# Financial Risk and Unemployment*

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**Abstract**
There is a strong correlation between the corporate interest rate (BAA rated), and its spread relative to Treasuries, and the unemployment rate. We model how interest rates and potential default rates impact equilibrium unemployment in a Diamond-Mortesen-Pissarides model. We calibrate the model using US data without targeting business cycle statistics. Volatility in the corporate interest rate can explain about 80% of the volatility of unemployment, vacancies, and market tightness. Simulating the Great Recession shows the model can account for much of the rise in unemployment. Without Fed action, unemployment would have been 6% higher.

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# 1 Introduction

There is a strong correlation between the corporate interest rate (BAA rates), and its spread, as defined by the difference in yields on BAA grade corporate bonds and US Treasury bonds, and the unemployment rate, as seen in Figure 1.[1] BAA interest rates rise during recessions, even as Treasury rates and the Federal Funds rate decline, reflecting a countercyclical interest rate spread, as defined above. Figure 1 documents these facts in the US in the years 1982-2012.[2] Running a bivariate VAR, we cannot reject the hypothesis that either the interest rate or spread Granger-cause unemployment fluctuations.[3]

We analyze these facts by adding capital to the classic Search and Matching model, as in Diamond (1982), Mortensen (1982), and Pissarides (1985) (DMP), where we add capital. This allows us to quantify the mechanisms through which corporate interest rates and potential default affect equilibrium unemployment.

There are two shocks in our economy: default (bankruptcy) and financial intermediation risk. The financial intermediation shock represents monitoring costs, intermediation costs, or any other shock besides default that would affect the interest rate perceived by firms.[4] Interest rates affect firms profits both directly by influencing capital costs and indirectly by influencing wages. Firms discount the future at a rate that includes both the standard discount rate and potential default, as firm owners are assumed to lose control of matches upon default. There are no changes in the worker's problem relative to the standard DMP literature.

We solve for the general equilibrium of the model with capital in fixed proportions, Nash bargaining to determine wages, and free entry to determine vacancies.[5] In the model, shocks di-

[1] BAA is a credit rating of the risk of default. 75% of US firms are rated BAA or lower, so we use this rating as a basis for exploration. For the US treasury we use 5-Year Constant Maturity Rate. Gilchrist and Zakrajsek (2012) calculate a representative interest rate for US businesses that turns out to be almost exactly the same to the BAA interest rate with a correlation of 0.97 over the period of our sample. For the purposes of this paper, we will frequently refer to the corporate interest rate as the interest rate, and the corporate interest rate spread as the spread.

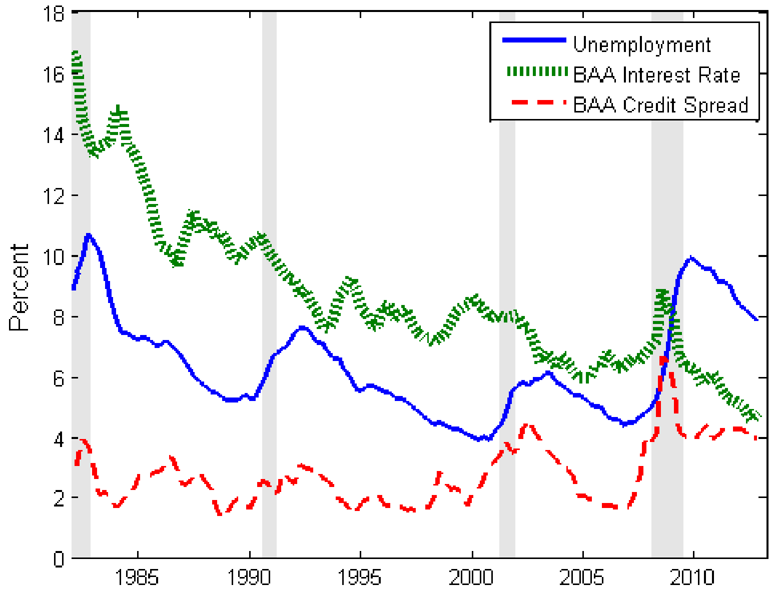
[2] We choose this time period as Gali and van Rens (2014) claim that during this time, labor productivity became less procyclical, opening the door for other mechanisms to be explored. For the sake of simplicity, we use the nominal BAA interest rate in this figure. Later in the paper we discuss sensitivity of our results to various definitions of inflation.

[3] For the Granger causality test, we lag unemployment by 2 quarters behind both the interest rate and the spread. Accordingly, we use lags of 2 quarters throughout this paper.

[4] It is well known that not all of the interest rate spread can be accounted for by default, such as shown in Elton (2001). Our inclusion of the intermediation cost shock allows us to accurately measure default risk while matching corporate interest rates.

[5] The assumption of fixed proportions of capital to labor requires justification, which we defer to Section 2.1. Robustness analysