workers. The presence of financial frictions makes hiring more costly, as firms have to finance the additional worker’s wage via intra-period loans. When intra-period borrowing cannot be increased due to a binding borrowing constraint, firms have to cut investment or dividend payments to finance wage payments. This reduces the marginal value of hiring an additional worker whenever the borrowing constraint is binding. Since hiring is more costly when credit conditions are tight, the degree to which firms are affected by wage rigidity also varies with credit tightness.

I calibrate the model using U.S. data and simulate it using technology and credit shocks. I find that the model matches the empirical volatility of labor market variables well. More precisely, it can account for nearly 50% of the variation in unemployment, 92% of the fluctuations in vacancies and nearly 70% of the variation observed in labor market tightness. The amplification of technology shocks in the model is in line with empirical evidence. Remarkably, even a small amount of wage rigidity is sufficient to generate these results. I verify that this would not be the case in the absence of financial frictions.

Wage rigidity amplifies the initial response of the unemployment rate to technology and credit shocks. Following a negative shock of either kind, the increase in the unemployment rate is both briefer and more violent than in a model without wage rigidity. Financial frictions generate the flatter decreases in the unemployment rate. Following a positive technology shock, firms prioritize investment into the asset used as collateral. This relaxes the borrowing constraint and increases the marginal value of hiring additional workers. The initial increase in vacancies and hiring after a positive technology shock is lower compared to models without financial frictions.

I simulate different versions of the model and show that neither financial frictions nor wage rigidity alone can account for the high positive skewness of the cyclical component of the unemployment rate. Combining financial frictions and

wage rigidity increases the skewness of the unemployment rate by at least one third compared to the benchmark specifications.

The model is also able to account for the increase in the number of hires in recessions.³ Since the initial response of unemployment to either negative technology or credit shocks is amplified due to the presence of wage rigidity, the increase in the pool of unemployed workers is larger. This makes hiring cheaper for the following periods, as the job-filling rate increases. Consequently, the number of hires is raised above its steady state value before output begins to recover. This mechanism does not generate a counterfactual positive correlation between unemployment and vacancies, such that the model is able to replicate the Beveridge curve.

The remainder of the paper is organized as follows. The next two sections discuss previous research and empirical observations. Section IV presents the model. Section V describes the quantitative analysis in detail. Policy implications of the model are discussed in Section VI. To conclude, Section VII summarizes the results.

II. Related Literature

This paper adds to the literature trying to understand the effects of financial conditions on macroeconomic aggregates. A contemporaneous study by Schoefer (2015) uses a similar channel through which wage rigidity and financial frictions influence the job-creation decision. His work relies on inframarginal wage rigidity among incumbent workers in a search and matching framework with an ad hoc borrowing constraint. Wage rigidity and financial frictions work by squeezing firms' internal funds. The quantitative analysis focuses on the response of labor market tightness with respect to productivity shocks. By contrast, my work relies on wage rigidity among new hires, as is common in the search and matching literature. While many studies, including for example Heafke et al. (2006), find that wage rigidity is stronger among incumbents, Gertler and Trigari (2009) and Huckfeldt et al. (2015) show that wages for new hires are no more cyclically sensitive than wages for incumbent workers, after controlling for compositional effects. Additionally, in the model presented here, the borrowing constraint arises from an optimal contract with limited enforcement. This provides more discipline in the evaluation of the results. Another point that differentiates my work from the study by Schoefer (2015) is the role of physical capital. While capital is not included in his model, one of the main results of this paper relies upon the possibility of investing into the asset used as collateral. As firms tend to prioritize investment in capital following a positive productivity shock, the response of labor market variables is protracted. This creates significant skewness in the cyclical component of the unemployment rate. Finally, the quantitative analysis in this

³Several studies, including Blanchard and Diamond (1990), Fujita and Ramey (2006), Yashiv (2007) and Elsby, Michaels and Solon (2009), document that while the hiring rate is procyclical, the number of hires tends to increase in recessions.

paper includes full business cycle statistics and impulse response functions, which allow for a detailed evaluation of the model.

There are a few studies that try to reconcile the dynamics of the unemployment rate with economic models. Barnichon (2010) uses a search and matching model with endogenous separations. In contrast to the model presented here, in his model the asymmetry in the unemployment rate arises not endogenously but from an ad hoc lower bound on the separation rate. McKay and Reis (2008) propose a model with creative destruction and asymmetric costs of adjusting employment to account for unemployment dynamics. My work provides an alternative approach.

Another strand of literature that this work is related to is engaged with determining the relative importance of job-creation and job-destruction in explaining unemployment fluctuations. Shimer (2005) argues that, taking time-aggregation bias into account, the separation rate is nearly acyclic. Fujita and Ramey (2006) use a different method for decomposing unemployment fluctuations and find a highly negative correlation between the job-separation rate and productivity. They point out that using models with only exogenous separations might seriously distort the analysis of unemployment dynamics. This is not the case for the model presented here. The combination of wage rigidity and financial frictions is able to generate the dynamics presented in the following section in a model without endogenous separations.

III. Empirical Observations

In this section, I highlight three empirical observations that standard search and matching models are unable to explain jointly.

A. *Skewness of the Unemployment Rate*

One important aspect of unemployment dynamics that is regularly overlooked in the search and matching literature is the significant asymmetry in steepness. More precisely, increases in the unemployment rate tend to be a lot steeper than decreases. For example, for the time period between 1964 and 2009 the quarterly unemployment rate displayed a positive skewness of 1.03 for U.S. data.⁴ Even though a large body of literature, including studies by Neftci (1984), Sichel (1993) and Barnichon (2010), has documented the asymmetric behavior of the unemployment rate, most standard search and matching models are unable to match this observation. Notably, McKay and Reis (2008) have shown that contractions in employment are shorter and more rapid than expansions, while this is not the case for output. Additionally, output and employment coincide in troughs but employment lags output at peaks. Neither standard search and matching models, nor existing models with borrowing constraints can fully account for these

⁴Quarterly unemployment is the hp-filtered quarterly average of the monthly unemployment series constructed by the Bureau of Labor Statistics from the Current Population Survey.

dynamics.⁵

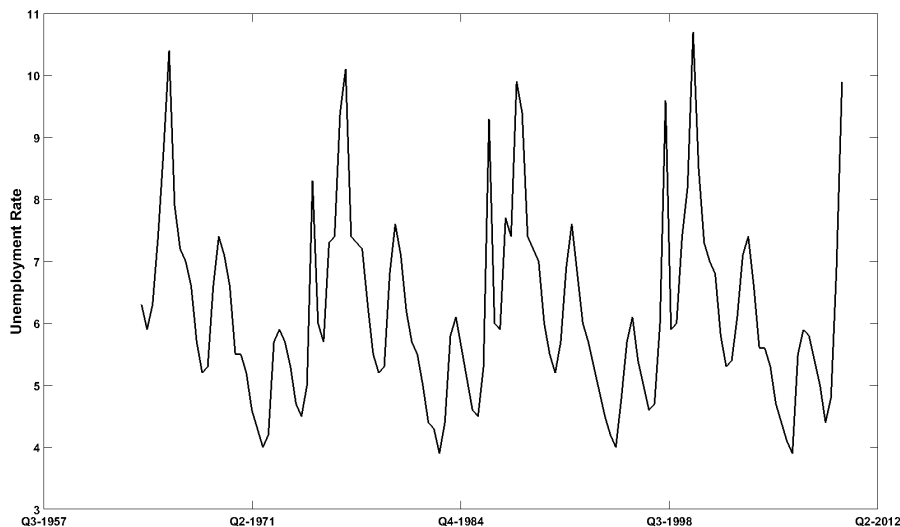


FIGURE 2. UNEMPLOYMENT RATE IN THE U.S. 1964-2009

Figure 1 displays the unemployment rate for the respective time period. During the entire period, increases in the unemployment rate are steeper than decreases. The reason why standard models cannot match this pattern is intuitively very simple; they lack a mechanism creating asymmetry in the unemployment dynamics. Since technology shocks are generally assumed to be symmetric, the simulated unemployment rate follows this symmetric behavior.

B. Number of Hires

Another aspect of unemployment dynamics that is often neglected is the behavior of the number of new hires from unemployment. Many studies solely focus on the business cycle dynamics of the job-finding rate and the job-separation rate. However, understanding the empirical dynamics of the number of hires is not trivial. Several studies, including Blanchard and Diamond (1990), Fujita and Ramey (2006), Elsbey, Michaels and Solon (2009) and Yashiv (2007), document an increase in the number of hires in recessions. While this observation might seem counterintuitive at first, keep in mind that the statement is about numbers and not about rates. In line with conventional wisdom, the mentioned studies confirm

⁵McKay and Reis (2008) state that borrowing constraints should affect employment and output equally. However, this is not the case for the combination of financial frictions and wage rigidity presented here.

a decrease in the hiring rate in recessions. The number of new hires from unemployment is equal to the job-finding probability times the number of unemployed workers. For the number of hires to increase in recessions, while the job-finding probability declines, the pool of unemployed workers has to increase proportionally more than the job-finding probability decreases. Models with endogenous separations can explain this proportionally larger increase by a burst of layoffs in recessions. For models with a constant separation margin, this observation is hard to match.

Taking a look at the data, measures of the correlation between the number of new hires and productivity differ a lot. One of the highest negative estimates is provided by Fujita and Ramey (2006) who measure a contemporaneous correlation between hiring and industrial production of -0.75. Their results imply that hiring is strongly countercyclical. In contrast, Shimer (2012) argues that the number of hires is not strongly countercyclical for U.S. data.⁶ Using flow data constructed by Shimer, I estimate a correlation between hiring from unemployment and industrial production of 0.29 for the time period between 1964 and 2004.⁷ Models with endogenous separations are in general unable to generate a positive correlation between hiring and production, as significant countercyclical separations tend to make the number of hires strongly countercyclical.

C. Beveridge Curve

The strong negative correlation between unemployment and vacancies, known as the Beveridge curve, is a well documented fact about the labor market. At quarterly frequencies the correlation is -0.89 for U.S. data over 1964-2009. While standard search and matching models with endogenous separations can easily replicate the increasing number of hires in recessions described above, they generally cause the unemployment-vacancy correlation to become counterfactually positive. After a negative technology shock, a burst of layoffs elevates the pool of unemployed workers. The job-filling rate increases, hiring becomes cheaper and vacancy creation is stimulated.

IV. Model with Financial Frictions and Wage Rigidity

In this section I build upon the model presented in Garín (2015). The model economy is populated by two types of agents: workers and capitalists. Capitalists

⁶Both Shimer (2012) and Fujita and Ramey (2006) use CPS gross flow data but apply different filtering methods.

⁷All time series are quarterly averages of instantaneous transition rates corrected for time aggregation. For additional details, please see Shimer (2012) and his webpage (<http://home.uchicago.edu/~shimer/data/flows/>). The data from June 1967 and December 1975 were tabulated by Joe Ritter and made available by Hoyt Bleakley. Hiring is measured as the quarterly unemployment-employment transition rate times the unemployment pool. The unemployment pool is constructed using the quarterly average of the monthly unemployment series constructed by the Bureau of Labor Statistics from the Current Population Survey and population estimates from the United States Census Bureau. Industrial production is the Industrial Production Index published by the Federal Reserve Board of the U.S.

own the firms. Firms produce a homogenous good y_t by hiring labor n_t and accumulating physical capital k_t . All dividends d_t are transferred to the capitalists. Workers have access to a one-period riskless bond a_t that is issued by capitalists.

The labor market is subject to search frictions in the sense of Mortensen and Pissarides (1994). Hiring workers entails vacancy posting costs that are paid by the firms. Wages are determined by standard Nash-bargaining over the entire surplus of a worker-firm match. Following Merz (1995) and Andolfatto (1996), I assume that each household consists of a continuum of workers that perfectly shares all risks.

A. The Labor Market

The number of matches on the labor market is determined by a standard Cobb-Douglas matching function: $h_t = \mu u_t^\eta v_t^{1-\eta}$. The efficiency of the matching technology is given by μ , u_t is unemployment and v_t vacancies. The parameter η governs the elasticity of the matching function with respect to unemployment and vacancies respectively. The job-filling rate, the probability with which a firm fills a vacancy, is given by $\frac{h_t}{v_t} \equiv q(\theta_t) = \mu \theta_t^{-\eta}$. The job-finding rate, the probability with which an unemployed worker finds a job, is given by $\frac{h_t}{u_t} \equiv f(\theta_t) = \mu \theta_t^{1-\eta}$. Labor market tightness θ is defined as $\theta_t = \frac{v_t}{u_t}$. When labor market tightness is high, many unemployed workers compete for few vacant jobs. This implies that the job-filling rate is high and the job-finding rate is low. At the beginning of each period, a fraction s of all existing worker-firm matches is exogenously separated. Newly separated workers can immediately begin searching for a new job and have the same probability of finding a job as the other unemployed workers. Employment evolves according to

$$n_t = (1 - s)n_{t-1} + h_t.$$

In each period $1 - (1 - s)n_{t-1}$ unemployed workers are searching for a job and at the end of each period

$$(1) \quad u_t = 1 - n_t$$

workers remain unemployed. Since search is costless from the household perspective, all unemployed workers search for a job.

Posting a vacancy entails costs of $c(v_t) = \kappa v_t^2$ per period, where $\kappa \in (0, +\infty)$ represent the resources a firm must spend because of matching frictions. I follow Yashiv (2007) in assuming convex vacancy posting costs. Furthermore, I assume that there is no risk on the firm side. Firms can hire h_t workers with certainty by posting $\frac{h_t}{q(\theta_t)}$ vacancies. When the labor market is tight, many firms compete for few unemployed workers. A vacancy is unlikely to be filled and firms have to post more vacancies in order to fill a vacant position.

B. Households

The setup allows for the existence of a representative household, consisting of a continuum of workers of measure one. The goal of the household is utility maximization by allocating consumption across all members. The representative household maximizes lifetime utility,

$$\mathbb{E}_t \sum_{n=0}^{\infty} \beta^n [u(c_{t+n}) - \varphi n_{h,t+n}],$$

where c is consumption, β is the discount factor, φ is the disutility from work and $n_{h,t}$ is the measure of workers that is employed at time t . Since the utility function is separable between consumption and leisure and perfect risk-sharing is assumed, all workers will have the same level of consumption. The household's flow of funds constraint is given by

$$c_t + \frac{a_{t+1}}{R_t} + T_t \leq w_t n_{h,t} + a_t + (1 - n_{h,t})x.$$

Employed workers earn wages w_t and unemployed workers receive benefits x . The benefits are financed through a lump-sum tax T_t : $T_t = (1 - n_{h,t})x$. The one-period riskless bond a_t pays an interest rate of R_t and is used for consumption smoothing.

Using the labor market setup, I derive the maximization problem of the representative household. The household chooses consumption and the number of bonds in order to maximize the expected discounted lifetime utility over consumption and leisure. Since it takes the job-finding rate as given, employment evolution from the household perspective can be described by

$$n_{h,t} = (1 - s)n_{h,t-1} + f(\theta_t)u_{t-1}.$$

In order to express the maximization problem in recursive form, state variables are aggregated. The vectors $\omega_t^h = \{n_{h,t-1}, a_t\}$ and $\Omega_t = \{k_t, n_{t-1}, z_{t-1}\}$ contain the individual and aggregate states, where z_t is the level of total factor productivity common to all firms. It follows an AR(1)-process given by

$$(2) \quad \ln(z_t) = \rho_z \ln(z_{t-1}) + \epsilon_{z,t}$$

with $\epsilon_{z,t} \sim \mathcal{N}(0, \sigma_z)$.

Having defined the state vectors, the maximization problem can be written as

$$\mathbb{H}_t(\omega_t^h; \Omega_t) = \max_{\{c_t, a_t\}} u(c_t) - \varphi n_{h,t} + \mathbb{E}_t \beta \mathbb{H}_{t+1}(\omega_{t+1}^h; \Omega_{t+1})$$

subject to

$$(3) \quad c_t + \frac{a_{t+1}}{R_t} + T_t \leq w_t n_{h,t} + a_t + u_t x$$

and

$$(4) \quad \ln(z_t) = \rho_z \ln(z_{t-1}) + \epsilon_{z,t}.$$

Combining the first-order conditions with respect to consumption and bonds results in the standard Euler equation

$$(5) \quad \frac{1}{R_t} = \beta \mathbb{E}_t \frac{u'(c_{t+1})}{u'(c_t)}.$$

The household invests into the asset until the marginal utility of today's consumption is equal to the discounted marginal utility of consuming tomorrow, weighted by the rental rate R_t .

C. Financial Markets

As Garín (2015), I introduce financial frictions in the sense of Kiyotaki and Moore (1997) into the model. A cash-flow mismatch forces firms to raise funds via intra-period loans l_t . Firms need these loans in order to finance their working capital requirements, meaning the total costs of production and dividend payouts.⁸ As in Jermann and Quadrini (2012) and Garín (2015), wage payments, dividend payouts, investments, current debt and vacancy posting costs all accrue before the realization of revenues.⁹ Under these assumptions, the loan is given by

$$(6) \quad l_t = d_t + w_t n_{c,t} + c \left(\frac{h_t}{q(\theta_t)} \right) + i_t + b_t - \frac{b_{t+1}}{R_t}.$$

In line with Garín (2015), Perri and Quadrini (2011), and Jermann and Quadrini (2012), l_t can be interpreted as the liquid funds of a firm.

After production has realized and before the payment of the intra-period loan is due, the possibility of default arises in the model because of costly contract enforcement. This implies that firms are subject to a collateral requirement arising from an optimal contract. Following a default, financial intermediaries cannot seize production. Only the installed capital stock can be recovered and sold at $\eta_t q_{k,t} k_t$, where η_t captures uncertainty in the tightness of the credit market and $q_{k,t}$ is the marginal Tobin's Q . Financial intermediaries have no bargaining power in the debt renegotiation and they do not value the stock of workers in the firm. Like Garín (2015) and Liu, Wang and Zha (2010), I interpret η_t as exogenous collateral shocks following the stochastic process

$$\ln \eta_t = (1 - \rho_\eta) \ln \bar{\eta} + \rho_\eta \ln \eta_{t-1} + \epsilon_{\eta,t}$$

⁸Evidence by Buera and Shin (2008) supports the assumption that most of a firm's costs require working capital.

⁹Vacancy posting costs are not present in the model of Jermann and Quadrini (2012).

with $\epsilon_{\eta,t} \sim \mathbb{N}(0, \sigma_\eta)$, where $\bar{\eta}$ is the mean of the stochastic process.

The derivation of the enforcement constraint follows the derivation in Garín (2015). Referring to the respective optimization problem, the value of a firm can be written as

$$\mathbb{J}(\omega_t^c; \Omega_t) = d_t + \mathbb{E}_t \Lambda_{t+1|t}^c \mathbb{J}(\omega_{t+1}^c; \Omega_{t+1}).$$

With the possibility of default before the loan is due and after production is realized, the value of not defaulting is

$$\nu^{f,n} = \mathbb{E}_t \Lambda_{t+1|t}^c \mathbb{J}(\omega_{t+1}^c; \Omega_{t+1}).$$

In the case of default, firms and lenders renegotiate. If an agreement is reached, firms pay lenders a fraction ν_t of the continuation value. Therefore, the value of a successful renegotiation is

$$\nu^{f,s} = \mathbb{E}_t \Lambda_{t+1|t}^c \mathbb{J}(\omega_{t+1}^c; \Omega_{t+1}) + l_t - \nu_t,$$

where firms continue to produce, get another loan l_t , but have to pay a part of the continuation value to the lenders. As production cannot be seized by lenders in the case of default, the value of an unsuccessful renegotiation for the firm is simply $\nu^{f,u} = l_t$. Consequently, the net value of an agreement is given by

$$\nu^{f,net} = \mathbb{E}_t \Lambda_{t+1|t}^c \mathbb{J}(\omega_{t+1}^c; \Omega_{t+1}) - \nu_t.$$

From the perspective of a lender, the value of a successful renegotiation is

$$\nu^{l,s} = \nu_t + \frac{b_{t+1}}{R_t}.$$

In the case that no agreement is reached, lenders cannot seize production. As they do not value the stock of workers in the firm, the value of an unsuccessful renegotiation is

$$\nu^{l,u} = \eta_t q_{k,t} k_t$$

from the lender's perspective. This results in the net value of an agreement for the lender of

$$\nu^{v,net} = \nu_t + \frac{b_{t+1}}{R_t} - \eta_t q_{k,t} k_t.$$

The joint surplus of renegotiating is the sum of the net values of the firm and the lender. Since financial intermediaries have no bargaining power in the renegotiation of debt, in case of default the firm gets the value

$$\nu^{f,d} = \mathbb{E}_t \Lambda_{t+1|t}^c \mathbb{J}(\omega_{t+1}^c; \Omega_{t+1}) + l_t + \frac{b_{t+1}}{R_t} - \eta_t q_{k,t} k_t$$

which is equal to its liquidity plus the joint surplus of renegotiating the debt. In order to rule out defaults, the value of not defaulting for the firm has to be at

least as large as the value of defaulting. Using this inequality and rearranging terms results in the following enforcement constraint:

$$(7) \quad l_t + \frac{b_{t+1}}{R_t} \leq \eta_t q_{k,t} k_t,$$

which constraints a firm's ability to borrow below the value of the fraction of its physical capital stock that lenders can recuperate after default.

D. Firms

Following Perri and Quadrini (2011), capitalists are risk-averse and derive utility from the consumption of dividend payouts. Capitalists have no other access to the financial market than through the firm.¹⁰

In line with Garín (2015), I assume that capitalists are relatively more impatient than households, which implies $\beta_h > \beta_c$, where β_h is the discount factor of the household and β_c is the discount factor of the firm.¹¹ This impedes capitalists from saving enough to avoid the borrowing constraint. Under this assumption, the borrowing constraint is binding in the steady state. To see this, note that from the household and the firm problem we get

$$\frac{1}{R_t} = \mathbb{E}_t \beta_h \frac{c_t}{c_{t+1}}$$

and

$$\frac{1}{R_t} = \mathbb{E}_t \Lambda_{t|t+1}^c \frac{1}{1 - \lambda_{4,t}}.$$

Combining the two equations, considering only the steady state, gives

$$\frac{\beta_h - \beta_c}{\beta_h} = \bar{\lambda}_4,$$

where $\bar{\lambda}_4$ denotes the steady state of the Lagrange multiplier on the borrowing constraint in the firms' optimization problem. As long as the discount factor of the households is larger than the discount factor of capitalists, the multiplier is

¹⁰This assumption is crucial for the results, as it implies that capitalists consume all the received dividends d_t in each period. With access to financial markets, capitalists could smooth consumption and reduce the costs associated with changes in dividends. This would dampen any effect of credit frictions. The assumption might be justified by arguing that a significant share of firms worldwide are family businesses. According to Kachaner et al. (2012), family businesses account for more than 30% of firms who exceed one billion dollars in sales. Furthermore, family businesses tend to leave most of their wealth inside the company. Thus, at least for those firms, access to financial markets might be easiest through the firm.

¹¹While this assumption is standard in the literature, it might seem counterintuitive at first, as in many other applications capitalists are assumed to be more patient than households. Garín (2015) argues that an alternative modelling strategy would be to follow Jermann and Quadrini (2012) and assume that the tax structure favors debt financing. Thus, the assumption $\beta_h > \beta_c$ may be seen as a shortcut that does not change the qualitative results.

positive in the steady state. This directly implies that the borrowing constraint is binding.

Under these assumptions, capitalists lifetime expected utility is

$$\mathbb{E}_t \sum_{j=0}^{\infty} \beta^{t+j} u(d_{t+j}).$$

As firms are owned by capitalists, the objective of a firm is to maximize the expected future stream of discounted dividends. The stochastic discount factor of capitalists is $\Lambda_{t|t+j}^c = \beta^j \frac{u'(d_{t+j})}{u'(d_t)}$. Firms own the capital stock that evolves according to

$$k_{t+1} = (1 - \delta)k_t + \left[\frac{\delta\xi}{1 - \xi} \left(\frac{i_t}{k_t} \right)^{1-\xi} - \frac{\xi\delta}{(1 - \xi)} \right] k_t$$

where i_t is investment into physical capital and δ is the depreciation rate for physical capital. The functional form is commonly used in the literature and captures the costs associated with adjusting the capital stock.¹² Firms use capital k_t and labor $n_{c,t}$ to produce a homogenous good with a standard Cobb-Douglas production function: $y_t = z_t n_{c,t}^\alpha k_t^{1-\alpha}$. They can borrow using one-period riskless bonds b_{t+1} with the gross interest rate R_t . The vector $\omega_t^e = \{k_t, n_{c,t-1}, b_t\}$ contains the individual states of a firm. Since the model does not feature any idiosyncratic shocks, I follow Garín (2015) in focusing on a symmetric equilibrium and a representative firm. With all assumptions in place, the optimization problem of the firm can be summarized by

$$\mathbb{J}_t(\omega_t^e; \Omega_t) = \max_{\{d_t, h_t, i_t, k_{t+1}, b_{t+1}\}} d_t + \mathbb{E}_t \Lambda_{t|t+1}^c \mathbb{J}_{t+1}(\omega_{t+1}^e; \Omega_{t+1})$$

subject to the budget constraint

$$(8) \quad z_t n_{c,t}^\alpha k_t^{1-\alpha} + \frac{b_{t+1}}{R_t} = d_t + b_t + w_t n_{c,t} + i_t + c \left(\frac{h_t}{q(\theta_t)} \right),$$

the law of motion for the capital stock

$$(9) \quad k_{t+1} = (1 - \delta)k_t + \left[\frac{\delta\xi}{1 - \xi} \left(\frac{i_t}{k_t} \right)^{1-\xi} - \frac{\xi\delta}{(1 - \xi)} \right] k_t,$$

the law of motion for employment

$$(10) \quad n_{c,t} = (1 - s)n_{c,t-1} + h_t,$$

¹²See, for example, Jermann (1998), Perri and Quadrini (2011) and Garín (2015).

and the borrowing constraint

$$(11) \quad d_t + w_t n_{c,t} + c \left(\frac{h_t}{q(\theta_t)} \right) + i_t + b_t \leq \eta_t q_{k,t} k_t,$$

where the loan l_t is replaced by Equation 6. Denoting the multipliers on the budget constraint, the law of motion for the capital stock, the law of motion for employment, and the borrowing constraint with $\lambda_{1,t}$, $\lambda_{2,t}$, $\lambda_{3,t}$, and $\lambda_{4,t}$, respectively, and taking derivatives results in the following first order conditions:

$$(12) \quad \lambda_{1,t} = 1 - \lambda_{4,t}$$

$$(13) \quad \lambda_{3,t} = \frac{c'(v_t)}{q(\theta_t)}$$

$$(14) \quad \lambda_{2,t} = \frac{1}{\delta \xi \left(\frac{i_t}{k_t} \right)^{-\xi}}$$

$$(15) \quad \begin{aligned} \lambda_{2,t} = & \mathbb{E}_t \Lambda_{t|t+1}^c \left\{ [(1 - \alpha) z_{t+1} n_{c,t+1}^\alpha k_{t+1}^{-\alpha}] (1 - \lambda_{4,t+1}) - \frac{i_{t+1}}{k_{t+1}} \right. \\ & \left. + \lambda_{2,t+1} \left[(1 - \delta) + \frac{\delta \xi}{1 - \xi} \left(\frac{i_t}{k_t} \right)^{1-\xi} - \frac{\xi \delta}{(1 - \xi)} \right] \right\} \\ & + \mathbb{E}_t \Lambda_{t|t+1}^c \lambda_{4,t+1} \eta_{t+1} q_{k,t+1} \end{aligned}$$

$$(16) \quad \frac{1}{R_t} = \mathbb{E}_t \Lambda_{t|t+1}^c \frac{1}{1 - \lambda_{4,t}},$$

where q_k is the ratio of the Lagrange multipliers $\lambda_{2,t}$ and $\lambda_{1,t}$. From this, it follows that q_k represents the value of the installed capital relative to its replacement cost, as is standard in the literature.¹³

Deriving the job-creation condition is necessary to solve the Nash-bargaining problem between workers and firms. The marginal value of an additional worker to the firm $\mathbb{J}_{n,t}$ can be obtained by taking the first derivative of the firm's value function \mathbb{J}_t with respect to employment:

$$\mathbb{J}_{n,t} = [\{\alpha z_t n_{c,t}^{\alpha-1} k_t^{1-\alpha}\} (1 - \lambda_{4,t}) - w_t] + (1 - s) \mathbb{E}_t \Lambda_{t|t+1}^c \mathbb{J}_{n,t+1}.$$

The term in square brackets is equal to the net return of an additional worker,

¹³See, for example, Garín (2015).

while the second term is the present discounted value of the hired worker. Note that in the case without financial frictions $\lambda_{4,t} = 0$; financial conditions do affect the marginal value of having an additional worker. Consider an increase in collateral requirements. The firm is more credit constrained, which increases the value of relaxing the borrowing constraint, e.g. $\lambda_{4,t}$. This increase reduces the net return of an additional worker and therefore the marginal benefit of hiring. Intuitively, the firm has to finance an additional worker's wage via intra-period loans. When the borrowing constraint is already binding, this can only be done by reducing investment or dividend payments. This reduces the value of an additional worker. Using Equation 13, the job-creation condition is

$$(17) \quad \frac{c'(v_t)}{q(\theta_t)} = [\{\alpha z_t n_{c,t}^{\alpha-1} k_t^{1-\alpha}\}(1 - \lambda_{4,t}) - w_t] + (1 - s)\mathbb{E}_t \Lambda_{t|t+1}^c \frac{c'(v_{t+1})}{q(\theta_{t+1})}.$$

This condition is very similar to the job-creation conditions in, for example, Michaillat (2012) and Barnichon (2010). Firms hire workers until the marginal product of labor equals the marginal costs of labor, where the costs consist of the hiring costs and the wage minus the discounted cost of hiring next period. As in Petrovsky-Nadeau (2011), the presence of financial frictions creates a wedge in the job-creation condition. In this way, financial frictions affect firms' ability to create new jobs. When collateral requirements are too high, firms cannot borrow enough to finance the otherwise optimal amount of new workers. This mechanism introduces another aspect into the model: the elasticity of the marginal value of an additional worker with respect to hypothetical changes in the wage increases with collateral requirements. Note that the elasticity of the marginal value of an additional worker is given by

$$\epsilon_{w_t}^{\mathbb{J}_{n,t}} = -\frac{w_t}{\mathbb{J}_{n,t}}.$$

The absolute value of this elasticity increases with $\lambda_{4,t}$. As the marginal value of relaxing the borrowing constraint increases proportionally with collateral requirements, the elasticity of the marginal value of an additional worker with respect to changes in the wage increases with collateral requirements, too. One implication is that the marginal benefit of hiring an additional worker from the firm perspective reacts more strongly to changes in the wage than in standard search and matching models. Thus, in the model, even a small amount of wage rigidity might have large effects on labor market variables.¹⁴

E. Wage Bargaining and Wage Rigidity

As is standard in most of the search and matching literature, wages are determined as the solution of a generalized Nash-bargaining problem. The production

¹⁴Among others, Krause and Lubik (2004) point out that, in order to create empirically plausible fluctuations in unemployment and vacancies, the amount of wage rigidity that has to be assumed for standard models is excessively large. I show that the presence of financial frictions reduces the necessary amount of wage rigidity to an empirically plausible value.

function exhibits constant returns to scale, which greatly simplifies the bargaining problem. Models with diminishing returns are subject to the critique by Stole and Zwiebel (1996), as each additional worker has a lower marginal product than the last. With constant returns to scale, the Nash-bargaining problem remains simple.¹⁵ In order to derive the wage schedule, I first define the value functions $\mathbb{H}_{m,t}$, $\mathbb{H}_{n,t}$ and $\mathbb{H}_{u,t}$. $\mathbb{H}_{m,t}$ is the marginal value of having an additional member matched from the household perspective, $\mathbb{H}_{n,t}$ the value function associated with having an additional member employed and $\mathbb{H}_{u,t}$ the value function associated with having an additional member unemployed. Using the law of motion for employment from the household perspective, $n_{h,t} = (1-s)n_{h,t-1} + f(\theta)u_t$, $\mathbb{H}_{n,t}$ can be written as

$$\mathbb{H}_{n,t} = -\varphi + \lambda_t w_t + \beta \mathbb{E}_t \{ s[1 - f(\theta_{t+1})] \mathbb{H}_{u,t+1} + [1 - s + sf(\theta_{t+1})] \mathbb{H}_{n,t+1} \}$$

and $\mathbb{H}_{u,t}$ as

$$\mathbb{H}_{u,t} = \lambda_t x + \beta \mathbb{E}_t \{ f(\theta_{t+1}) \mathbb{H}_{n,t+1} + [1 - f(\theta_{t+1})] \mathbb{H}_{u,t+1} \},$$

where λ_t is the Lagrange multiplier on the households budget constraint. The marginal value of a match, $\mathbb{H}_{m,t} = \frac{\mathbb{H}_{n,t} - \mathbb{H}_{u,t}}{\lambda_t}$ is therefore given by

$$(18) \quad \mathbb{H}_{m,t} = -\frac{\varphi}{\lambda_t} + w_t - x + (1-s) \mathbb{E}_t \Lambda_{t+1|t}^h [1 - f(\theta_{t+1})] \mathbb{H}_{m,t+1},$$

with $\Lambda_{t+1|t}^h$ being the household's stochastic discount factor.¹⁶

With both value functions defined, the wage that solves the bargaining problem can be expressed as

$$w_t^* = \arg \max_{w_t} \mathbb{J}_{n,t}^{1-\phi} \mathbb{H}_{m,t}^\phi,$$

where ϕ is the bargaining power of the worker. Taking the first derivative results in the standard first-order condition

$$\phi \frac{\partial \mathbb{H}_{m,t}}{\partial w_t} \mathbb{J}_{n,t} + (1-\phi) \frac{\partial \mathbb{J}_{n,t}}{\partial w_t} \mathbb{H}_{m,t} = 0,$$

that can be rewritten as

$$\phi \mathbb{J}_{n,t} = (1-\phi) \mathbb{H}_{m,t}.$$

In the next step I define the total surplus of the match \mathbb{S}_t as the sum of the firm's and the worker's surplus. This results in

$$\mathbb{S}_t = (\alpha z_t n_{c,t}^{\alpha-1} k_t^{1-\alpha}) (1 - \lambda_{4,t}) - x - \frac{\varphi}{u'(c_t)} + (1-s) \mathbb{E}_t \{ \Lambda_{t+1|t}^c \mathbb{J}_{n,t+1} \Lambda_{t+1|t}^h [1 - f(\theta_{t+1})] \mathbb{H}_{m,t+1} \}.$$

¹⁵ Additionally, Krause and Lubik (2013) show that Stole-Zwiebel-bargaining has only small effects on the simulated business cycle statistics of search and matching models of the labor market.

¹⁶ $\Lambda_{t+1|t}^h = \beta \mathbb{E}_t \frac{\lambda_{t+1}}{\lambda_t}$.

Using $\mathbb{H}_{m,t}$ I can write $\mathbb{H}_{m,t} = \phi \mathbb{S}_t$ and $\mathbb{J}_{n,t} = (1 - \phi) \mathbb{S}_t$. Multiplying the total surplus with $(1 - \phi)$, using $\mathbb{J}_{n,t} = (1 - \phi) \mathbb{S}_t$, the first order condition and rearranging terms gives

$$\begin{aligned} \mathbb{J}_{n,t} &= (1 - \phi)(\alpha z_t n_{c,t}^{\alpha-1} k_t^{1-\alpha})(1 - \lambda_{4,t}) - (1 - \phi) \left[x + \frac{\varphi}{u'(c_t)} \right] \\ &\quad + (1 - \phi)(1 - s) \mathbb{E}_t \{ \Lambda_{t+1|t}^c \mathbb{J}_{n,t+1} \} \\ &\quad + \phi(1 - s) \mathbb{E}_t \{ \Lambda_{t+1|t}^h [1 - f(\theta_{t+1})] \mathbb{J}_{n,t+1} \}. \end{aligned}$$

In the last step I replace $\mathbb{J}_{n,t}$ by the value function and use that $\mathbb{J}_{n,t+1} = \frac{c'(v_{t+1})}{q(\theta_{t+1})}$. Rearranging terms gives the wage equation

$$\begin{aligned} (19) \quad w_t &= \phi \left[(\alpha z_t n_{c,t}^{\alpha-1} k_t^{1-\alpha})(1 - \lambda_{4,t}) + (1 - s) \mathbb{E}_t \left\{ \Lambda_{t+1|t}^c \frac{c'(v_{t+1})}{q(\theta_{t+1})} \right\} \right] \\ &\quad + (1 - \phi) \left[x + \frac{\varphi}{u'(c_t)} \right] \\ &\quad - \phi(1 - s) \mathbb{E}_t \left\{ \Lambda_{t+1|t}^h [1 - f(\theta_{t+1})] \frac{c'(v_{t+1})}{q(\theta_{t+1})} \right\}. \end{aligned}$$

Since the model economy is subject to two kinds of shocks, wage rigidity in the style of Blanchard and Galí (2010) or Michaillat (2012) is not suitable. Instead, I assume an ad hoc wage rigidity that is similar to the sticky wage norm proposed in Hall (2005):

$$(20) \quad w_t = \pi w_t^* + (1 - \pi) w_{t-1},$$

where w_t^* is the solution to the generalized Nash bargaining problem given by Equation 19. The parameter π governs the size of the wage rigidity. With this wage schedule, the steady state real wage remains the same regardless of the amount of wage rigidity in the model. Possible reasons for this kind of wage rigidity include the widespread organization of firms around internal labor markets, labor market institutions and the managerial best practice of avoiding paycuts.¹⁷

The wage schedule in Equation 20 has an alternative interpretation. Assume a standard Calvo wage setting scenario in the sense that in every period only a fraction π of all firms is able to renegotiate wages. If a firm is able to adjust wages in a given period, the new wage is determined by generalized Nash bargaining over the total surplus of the match. This setting is analyzed in Gertler and Trigari (2009) who derive a log-linearized wage index in this setting of staggered Nash bargaining that looks very similar to the wage schedule in Equation 20. Particularly, Equation 20 is the outcome of the staggered Nash bargaining in Gertler and Trigari (2009), if neither firms nor workers take into account that

¹⁷See Michaillat (2012) for a more detailed discussion and many citations.

they might not be able to renegotiate wages in the subsequent periods. In this sense Equation 20, and consequently my analysis, is at the upper bound of wage rigidity.

Another appealing feature of this interpretation of the wage schedule is that the parameter π receives an intuitive interpretation instead of being an ad hoc variable governing the amount of wage rigidity. Using a wage setting mechanism in the sense of Calvo, $\frac{1}{\pi}$ can be interpreted as the average duration between wage renegotiations.

CLAIM 1: *Assume that the wage schedule is given by Equation 20. Wages are privately efficient if the wage schedule satisfies*

$$\begin{aligned} x + \frac{\varphi}{u'(c_t)} - (1-s)\mathbb{E}_t\Lambda_{t+1}^h[1-f(\theta_{t+1})]\mathbb{H}_{m,t+1} \\ \leq w_t \leq \alpha z_t[(1-s)n_{c,t-1}]^{\alpha-1}k_t^{1-\alpha}(1-\lambda_{4,t}) \\ + (1-s)\mathbb{E}_t\Lambda_{t+1}^h\frac{c'(v_{t+1})}{q(\theta_{t+1})}. \end{aligned}$$

This claim implies that no worker-firm match generating a positive bilateral surplus is separated because of wage rigidity, as long as the actual wage remains within the postulated bounds. This seems to be a sensible assumption when looking at long-term worker-firm relationships with wage renegotiations. The proof for this claim is given in the appendix. The wage schedule is not subject to the Barro (1977) critique that bargaining workers and firms should be able to exploit all possible bilateral gains. Due to constant returns in production, the model is not affected by Brüggemann's (2014) critique of wage rigidity in search and matching models with diminishing returns which applies to Michaillat (2012), for example. He argues that in such models, wage rigidity with respect to firm level employment might lead to private inefficiency of the wage schedule off the equilibrium path. This is not the case here.

F. Equilibrium

With the model completely described, I define the equilibrium.

DEFINITION 1: *A recursive equilibrium is defined as a set of i) firm's policy functions $d(\omega^c; \Omega)$, $n_c(\omega^c; \Omega)$, $b(\omega^c; \Omega)$, $k(\omega^c; \Omega)$, $i(\omega^c; \Omega)$ and $v(\omega^c; \Omega)$; ii) household's policy functions $c(\omega^h; \Omega)$, $a(\omega^h; \Omega)$ and $n_h(\omega^h; \Omega)$; iii) a lump sum tax $T(\Omega)$, iv) prices $w(\Omega)$ and $R(\Omega)$; and v) law of motion for the aggregate states, $\Omega' = \Psi(\Omega)$, such that: i) firms' policies satisfy the firms' first order conditions (Equations 12 - 16) and the job-creation condition (Equation 17); ii) household's policy function satisfies the household's first order condition (Equation 5), iii) the wage is determined by Equation 20; iv) $R(\Omega)$ clears the market for riskless assets such that $a(\Omega) = b(\Omega)$; v) labor demand by the firms is equal to labor supply by the households, $n_c(\omega^c; \Omega) = n_h(\omega^h; \Omega)$; vi) the law of motion $\Psi(\Omega)$ is consistent*

with individual decisions and with the stochastic processes for z and η , and vi) the government has a balanced budget so that $x(1 - n) = T$.

This definition is similar to Definition 1 in Garín (2015). The complete set of equations used to simulate the model is given in the appendix.

V. Quantitative Analysis

This section calibrates all the parameters discussed above to match different aspects of quarterly U.S. data. I use the calibrated model to simulate time series of all variables. The model performance is evaluated along several dimensions. Most importantly, I discuss the behavior of the unemployment rate, the impulse response functions and several aspects about the business cycle statistics generated by the model.

A. Calibration

The model is calibrated to quarterly frequencies. Table 1 lists the exact parameter values as well as the source that encourages the specific choice. I first calibrate the labor market variables. For the separation rate I choose a conventional value of 0.1.¹⁸ This value is also close to the actual separation rate constructed by the Bureau of Labor Statistics using the Job Openings and Labor Turnover Survey for the time period between December 2000 and June 2009 which is equal to 0.038 for the seasonally adjusted monthly time series.¹⁹ In the literature, there is a relatively wide range concerning the admissible values of vacancy posting costs. Using microdata by Barron, Berger and Black (1997), Michailat (2012) estimates the costs of posting a vacancy at 9.8% of a workers steady state wage. This estimate accounts only for the labor costs of recruiting, ignoring travel expenses, agency fees or advertising costs. Vacancy costs calibrated to match this value imply steady state vacancy posting costs of 0.28% of the total wage bill and 0.17% of GDP. I calibrate κ to 0.18, which is slightly more than 9% of a workers steady state wage. With this value steady state vacancy posting costs account for 0.31% of the total wage bill and 0.2 % of GDP.²⁰ I deliberately calibrate κ to match vacancy posting costs at the lower end of the admissible range. Low vacancy posting costs allow firms to recruit cheaply, even in times of high financial frictions.²¹ The simulation results imply that the mechanism explained above is relevant even for low recruitment costs.

The efficiency of the matching function is chosen to match a quarterly job-finding rate of 0.9 and the elasticity of the matching function with respect to un-

¹⁸See, for example, Garín (2015) and Shimer (2005).

¹⁹The Job Openings and Labor Turnover Survey is only available since December 2000. A month is one third of a quarter. Thus, the average quarterly separation rate is roughly equal to 0.11.

²⁰The most commonly used calibration target is steady state vacancy posting costs of 1% of the GDP. See, for example, Andolfatto (1996), Barnichon (2010), Blanchard and Gal (2010), Gertler and Trigari (2009) and Thomas (2008).

²¹The results of this paper do not change qualitatively when using higher vacancy posting costs.

TABLE 1—CALIBRATION OF THE MODEL WITH FINANCIAL FRICTIONS

Interpretation	Value	Source
β_h Household's discount factor	0.996	Annual steady-state interest rate of 1.6%
β_h Household's discount factor	0.983	Annual steady-state return on equity of 7%
φ Disutility of labor	0.85	Matches unemployment rate of 10%
σ Agents relative risk aversion	2	Standard in the literature
x Unemployment benefits	0.4	Steady state replacement ratio of 0.2
ϕ Worker's bargaining power	0.4	Midpoint of values in the literature
s Separation rate	0.1	Garín (2015) and Barnichon (2010)
μ Matching efficiency	0.651	Quarterly job-finding rate 0.9
η Unemployment-elasticity of matching	0.5	Petrongolo and Pissarides (2001)
π Renegotiation probability	0.25	Taylor (1999) and Gottschalk (2005)
κ Recruiting costs	0.18	Michaillat (2012)
α Marginal returns to labor	0.66	Matches labor share of 0.66
ρ_z Autocorrelation of technology	0.907	Michaillat (2012)
σ_z Standard deviation of technology shocks	0.0089	Michaillat (2012)
ρ_η Autocorrelation of credit shocks	0.9703	Jermann and Quadrini (2012)
σ_η Standard deviation of credit shocks	0.0132	Jermann and Quadrini (2012)
$\bar{\eta}$ Steady state credit market tightness	0.3086	Debt-to-output ratio of 1.75
ε Investment adjustment cost	0.050	Empirical volatility of capital stock
δ Capital depreciation rate	0.025	Jermann and Quadrini (2012)

employment to match empirical evidence from Petrongolo and Pissarides (2001). Unemployment benefits are set to 0.4, as in Garín (2015). This value implies a steady state replacement ratio of about 0.2 which is at the lower end of the values found in the literature. The parameter φ , governing the disutility of labor, is set to match a steady state unemployment rate of 10%, which is not uncommon in the literature. Even though the average U.S. unemployment rate for the period 1964-2009 is 5.8%, a higher value is targeted since the model does not account for workers that are not strongly attached to the labor market. For this reason, Barnichon (2010), Chugh (2009), Garín (2015) and Petrosky-Nadeau (2011) also choose a steady state unemployment rate of 10%. Next I calibrate the parameter governing wage rigidity based on the interpretation of the wage schedule as coming from a staggered Nash bargaining setting. Keep in mind that with this calibration strategy, π can be interpreted as representing the upper bound on wage rigidity. Taylor (1999) argues that, for union and non-union workers, most of the medium and large sized firms typically readjust wages annually. Additional evidence is provided by Gottschalk (2005), who, based on microeconomic evidence about wages, argues that wage adjustments are most common one year after the last change. Thus, I set π to 0.25, implying an average renegotiation frequency of once per year. The mean of the credit shock process is set to match the debt-to-output ratio of 1.75 found in the data. The parameters for the persistence

and standard deviation of the credit shock sequence are taken from Jermann and Quadrini (2012) who estimate those values for the period from 1984 to 2004.²²

B. Simulated Moments

TABLE 2—SUMMARY STATISTICS, QUARTERLY US DATA, 1964-2009

	u	v	θ	w	y	z
Standard deviation	0.170	0.184	0.342	0.021	0.030	0.020
Autocorrelation	0.919	0.940	0.930	0.955	0.898	0.881
Correlation	1	-0.889	-0.970	-0.234	-0.831	-0.561
	—	1	0.973	0.198	0.777	0.524
	—	—	1	0.223	0.824	0.559
	—	—	—	1	0.502	0.627
	—	—	—	—	1	0.891
	—	—	—	—	—	1

Note: All data are seasonally adjusted. The sample period is 1964:I - 2009:II. The unemployment rate u is the quarterly average of the monthly series constructed by the Bureau of Labor Statistics from the Current Population Survey. Vacancies are taken from Michaillat (2012) and constructed as detailed in the text. Labor market tightness θ is the ratio of vacancies to unemployment. The real wage is quarterly, average hourly earning in the nonfarm business sector, constructed by the Bureau of Labor Statistics Current Employment Statistics program, and deflated by the quarterly average of monthly Consumer Price Index for all urban households, constructed by the Bureau of Labor Statistics; y is the quarterly real output in the nonfarm business sector constructed by the Bureau of Labor Statistic Major Sector Productivity and Costs dataset; $\ln(z)$ is the estimated series taken from Michaillat (2012). All variables are reported in log as deviations from an HP trend with smoothing parameter 10^5 .

I compare the simulated models to business cycle statistics for U.S. data for the time period between the first quarter of 1964 and the second quarter of 2009. For the vacancy series I take data from Michaillat (2012) who merged the Job Openings and Labor Turnover Survey from the Bureau of Labor Statistics for 2001-2009 with the Conference board help-wanted advertising index for 1964-2001.²³ Unemployment data is taken from the Bureau of Labor Statistics and labor market tightness is calculated as the ratio of vacancies to unemployment. For each of these series I take the quarterly average. The real wage estimates are taken from Michaillat (2012) who uses average hourly earnings in the nonfarm business sector constructed by the Bureau of Labor Statistics Current Employment Statistics. Output is quarterly real output from the Bureau of Labor Statistics Major Sector Productivity and Costs program. Estimates for the AR(1) process for technology

²²All other parameters are set according to Table 1. As those parameter values are fairly standard, there is no benefit in discussing them at length.

²³The reason for merging the datasets is that the Job Openings and Labor Turnover Survey only began in 2000, while the help-wanted advertising index measures only advertisements in major newspapers. With the increasing importance of online job search this standard proxy for vacancy posting is less relevant for the time after 2000.

TABLE 3—SIMULATED MOMENTS WITHOUT FINANCIAL FRICTIONS

	u	v	θ	w	y	z
Standard deviation	0.009 (0.002)	0.014 (0.002)	0.022 (0.004)	0.013 (0.002)	0.016 (0.003)	0.015 (0.003)
Autocorrelation	0.931 (0.028)	0.754 (0.078)	0.838 (0.059)	0.808 (0.071)	0.814 (0.068)	0.798 (0.070)
Correlation	1	-0.874 (0.031)	-0.950 (0.015)	-0.932 (0.023)	-0.939 (0.021)	-0.921 (0.024)
	—	1	0.982 (0.003)	0.970 (0.008)	0.975 (0.005)	0.993 (0.001)
	—	—	1	0.986 (0.006)	0.992 (0.004)	0.996 (0.001)
	—	—	—	1	0.999 (0.000)	0.988 (0.005)
	—	—	—	—	1	0.993 (0.003)
	—	—	—	—	—	1

Note: Results from simulating the model with stochastic technology with a second-order perturbation method. All variables are reported in log as deviations from an HP trend with smoothing parameter 10^5 . Simulated standard errors (standard deviations across 30 simulations) are reported in parentheses.

are taken from Michaillat (2012). These estimates are close to the values chosen in Garín (2015) and match the considered time period. All series are seasonally adjusted. In order to isolate business cycle fluctuations, I use a Hodrick-Prescott filter with smoothing parameter 100.000 as recommended in Shimer (2005). Table 2 presents the second order moments for key labor market variables that will be used primarily to evaluate the performance of the models.

I simulate 182 quarters of data corresponding to 1964:I to 2009:II.²⁴ The data is detrended using the same HP filter. The simulation is repeated 30 times and each repetition provides an estimate of the means of the simulated data. Standard deviations are calculated to judge the precision of the estimates. While the technology and credit shock processes are calibrated to match the empirical data, all other simulated moments are outcomes of the mechanics of the model. All simulations are performed using the second-order perturbation method provided in Dynare.

First, I present the results for a model without financial frictions and wage rigidity. The model is described in detail in the appendix and serves as a benchmark when evaluating the performance of the model with financial frictions and wage rigidity. The benchmark model is calibrated to match the same steady state values as the complete model. Simulation results are given in Table 3 and are strikingly close to the results obtained by Shimer (2005) for the simulation of

²⁴The first 100 quarters are discarded as a burn-in period.

a model with labor productivity shocks. While the model performance is good along several important dimensions, it is unable to match the high volatility of the key labor market variables unemployment, vacancies and labor market tightness. In fact, the volatility of vacancies and the labor market tightness is even

TABLE 4—SIMULATED MOMENTS WITH FINANCIAL FRICTIONS AND WAGE RIGIDITY = 0.25

	u	v	θ	w	y	z
Standard deviation	0.083 (0.018)	0.171 (0.017)	0.236 (0.029)	0.010 (0.002)	0.021 (0.004)	0.015 (0.003)
Autocorrelation	0.804 (0.062)	0.383 (0.102)	0.525 (0.098)	0.953 (0.022)	0.825 (0.067)	0.795 (0.075)
Correlation	1	-0.782 (0.020)	-0.880 (0.015)	-0.507 (0.087)	-0.854 (0.050)	-0.757 (0.095)
	—	1	0.976 (0.003)	0.228 (0.067)	0.649 (0.049)	0.606 (0.074)
	—	—	1	0.338 (0.079)	0.748 (0.050)	0.689 (0.084)
	—	—	—	1	0.798 (0.036)	0.746 (0.037)
	—	—	—	—	1	0.969 (0.015)
	—	—	—	—	—	1

Note: Results from simulating the model with stochastic technology with a second-order perturbation method. All variables are reported in log as deviations from an HP trend with smoothing parameter 10^5 . Simulated standard errors (standard deviations across 30 simulations) are reported in parentheses.

lower than in Shimer (2005). The reason is that the presence of capital and the financial instrument in the benchmark model gives firms more possibilities to adjust to technology shocks. Another aspect that the model does not match is the low correlation between technology and the other variables of the model. As in most models with only one shock, the correlation is too high. However, the model captures the high autocorrelation of the considered variables and the high negative correlation between vacancies and unemployment, e.g. the slope of the Beveridge curve.

The model with financial frictions and wage rigidity performs well along most dimensions that the benchmark model fails to capture. While the standard deviation of unemployment is still too low, it is now about four times the standard deviation of output, which is a huge improvement. In addition, the model accounts for roughly 70% of the volatility of labor market tightness and over 90% of the volatility in vacancies. The correlation between vacancies and unemployment is a bit lower, but still highly negative. The model also amplifies shocks by roughly as much as in the data. A 1% decrease in technology increases unemployment by 4.8%, decreases vacancies by 4.8% and decreases labor market tightness by 9.6%

in the data.²⁵ In the model, a 1% decrease in technology increases unemployment by 4.2%, decreases vacancies by 6.9% and decreases labor market tightness by 10.8%. The response of vacancies and labor market tightness is a bit higher in the model than in the data, which might be due to a lower elasticity of wages with respect to changes in technology. Heafke, Sonntag and van Rens (2013) find an elasticity of about 0.7 while the business cycle statistics for the U.S. suggest a value of 0.66. The simulated elasticity is a bit lower with a value of 0.5. However, keep in mind that this simulation can be seen as representing the upper bound of wage rigidity and wage rigidity increases the response of labor market variables to technology shocks.

Descriptions of the business cycle statistics of the model with financial frictions but without wage rigidity and of the benchmark model with wage rigidity are given in the appendix. These simulations are robustness exercises in order to confirm that wage rigidity and especially the interaction between wage rigidity and financial frictions play an important role in explaining unemployment and hiring dynamics and also in matching business cycle statistics.

C. Impulse Response Functions

In this section, I present the impulse response functions of several variables to a one standard deviation shock to total factor productivity. The scale represents deviations from the steady state.

First, consider a model with financial frictions but without wage rigidity (setting π equal to one). This model contains a mechanism that enables it to match the sluggish response of key labor market variables to technology shocks. Following a positive technology shock, firms prioritize investment into the asset used as collateral.²⁶ The investments into capital loosens the borrowing constraint and allows firms to take advantage of the high productivity level. This mechanism generates the sluggish responses of vacancies and labor market tightness present in Garín (2015). For example, when shutting down wage rigidity, about 50% of the total increase in labor market tightness following a positive technology shock occurs after the initial period. This is in line with the findings in Fujita and Ramey (2007), who report that about 58% of the total increase in labor market tightness occurs in the subsequent periods. However, much of this sluggish response in vacancies and labor market tightness is caused by an unplausibly high response of wages to productivity shocks. In the data, the elasticity of wages with respect to technology is 0.658, while in the model proposed in Garín (2015), this elasticity is equal to 0.86. As Shimer (2005) pointed out, Nash-bargained wages react too strongly to technology shocks, dampening the amplification of shocks

²⁵The elasticity of unemployment with respect to technology ϵ_a^u is the coefficient obtained in an ordinary least squares regression of log unemployment on log technology. This coefficient can be calculated as $\epsilon_a^u = \rho(u, a) \times \frac{\sigma(u)}{\sigma(a)} = -0.561 \times \frac{0.170}{0.020}$. All other elasticities can be calculated accordingly.

²⁶The mechanism also seems to match empirical data; Chen and Funke (2010) for example show that recessions are periods of waiting during which investment is delayed.

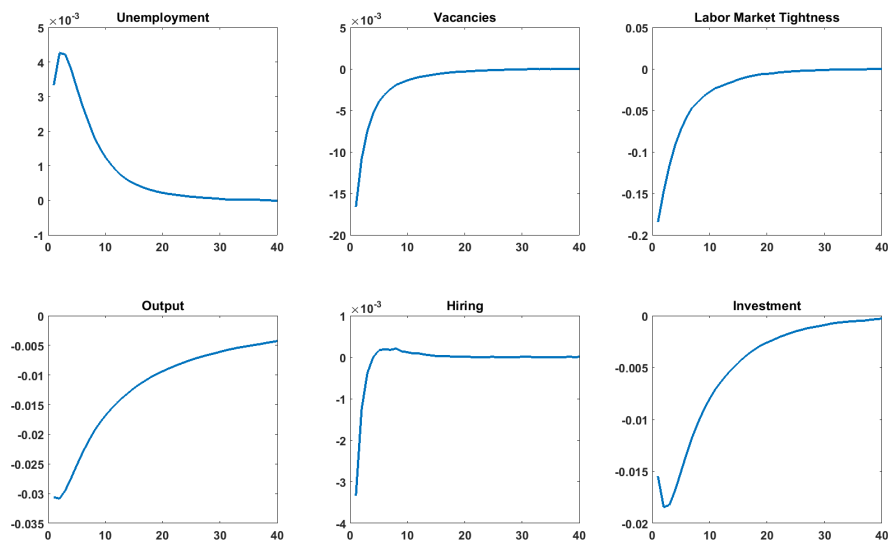


FIGURE 3. IMPULSE RESPONSE FUNCTIONS TO A POSITIVE TECHNOLOGY SHOCK

in the model.

Introducing wage rigidity by setting π to the calibrated value of 0.25 overlays the effect of financial frictions and the sluggish response of vacancies and labor market tightness. After a positive technology shock, the increase in the firm's marginal surplus from hiring is larger as wages remain closer to their previous level. This increases the incentive to post vacancies immediately. Thus, the impulse response functions in the model with financial frictions and wage rigidity are similar to the impulse response functions in standard search and matching models. An alternative way to generate the sluggish response of labor market variables is provided by Epstein (2012) who uses a heterogeneous agent framework in a search and matching model with endogenous search effort.

Since this article is mostly concerned with unemployment dynamics, the response of unemployment to technology shocks is important even if the model is not able to match the sluggish response of labor market tightness due to the more rapid adjustment of vacancies that is caused by rigid wages. After a negative technology shock, unemployment builds up and peaks around four months after the initial shock, which is in line with the findings in Stock and Watson (1999).

D. Unemployment Dynamics

The prior analysis has already shown that the presented model is able to match the delayed increase of unemployment after a negative technology shock. Additionally, the volatility of unemployment is larger than in standard search and

matching models, albeit still too low. In this section I turn to the asymmetric behavior of the unemployment rate documented in McKay and Reis (2008) and Barnichon (2010), for example. For U.S. data in the time period between 1964 and 2009, the skewness of the unemployment rate is about one.²⁷ This value suggests that increases in the unemployment rate are steeper than decreases.

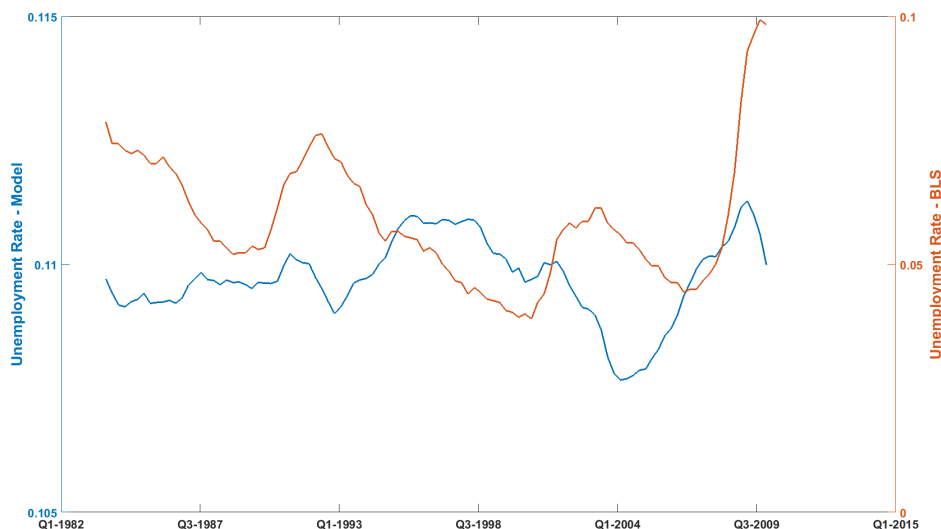


FIGURE 4. SIMULATED AND ACTUAL UNEMPLOYMENT SERIES - BENCHMARK MODEL

A standard search and matching model with symmetric shocks is unable to match that skewness. The unemployment series simulated with the benchmark model displays a skewness of 0.148 which is roughly one sixth of the value found in the data. I go one step further by simulating the benchmark model with technology shocks obtained with the method described in and the dataset provided by Jermann and Quadrini (2012). The authors use an extensive dataset in order to estimate technology and credit shocks for the time period between 1984:I and 2010:II.²⁸ The skewness of the actual unemployment rate in the U.S. was 0.82 between 1984 and 2009. The simulated skewness using the estimated shocks is -0.127. Additionally, the correlation between the simulated and the actual unemployment series in Figure 4 is nearly zero (0.029).²⁹

For the model with financial frictions and wage rigidity, the skewness of the sim-

²⁷The unemployment data is the quarterly average of the monthly series constructed by the Bureau of Labor Statistics from the Current Population Survey. This series is detrended by an HP filter with smoothing parameter 100.000.

²⁸The equations used in Jermann and Quadrini (2012) to estimate the shocks are very close to the equations presented here. Nevertheless, this analysis is only the first step. Future research aims at

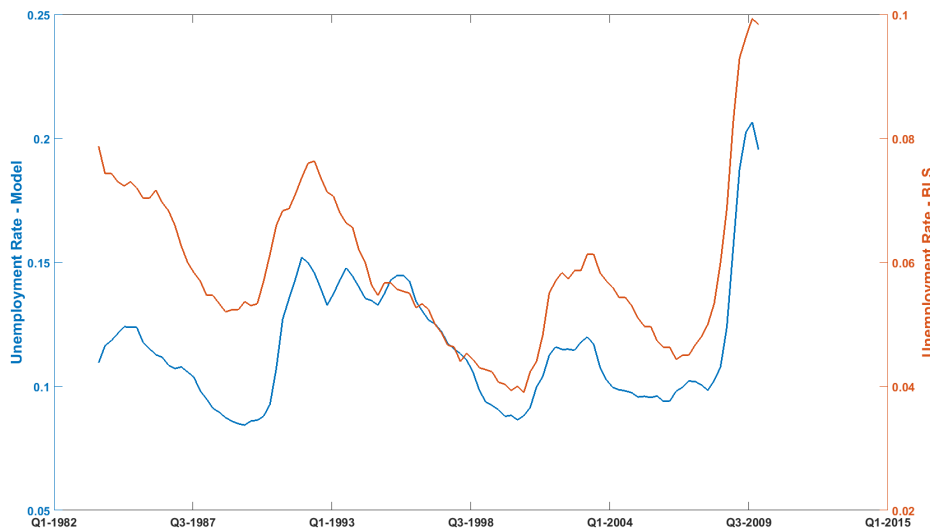


FIGURE 5. SIMULATED AND ACTUAL UNEMPLOYMENT SERIES - MODEL WITH FINANCIAL FRICTIONS AND WAGE RIGIDITY

ulated unemployment series is 0.54. Using the estimated technology and credit shocks gives a skewness of 1.58, which is even larger than for the actual unemployment series. The large discrepancy between the skewness in the simulated unemployment series and the simulated unemployment series using the estimated shocks might be due to the calibration of the credit shock. Since the shock process is calibrated using the estimates from Jerman and Quadrini (2012), they might not match the targeted time period perfectly.³⁰ In addition to the high skewness, the simulated unemployment series in Figure 5 is also strongly correlated with its empirical counterpart, displaying a correlation coefficient of 0.76. In line with the data, simulated output displays next to no skewness (-0.096).

The model with financial frictions and wage rigidity is also able to match another business cycle fact about unemployment dynamics put forward by McKay and Reis (2008): employment and output coincide in troughs but employment lags output at peaks. Some evidence is given by the simulated time series of

estimating the shock processes using the model presented in Section III.

²⁹The different axis in Figure 3 are used since the model does not differentiate between workers that are unemployed and workers that are out of the labor force. Therefore, I target a higher unemployment rate than the average quarterly unemployment rate in the U.S. for the considered time period.

³⁰Jermann and Quadrini estimate the shocks for the time period between 1984 and 2009. In the calibration I target the time period between 1964 and 2009. Due to what is commonly known as the Great Moderation, the estimated shocks might be lower than they were in the period over 1967-1983. Increasing the size of the credit shock in the model also increases the skewness of the unemployment rate.

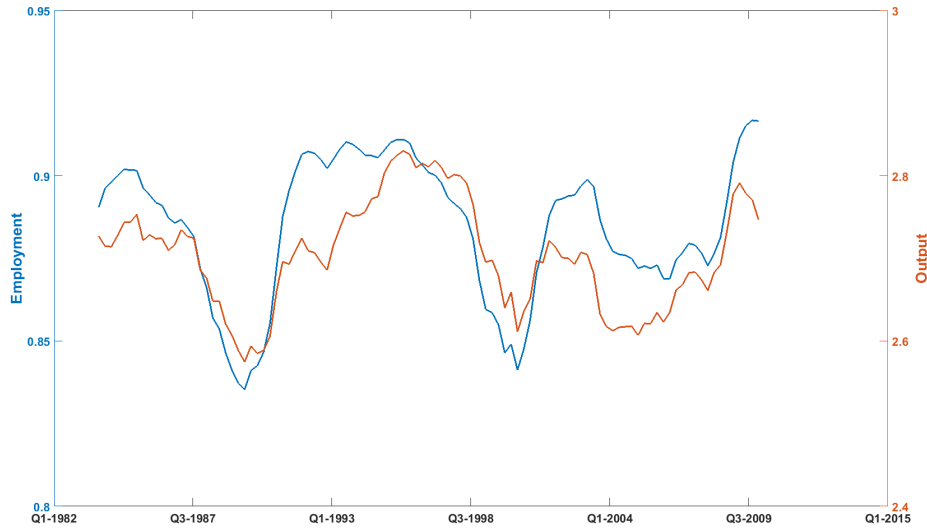


FIGURE 6. SIMULATED EMPLOYMENT AND OUTPUT - MODEL WITH FINANCIAL FRICTIONS AND WAGE RIGIDITY

output and employment in Figure 6, where the model is again simulated using the shocks estimated by Jerman and Quadrini (2012).³¹

The mechanism behind the results is intuitively simple and depends on both financial frictions and wage rigidity. With rigid wages the response of the unemployment rate to a negative technology shock increases as the firm's surplus reacts stronger to changes in technology. This implies steeper increases in the unemployment rate on impact than in models with flexible wages. With financial frictions, a positive technology shock tightens the credit constraint as it increases the working capital requirements. Thus, firms invest in the asset used as collateral in order to loosen the constraint and to profit from the high technology. The increase in employment is delayed and the decrease in unemployment is flatter than in standard search and matching models. Table 5 displays the skewness of the unemployment rate for different amounts of wage rigidity for the benchmark model and the model with financial frictions. Regardless of the size of the wage rigidity, the skewness is always at least twice as large in the model with financial frictions.

Another aspect is the volatility of the job-finding rate, which is according to Shimer (2012) the driving force behind unemployment dynamics. In the model

³¹The model presented here can basically account for the new business cycle facts documented by McKay and Reis (2008): contractions in employment are briefer and more violent than expansions, contractions and expansions in output are almost symmetric, and employment lags output in troughs but not at peaks.

TABLE 5—SKEWNESS OF THE SIMULATED UNEMPLOYMENT RATE

	Benchmark Model	With Financial Frictions
$\pi = 1$	0.148	0.398
$\pi = 0.5$	0.143	0.440
$\pi = 0.25$	0.167	0.540
$\pi = 0.1$	0.290	0.698

with financial frictions and wage rigidity, this volatility is equal to 0.118, which is very close to the empirical values of 0.118 in Barnichon (2010) and 0.116 in Shimer (2012). The volatility of the job-finding rate is only about 0.018 in the benchmark model.

E. Hiring Dynamics

A large body of literature has pointed out that while the hiring rate decreases in recessions, the number of hires does not. Blanchard and Diamond (1990), Fujita and Ramey (2006) and Elsby, Michaels and Solon (2009), among others, even document an increase in the number of hires in recessions. These dynamics are not present in standard search and matching models, as hires tend to follow production closely. This is also visible in the benchmark model. The simulated series for output and hires display a positive correlation of 0.61. Simulating the

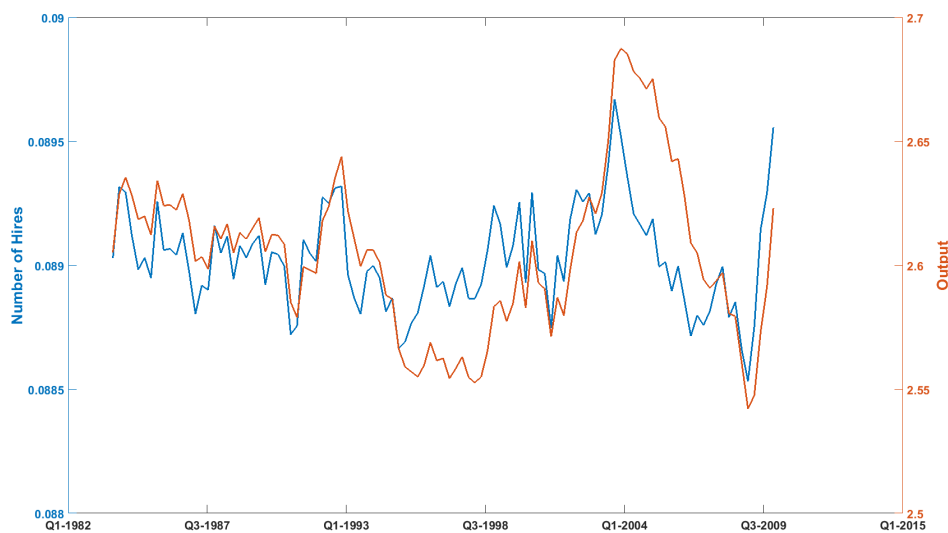


FIGURE 7. OUTPUT AND NUMBER OF HIRES - BENCHMARK MODEL

model using the estimated technology shocks described in the previous section gives the same impression. The time series of hires in Figure 7 follows output closely over the entire period. There is no evidence that the number of hires tends

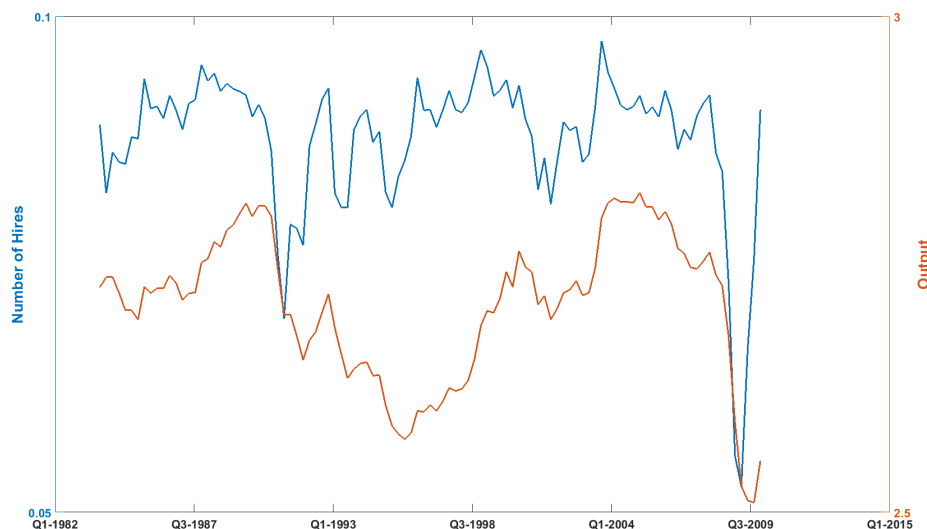


FIGURE 8. OUTPUT AND NUMBER OF HIRES - MODEL WITH FINANCIAL FRICTIONS AND WAGE RIGIDITY

to increase in recessions. The correlation of the two series is 0.65. In the U.S. the correlation between production and number of hires is 0.29 for the time period between 1967 and 2004 and 0.32 for the period between 1984 and 2004.³²

Most models trying to reconcile these hiring dynamics with search and matching models resort to models with endogenous separations. These models have no difficulty in creating a rising number of hires in recessions: Recessions are periods with high layoffs, which increase the pool of unemployed workers. This reduces the labor market tightness and therefore increases the job-finding rate. As a result, hiring is cheap in recessions. However, as a side effect, the correlation between hiring and production becomes negative. As Shimer (2012) states, any significant endogenous separations counterfactually tend to make the number of hires countercyclical.

For the model with financial frictions and wage rigidity, the correlation between output and hires is 0.27. Simulating the model using the estimated shock

³²For these values I use the correlation between the number of hires and the Industrial Production Index published by the Federal Reserve Bank. The number of hires is constructed using population data from the Current Population Survey and the unemployment-employment transition rate constructed by Shimer (2012). The time period is restricted since the transition rates are only available for the time period between 1967 and 2004.

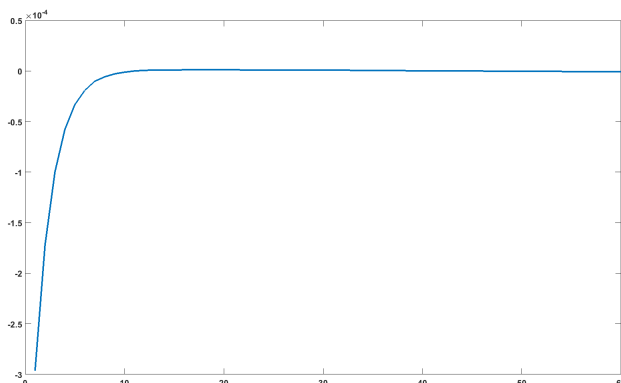


FIGURE 9. IMPULSE RESPONSE FUNCTION NUMBER OF HIRES - BENCHMARK MODEL

processes results in a correlation of 0.49. While these values are close to their empirical counterparts, the simulated series also display some evidence for an increasing number of hires in recessions. As the model contains only exogenous separations, the number of hires mechanically decreases after a negative shock. However, the large reduction on impact, which is amplified by wage rigidity, is followed by periods with increased numbers of hires. This is also evident in the impulse response functions.

In the benchmark model in Figure 9, the number of hires decreases on impact after a negative credit shock and monotonically reverts back to its steady state. By contrast, as can be seen in Figure 10, in the model with financial frictions, the decrease in hiring on impact is large enough to generate an increase in the number of hires for the subsequent periods, as the pool of unemployed workers increases by more after the shock.

F. Importance of Credit Shocks

Using a variance decomposition exercise, Garín (2015) argues that credit shocks explain over 70% of the volatility in the unemployment rate, over 80% of the volatility in vacancies and over 90% of the volatility in labor market tightness. The reason is that in his model the elasticity of wages with respect to productivity is higher than the elasticity of wages with respect to credit conditions. In particular, the elasticity with respect to productivity (0.86) is higher than its empirical counterpart (0.66).

I argue that ignoring wage rigidity might distort the analysis of the importance of credit shocks, as the mechanism behind the importance of credit shocks in Garín (2015) relies on the relatively high elasticity of wages with respect to technology shocks. Introducing wage rigidity decreases the elasticity of wages with respect to both technology and credit conditions. However, the difference between the

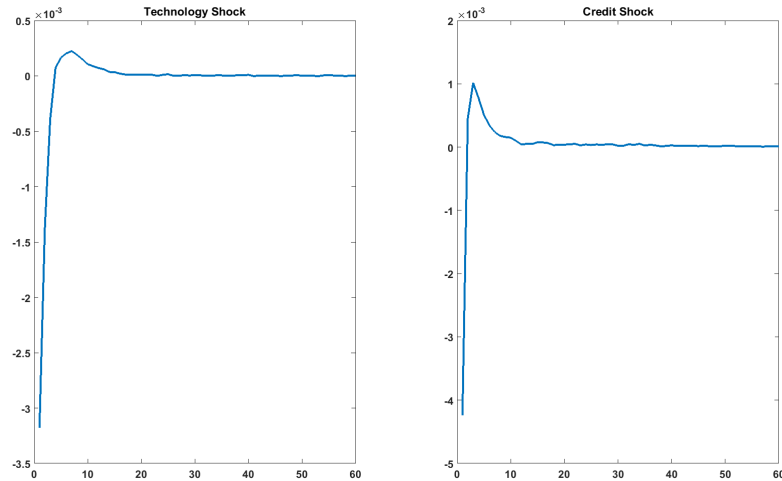


FIGURE 10. IMPULSE RESPONSE FUNCTION: NUMBER OF HIRES - MODEL WITH FINANCIAL FRICTIONS AND WAGE RIGIDITY

two elasticities becomes smaller the more rigid wages are.

Table 6 displays the volatilities of the key labor market variables unemployment, vacancies and labor market tightness for different specifications of the model with financial frictions and wage rigidity. I simulate the model using only technology and using only credit shocks for three different calibrations of wage rigidity.

TABLE 6—VOLATILITY OF LABOR MARKET VARIABLES

	TFP Shocks Only			Credit Shocks Only		
	$\pi = 1$	$\pi = 0.5$	$\pi = 0.25$	$\pi = 1$	$\pi = 0.5$	$\pi = 0.25$
u	0.030	0.038	0.063	0.045	0.047	0.049
v	0.044	0.069	0.114	0.114	0.118	0.121
θ	0.072	0.103	0.169	0.150	0.155	0.165

Comparing the results shows that the effect of wage rigidity is by far larger for the model with technology shocks: for all three considered variables the volatility increases by at least 100% from the specification without wage rigidity to the specification with $\pi = 0.25$. For the model with only credit shocks the volatilities also increase but by 9% at most. The reason is that Nash-bargained wages are already quite inelastic with respect to credit conditions. The analysis suggests that the importance of credit shocks for explaining the volatility of labor market variables decreases with wage rigidity.

VI. Policy Implications

Understanding unemployment dynamics might be a goal of its own, as the unemployment rate is one of the most important indicators for the economic condition of a country. Nonetheless, the presence of asymmetric unemployment dynamics in the search and matching model also has consequences for current discussions and policy implications.

The recessions and subsequent recoveries in 1991 and 2001 have sparked a debate about so called jobless recoveries in the U.S. The proposed reasons for this phenomenon are manifold. Meltzer (2003) argues for a downward bias in employment statistics, Bernanke (2003) proposes sluggish aggregate demand and Groshen and Potter (2003) increased speed of structural change.

The model presented in this paper features a slow increase of employment after positive technology shocks, as firms tend to prioritize investment into capital in order to relax the tighter borrowing constraint. At the beginning of a recovery period this could seem like joblessness, although it is just the normal recovery under binding borrowing constraints. This effect might even be strengthened by the low macroeconomic volatility following the Great Moderation.

VII. Conclusion

This paper explores how the combination of financial frictions and wage rigidity improves the performance of the search and matching model. Besides increasing the volatility of key labor market variables, the combination of the two frictions facilitates the replication of some important aspects of unemployment and hiring dynamics. These dynamics are not present in other search and matching models, which might seriously distort the analysis of unemployment and hiring in such models.

Simulating the complete model, I find that wage rigidity is responsible for the steeper increase in the unemployment rate after negative shocks, while credit constraints ensure that decreases after positive shocks are flatter. This generates a higher skewness in the unemployment rate. In contrast to standard search and matching models, the unemployment rate simulated with the model presented here is close to the actual unemployment rate. In addition, the model accounts for nearly 50% of the variation in unemployment, over 90% of the variation in vacancies and roughly 70% of the variation in labor market tightness.

I also show that ignoring wage rigidities can lead to an overestimation of the importance of credit shocks for explaining business cycle fluctuations in unemployment, vacancies and labor market tightness. The reason is that with Nash-bargained wages the elasticity of wages with respect to technology is way higher than the elasticity with respect to credit conditions.

While the explored mechanism provides an easy way to add important dynamics to search and matching models, it might also be beneficial for models with endogenous separations for a different reason. These models often have problems

recreating the highly negative correlation between unemployment and vacancies, e.g. the Beveridge Curve. After a negative technology shock the unemployment pool increases disproportionately due to the large inflow of separated workers. This decreases the labor market tightness and makes hiring in recessions cheap. Most models therefore resort to on-the-job search. In a model with endogenous separations and financial frictions, unemployment will also increase disproportionately after a negative credit shock. However, the incentive to post vacancies is reduced by a tightening of the borrowing constraint. It is an interesting task for further research to explore whether this mechanism is strong enough to generate a highly negative vacancy-unemployment correlation.

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Appendix

BENCHMARK MODEL

The model described in this section does neither feature financial constraints nor wage rigidity. It acts as a benchmark in the quantitative analysis in order to gauge the performance of the complete model with financial frictions and wage rigidity. The benchmark model is based on the model in the appendix to Garín (2015). The labor market and the household sector are unchanged by the introduction of financial frictions. Therefore, Subsections A. and B. from Section IV. also hold for this model.

A1. Firms

Under the same assumptions as in Section IV, the maximization problem of the firm can be expressed as

$$\mathbb{J}_t(\omega_t^e; \Omega_t) = \max_{\{d_t, h_t, i_t, k_{t+1}, b_{t+1}\}} d_t + \mathbb{E}_t \Lambda_{t|t+1}^c \mathbb{J}_{t+1}(\omega_{t+1}^e; \Omega_{t+1})$$

subject to the budget constraint

$$(A1) \quad z_t n_{c,t}^\alpha k_t^{1-\alpha} + \frac{b_{t+1}}{R_t} = d_t + b_t + w_t n_{c,t} + i_t + c \left(\frac{h_t}{q(\theta_t)} \right),$$

the law of motion for the capital stock

$$(A2) \quad k_{t+1} = (1 - \delta)k_t + \left[\frac{\delta \xi}{1 - \xi} \left(\frac{i_t}{k_t} \right)^{1-\xi} - \frac{\xi \delta}{(1 - \xi)} \right] k_t$$

and the law of motion for employment

$$(A3) \quad n_{c,t} = (1 - s)n_{c,t-1} + h_t.$$

Denoting the multipliers on the budget constraint, the law of motion for the capital stock and the law of motion for employment, with $\lambda_{1,t}$, $\lambda_{2,t}$ and $\lambda_{3,t}$ respectively, and taking derivatives results in the following first order conditions:

$$(A4) \quad \lambda_{1,t} = 1$$

$$(A5) \quad \lambda_{3,t} = \frac{c'(v_t)}{q(\theta_t)}$$

$$(A6) \quad \lambda_{2,t} = \frac{1}{\delta^\xi \left(\frac{i_t}{k_t}\right)^{-\xi}}$$

$$(A7) \quad \lambda_{2,t} = \mathbb{E}_t \Lambda_{t|t+1}^c \left\{ (1-\alpha) z_{t+1} n_{c,t+1}^\alpha k_{t+1}^{-\alpha} - \frac{i_{t+1}}{k_{t+1}} \right. \\ \left. + \lambda_{2,t+1} \left[(1-\delta) + \frac{\delta^\xi}{1-\xi} \left(\frac{i_t}{k_t}\right)^{1-\xi} - \frac{\xi\delta}{(1-\xi)} \right] \right\}$$

$$(A8) \quad \frac{1}{R_t} = \mathbb{E}_t \Lambda_{t|t+1}^c.$$

Under these specifications, the marginal value of an additional worker for the firm is given by

$$(A9) \quad \mathbb{J}_{n,t} = [\alpha z_t n_{c,t}^{\alpha-1} k_t^{1-\alpha} - w_t] + (1-s) \mathbb{E}_t \Lambda_{t|t+1}^c \mathbb{J}_{n,t+1}.$$

The first term is the net return of an additional worker in the firm. The second term is the discounted benefit of having an additional worker for the next period. Combining the marginal value with Equation A5 yields the job-creation condition

$$(A10) \quad \frac{c'(v_t)}{q(\theta_t)} = [\alpha z_t n_{c,t}^{\alpha-1} k_t^{1-\alpha} - w_t] + (1-s) \mathbb{E}_t \Lambda_{t|t+1}^c \frac{c'(v_{t+1})}{q(\theta_{t+1})}.$$

Again, the firm hires additional workers, until the marginal costs of hiring equal the marginal benefits. In contrast to the model in Section IV, the job creation condition does not depend on financial conditions.

A2. Wage Bargaining

Since the financial frictions introduced in Section IV only affect the firm side, the marginal value of the match for the household will be the same for the model with financial frictions. With both value functions defined, the wage that solves the bargaining problem can be expressed as

$$(A11) \quad w_t^* = \arg \max_{w_t} \mathbb{J}_{n,t}^{1-\phi} \mathbb{H}_{m,t}^\phi$$

where ϕ is a parameter that governs the bargaining power of the worker and the firm. Taking the first derivative results in the standard first-order condition

$$\phi \frac{\partial \mathbb{H}_{m,t}}{\partial w_t} \mathbb{J}_{n,t} + (1-\phi) \frac{\partial \mathbb{J}_{n,t}}{\partial w_t} \mathbb{H}_{m,t} = 0$$

that can be rewritten as

$$(A12) \quad \phi \mathbb{J}_{n,t} = (1 - \phi) \mathbb{H}_{m,t}.$$

As a next step, I define the total surplus of the match \mathbb{S}_t as the sum of the firm's and the worker's surplus. This results in

$$\begin{aligned} \mathbb{S}_t &= \alpha z_t n_{c,t}^{\alpha-1} k_t^{1-\alpha} - x - \frac{\varphi}{u'(c_t)} \\ &\quad + (1 - s) \mathbb{E}_t \{ \Lambda_{t+1|t}^c \mathbb{J}_{n,t+1} + \Lambda_{t+1|t}^h [1 - f(\theta_{t+1})] \mathbb{H}_{m,t+1} \} \end{aligned}$$

where I use that $\lambda_t = u'(c_t)$. Next I use Equation 18, $\mathbb{H}_{m,t} = \phi \mathbb{S}_t$ and $\mathbb{J}_{n,t} = (1 - \phi) \mathbb{S}_t$. Multiplying the total surplus with $(1 - \phi)$, using $\mathbb{J}_{n,t} = (1 - \phi) \mathbb{S}_t$, $\phi \mathbb{J}_{n,t} = (1 - \phi) \mathbb{H}_{m,t}$ and rearranging terms gives

$$(A13) \quad \begin{aligned} \mathbb{J}_{n,t} &= (1 - \phi) (\alpha z_t n_{c,t}^{\alpha-1} k_t^{1-\alpha}) - (1 - \phi) \left[x + \frac{\varphi}{u'(c_t)} \right] \\ &\quad + (1 - \phi) (1 - s) \mathbb{E}_t \{ \Lambda_{t+1|t}^c \mathbb{J}_{n,t+1} \} \\ &\quad + \phi (1 - s) \mathbb{E}_t \{ \Lambda_{t+1|t}^h [1 - f(\theta_{t+1})] \mathbb{J}_{n,t+1} \}. \end{aligned}$$

In the last step I replace $\mathbb{J}_{n,t}$ by the value function and use that $\mathbb{J}_{n,t+1} = \frac{c'(v_{t+1})}{q(\theta_{t+1})}$. Rearranging terms gives the wage equation

$$(A14) \quad \begin{aligned} w_t &= \phi \left[(\alpha z_t n_{c,t}^{\alpha-1} k_t^{1-\alpha}) + (1 - s) \mathbb{E}_t \left\{ \Lambda_{t+1|t}^c \frac{c'(v_{t+1})}{q(\theta_{t+1})} \right\} \right] \\ &\quad + (1 - \phi) \left[x + \frac{\varphi}{u'(c_t)} \right] \\ &\quad - \phi (1 - s) \mathbb{E}_t \left\{ \Lambda_{t+1|t}^h [1 - f(\theta_{t+1})] \frac{c'(v_{t+1})}{q(\theta_{t+1})} \right\}. \end{aligned}$$

A3. Equilibrium

With the model completely described, I define the equilibrium.

DEFINITION 2: *A recursive equilibrium is defined as a set of i) firm's policy functions $d(\omega^c; \Omega)$, $n_c(\omega^c; \Omega)$, $k(\omega^c; \Omega)$, $i(\omega^c; \Omega)$ and $v(\omega^c; \Omega)$; ii) household's policy functions $c(\omega^h; \Omega)$ and $n_h(\omega^h; \Omega)$; iii) a lump-sum tax $T(\Omega)$, iv) prices $w(\Omega)$ and $R(\Omega)$; and v) a law of motion for the aggregate states, $\Omega' = \Psi(\Omega)$, such that: i) firms' policies satisfy the firms' first order conditions (Equations A4 - A8) and the job-creation condition (Equation A10); ii) household's policy function satisfies the household's first order condition (Equation 5), iii) the wage is determined by Equation A14; labor demand by the firms is equal to labor supply by the households, $n_c(\omega^c; \Omega) = n_h(\omega^h; \Omega)$; v) the law of motion $\Psi(\Omega)$ is consistent*

with individual decisions and with the stochastic process for technology z , and vi) the government has a balanced budget so that $x(1 - n) = T$.

This definition is similar to Definition 2 in Garín (2015). The complete set of equations used to simulate the model is also given in the appendix.

PROOF OF CLAIM 1

PROOF:

First notice, that wages are privately efficient if neither firms nor workers have any incentive to separate as long as there are positive bilateral gains from the match.

The first part of the proof is relatively simple. For the household side private efficiency implies that the marginal value of an additional matched worker has to be positive:

$$\mathbb{H}_{m,t} = -\frac{\varphi}{\lambda_t} + w_t - x + (1 - s)\mathbb{E}_t\Lambda_{t+1}^h[1 - f(\theta_{t+1})]\mathbb{H}_{m,t+1} \geq 0.$$

This equation can be rearranged to give

$$w_t + (1 - s)\mathbb{E}_t\Lambda_{t+1}^h[1 - f(\theta_{t+1})]\mathbb{H}_{m,t+1} \geq x + \frac{\varphi}{\lambda_t}.$$

The household has no incentive to have the last worker separated from the match if the wage plus the continuation value of the match is larger than unemployment benefits plus the utility value of leisure. Since I focus only on symmetric equilibria, all firms pay equal wages and no worker has an incentive to switch firms.

For the second part of the proof, let the marginal revenue of an additional worker be defined by

$$\hat{v}_t \equiv \alpha z_t [(1 - s)n_{c,t-1}]^{\alpha-1} k_t^{1-\alpha} (1 - \lambda_{4,t})$$

which is the highest marginal product the firm can receive in a given period without laying off workers. Assume that there exist marginal costs $\hat{v}_t^H > \hat{v}_t^L$ such that

- (i) if $\hat{v}_t < \hat{v}_t^L$, the firm lays off workers³³;
- (ii) if $\hat{v}_t \in [\hat{v}_t^L, \hat{v}_t^H]$, the firm freezes hiring;
- (iii) if $\hat{v}_t > \hat{v}_t^H$, the firm hires workers.

Now define as L_t the value function of the firm accounting for the possibility of layoffs. This function is given by

$$L_t = \max_{\{d_t, h_t, i_t, k_{t+1}, b_{t+1}\}} d_t + \mathbb{E}_t \Lambda_{t|t+j}^c \mathbb{J}_{t+1}(\omega_{t+1}^e; \Omega_{t+1})$$

³³Here I allow for $h_t < 0$.

subject to

$$\begin{aligned} z_t n_{c,t}^\alpha k_t^{1-\alpha} + \frac{b_{t+1}}{R_t} &= d_t + b_t + w_t n_{c,t} + i_t \\ &+ \mathbb{1}\{n_{c,t} > (1-s)n_{c,t-1}\} c \left(\frac{h_t}{q(\theta_t)} \right) [n_{c,t} - (1-s)n_{c,t-1}], \\ k_{t+1} &= (1-\delta)k_t + \left[\frac{\delta^\xi}{1-\xi} \left(\frac{i_t}{k_t} \right)^{1-\xi} - \frac{\xi\delta}{(1-\xi)} \right] k_t, \\ n_{c,t} &= (1-s)n_{c,t-1} + h_t \end{aligned}$$

and

$$d_t + w_t n_{c,t} + \mathbb{1}\{n_{c,t} > (1-s)n_{c,t-1}\} c \left(\frac{h_t}{q(\theta_t)} \right) [n_{c,t} - (1-s)n_{c,t-1}] + i_t + b_t \leq \eta_t q_{k,t} k_t,$$

where $\mathbb{1}\{n_{c,t} > (1-s)n_{c,t-1}\}$ is the indicator function that is equal to one if and only if the firm hires workers and equal to zero otherwise. The marginal costs \hat{v}_t^H and \hat{v}_t^L are defined as follows:

$$\hat{v}_t^L = w_t - \Lambda_{t|t+j}^c \mathbb{E}_t \left[\frac{\partial L_{t+1}}{\partial n_t} \right]$$

and

$$\hat{v}_t^H = w_t + \frac{c'(v_t)}{q(\theta_t)} - \Lambda_{t|t+j}^c \mathbb{E}_t \left[\frac{\partial L_{t+1}}{\partial n_t} \right],$$

where L_{t+1} is the value function of the firm as seen from period $t+1$. \hat{v}_t^L are the lowest marginal costs a firm can achieve by keeping its workforce, while $\hat{v}_t^H \geq \hat{v}_t^L$ are the lowest marginal costs a firm can achieve by hiring an infinitesimal amount of workers. Now let \mathcal{F} be the σ -algebra generated by future realizations of the stochastic process z , taking as given the information set at time t . \mathcal{F} can be partitioned in

$$\mathcal{F} = \mathcal{F}^+ \cup \mathcal{F}^- \cup_{h=1}^{+\infty} \mathcal{F}^h$$

where \mathcal{F}^+ is the subset of all future realizations of z such that the firm is hiring next period, \mathcal{F}^- is the subset such that there are layoffs and \mathcal{F}^h is the subset such that there is a hiring freeze for the next h periods. Let $p^+ = \mathbb{P}(\mathcal{F}^+)$, $p^- = \mathbb{P}(\mathcal{F}^-)$ and $p^h = \mathbb{P}(\mathcal{F}^h)$ be the measures of these subsets, then it holds that

$$\mathbb{E}_t \left[\frac{\partial L_{t+1}}{\partial n_t} \right] = p^+ \mathbb{E}_t \left[\frac{\partial L_{t+1}}{\partial n_t} | \mathcal{F}^+ \right] + p^- \mathbb{E}_t \left[\frac{\partial L_{t+1}}{\partial n_t} | \mathcal{F}^- \right] + \sum_{h=1}^{+\infty} p^h \mathbb{E}_t \left[\frac{\partial L_{t+1}}{\partial n_t} | \mathcal{F}^h \right].$$

Using the value function, it can be shown that

$$\mathbb{E}_t \left[\frac{\partial L_{t+1}}{\partial n_t} | \mathcal{F}^+ \right] = (1-s) \mathbb{E}_t \left[\frac{c'(v_t)}{q(\theta_t)} | \mathcal{F}^+ \right],$$

$$\mathbb{E}_t \left[\frac{\partial L_{t+1}}{\partial n_t} | \mathcal{F}^- \right] = 0$$

and

$$\mathbb{E}_t \left[\frac{\partial L_{t+1}}{\partial n_t} | \mathcal{F}^h \right] = \mathbb{E}_t \left[\sum_{j=t+1}^{t+h} \Lambda_{0|j-(t+1)}^c (1-s)^{j-t} \right. \\ \left. \left\{ \alpha z_j [(1-s)^{j-t} n_{c,t}]^{\alpha-1} k_j^{1-\alpha} (1-\lambda_{4,j}) - w_j \right\} \right. \\ \left. + \Lambda_{0|h}^c (1-s)^{h+1} \frac{c'(v_{t+h+1})}{q(\theta_{t+h+1})} | \mathcal{F}^+ \right].$$

Next, note that in a symmetric environment hiring freezes occur with a probability of zero. As the environment is symmetric, if one firm decides to freeze hiring, all firms will do so. However, when all firms freeze hiring, θ is equal to zero, as there are no vacancies. This implies that $\frac{c'(v_t)}{q(\theta_t)} = 0$ and thus $v_t^L = v_t^H$. Hiring freezes are ruled out. We already know that a necessary and sufficient condition to avoid layoffs is $\hat{v}_t \geq v_t^L$. Now since $p^h = 0$ and $\mathbb{E}_t \left[\frac{\partial L_{t+1}}{\partial n_t} | \mathcal{F}^- \right] = 0$ it holds that

$$\mathbb{E}_t \left[\frac{\partial L_{t+1}}{\partial n_t} \right] = p^+ \mathbb{E}_t \left[\frac{\partial L_{t+1}}{\partial n_t} | \mathcal{F}^+ \right] = (1-s) \mathbb{E}_t \left[\frac{c'(v_{t+1})}{q(\theta_{t+1})} \right].$$

Using this equation, a necessary and sufficient condition to avoid layoffs is

$$x + \frac{\varphi}{u'(c_t)} - (1-s) \mathbb{E}_t \Lambda_{t+1|t}^h [1 - f(\theta_{t+1})] \mathbb{H}_{m,t+1} \\ \leq w_t \leq \alpha z_t [(1-s) n_{c,t-1}]^{\alpha-1} k_t^{1-\alpha} (1-\lambda_{4,t}) \\ + (1-s) \mathbb{E}_t \Lambda_{t+1|t}^h \frac{c'(v_{t+1})}{q(\theta_{t+1})}.$$

which is equal to the equation in Claim 1.

DYNARE EQUATIONS FOR THE BENCHMARK MODEL

$$c + a/R + T = w * n + a(-1) + (1-n) * x$$

$$T = (1-n) * x$$

$$1/R = \text{beta}_c * (c/c(+1))$$

$$\begin{aligned} w = & (\text{phi} * (\text{alpha} * z * (n^{(\text{alpha}-1)}) * (k(-1)^{(1-\text{alpha})}) + (1 - s) * (\text{beta}_c * (d/d(+1))^{\text{sigma}}) \\ & * ((\text{kappa}) * \text{chi} * ((h/(\text{mu} * \text{theta}(+1)^{(-\text{eta})}))^{(\text{chi}-1)}) * (1/(\text{mu} * \text{theta}(+1)^{(-\text{eta})})))) \\ & + (1 - \text{phi}) * (\text{psi} * c + x) - \text{phi} * (1 - s) * \text{beta}_h * (c/c(+1)) * (1 - \text{mu} * \text{theta}(+1)^{(1-\text{eta})}) \\ & * ((\text{kappa}) * \text{chi} * ((h/(\text{mu} * \text{theta}(+1)^{(-\text{eta})}))^{(\text{chi}-1)}) * (1/(\text{mu} * \text{theta}(+1)^{(-\text{eta})})))) * \text{pi} \\ & + w(-1) * (1 - \text{pi}) \end{aligned}$$

$$n = (1 - s) * n(-1) + h$$

$$u = 1 - n$$

$$h/u = \text{mu} * \text{theta}^{(1-\text{eta})}$$

$$f = h/u$$

$$y = d + w * n + i + \text{kappa} * (h/(\text{mu} * \text{theta}^{(-\text{eta})}))^{\text{chi}}$$

$$\ln(z) = \text{rho}_z * \ln(z(-1)) + e_z$$

$$y = z * (n^{\text{alpha}}) * (k(-1)^{(1-\text{alpha})})$$

$$\begin{aligned} k = & (1 - \text{delta}) * k(-1) + ((\text{delta}^\text{epsilon} * \text{epsilon}) / (1 - \text{epsilon})) * ((i/k(-1))^{(1 - \text{epsilon})}) \\ & - ((\text{epsilon} * \text{delta}) / (1 - \text{epsilon})) * k(-1) \end{aligned}$$

$$1/R = \text{beta}_c * ((d/d(+1))^{\text{sigma}}) * (1/(\text{lambda}_1))$$

$$\text{lambda}_1 = 1$$

$$\text{lambda}_2 = 1/((\text{delta} * (k(-1)/i))^{\text{epsilon}})$$

$$\begin{aligned} \lambda_2 = & (\beta_c * (d/d(+1))^{\sigma}) * ((1 - \alpha) * z(+1) * (n(+1)^{\alpha}) * (k^{(-\alpha)}) \\ & * (\lambda_c(+1)) - (i(+1)/k) + \lambda_k(+1) * (1 - \delta + (((\delta^{\epsilon}) \\ & / (1 - \epsilon)) * ((i(+1)/k)^{(1-\epsilon)} - ((\epsilon * \delta)/(1 - \epsilon)))))) \end{aligned}$$

$$\lambda_3 = ((\kappa) * \chi * ((h/(\mu * \theta^{(-\eta)}))^{\chi-1}) * (1/(\mu * \theta^{(-\eta)})))$$

$$\begin{aligned} \lambda_3 = & z * \alpha * (n^{(\alpha-1)}) * (k(-1)^{(1-\alpha)}) * (\lambda_1) \\ & - w + (1 - s) * (\beta_c * (d/d(+1))^{\sigma}) * \lambda_3(+1) \end{aligned}$$

DYNARE EQUATIONS FOR THE MODEL WITH FINANCIAL FRICTIONS AND WAGE RIGIDITY

$$c + a/R + T = w * n + a(-1) + (1 - n) * x$$

$$T = (1 - n) * x$$

$$1/R = \beta_h * (c/c(+1))$$

$$\begin{aligned} w = & (\phi * (\alpha * z * (n^{(\alpha-1)}) * (k(-1)^{(1-\alpha)}) * (1 - \lambda_4) + (1 - s) \\ & * (\beta_c * (d/d(+1))^{\sigma}) * ((\kappa) * \chi * ((h/(\mu * \theta(+1)^{(-\eta)}))^{\chi-1}) \\ & * (1/(\mu * \theta(+1)^{(-\eta)})))) + (1 - \phi) * (\psi * c + x) - \phi * (1 - s) * \beta_h \\ & * (c/c(+1)) * (1 - \mu * \theta(+1)^{(1-\eta)}) * ((\kappa) * \chi * ((h/(\mu * \theta(+1)^{(-\eta)}))^{\chi-1}) \\ & * (1/(\mu * \theta(+1)^{(-\eta)}))) * \pi + w(-1) * (1 - \pi) \end{aligned}$$

$$n = (1 - s)n(-1) + h$$

$$u = 1 - n$$

$$h/u = \mu * \theta^{(1-\eta)}$$

$$f = h/u$$

$$l = -b/R + d + w * n + i + b(-1) + (kappa * (h/(mu * theta^{(-eta)}))^{chi})$$

$$\ln(x) = (1 - rho_x) * \ln(x_{bar}) + rho_x * \ln(x(-1)) + e_x$$

$$l + b/R = x * q * k(-1)$$

$$y = z * (n^{alpha}) * (k(-1)^{(1-alpha)})$$

$$\ln(z) = rho_z * \ln(z(-1)) + e_z$$

$$k = (1 - delta) * k(-1) + (((delta^{epsilon})/(1 - epsilon)) * ((i/k(-1))^{(1-epsilon)})) - ((epsilon * delta)/(1 - epsilon)) * k(-1)$$

$$y + b/R = d + w * n + i + b(-1) + kappa * (h/(mu * theta^{(-eta)}))^{chi}$$

$$lambda_1 = 1 - lambda_4$$

$$1/R = beta_c * ((d/d(+1))^{sigma}) * (1/(1 - lambda_4))$$

$$lambda_2 = 1/((delta * (k(-1)/i)^{epsilon})$$

$$q = lambda_2/lambda_1$$

$$\begin{aligned} lambda_2 = & (beta_c * (d/d(+1))^{sigma}) * ((1 - alpha) * z(+1) * (n(+1)^{alpha}) * (k^{(-alpha)}) \\ & * (1 - lambda_4(+1)) - (i(+1)/k) + lambda_2(+1) * (1 - delta + (((delta^{epsilon}) \\ & / (1 - epsilon)) * ((i(+1)/k)^{(1-epsilon)})) - ((epsilon * delta)/(1 - epsilon)))) \\ & + (beta_c * (d/d(+1))^{sigma}) * lambda_4(+1) * x(+1) * q(+1) \end{aligned}$$

$$lambda_3 = ((kappa) * chi * ((h/(mu * theta^{(-eta)}))^{(chi-1)}) * (1/(mu * theta^{(-eta)})))$$

$$\begin{aligned} \lambda_3 &= z * \alpha * (n^{(\alpha-1)}) * (k(-1)^{(1-\alpha)}) * (1 - \lambda_4) \\ &\quad - w + (1 - s) * (\beta_c * (d/d(+1))^{\sigma}) * \lambda_4(+1) \end{aligned}$$

$$a = b$$

FURTHER BUSINESS CYCLE STATISTICS

In this section, I evaluate the business cycle statistics for the benchmark model with wage rigidity and the model with financial frictions but without wage rigidity. This is a robustness exercise to emphasize the importance of the interaction between wage rigidity and financial frictions, not only for explaining unemployment and hiring dynamics, but also for explaining business cycle statistics. I strengthen this point by showing that neither the introduction of wage rigidity into the benchmark model nor the absence of wage rigidity from the model with financial frictions is able to capture the statistics as well as the model with financial frictions and wage rigidity described in Section IV. Without wage rigid-

TABLE E1—SIMULATED MOMENTS WITH FINANCIAL FRICTIONS AND $\pi = 0$

	u	v	θ	w	y	z
Standard deviation	0.053 (0.009)	0.120 (0.011)	0.163 (0.016)	0.016 (0.002)	0.018 (0.004)	0.015 (0.003)
Autocorrelation	0.765 (0.057)	0.272 (0.081)	0.423 (0.086)	0.809 (0.071)	0.829 (0.069)	0.795 (0.075)
Correlation	1	-0.775 (0.016)	-0.879 (0.013)	-0.512 (0.184)	-0.662 (0.134)	-0.469 (0.194)
	—	1	0.979 (0.002)	0.395 (0.114)	0.492 (0.090)	0.375 (0.125)
	—	—	1	0.456 (0.138)	0.571 (0.105)	0.425 (0.150)
	—	—	—	1	0.978 (0.015)	0.968 (0.014)
	—	—	—	—	1	0.955 (0.019)
	—	—	—	—	—	1

Note: Results from simulating the model with stochastic technology with a second-order perturbation method. All variables are reported in log as deviations from an HP trend with smoothing parameter 10^5 . Simulated standard errors (standard deviations across 30 simulations) are reported in parentheses.

ity, the volatility of the key labor market variables drops sharply: the volatility of unemployment decreases by 36%, the volatility of vacancies by 30% and the volatility of labor market tightness by 42%. The correlations between the wage

and the key labor market variables increase. The autocorrelation of the selected variables is even lower than in the version with wage rigidity. The response of unemployment, vacancies and labor market tightness to a 1% percent decrease in technology is lower: unemployment increases by 1.7%, vacancies decrease by 3% and labor market tightness decreases by 4.6%.

TABLE E2—SIMULATED MOMENTS BENCHMARK MODEL WITH WAGE RIGIDITY = 0.25

	u	v	θ	w	y	z
Standard deviation	0.012 (0.002)	0.024 (0.002)	0.036 (0.004)	0.011 (0.003)	0.017 (0.003)	0.015 (0.003)
Autocorrelation	0.873 (0.035)	0.575 (0.086)	0.694 (0.075)	0.944 (0.026)	0.819 (0.066)	0.798 (0.070)
Correlation	1	-0.824 (0.022)	-0.922 (0.014)	-0.792 (0.025)	-0.950 (0.010)	-0.966 (0.007)
	—	1	0.978 (0.001)	0.472 (0.043)	0.824 (0.016)	0.872 (0.009)
	—	—	1	0.609 (0.039)	0.906 (0.014)	0.944 (0.007)
	—	—	—	1	0.885 (0.031)	0.832 (0.034)
	—	—	—	—	1	0.992 (0.003)
	—	—	—	—	—	1

Note: Results from simulating the model with stochastic technology with a second-order perturbation method. All variables are reported in log as deviations from an HP trend with smoothing parameter 10^5 . Simulated standard errors (standard deviations across 30 simulations) are reported in parentheses.

For the benchmark model, the introduction of wage rigidity increases the volatility of unemployment by 20%, the volatility of vacancies by 71% and the volatility of labor market tightness by 64%. Despite the large relative increases, the absolute values remain small. Even with larger wage rigidity than in the model with financial frictions, the benchmark model does not generate enough amplification of technology shocks in order to match the empirical volatility of the key labor market variables.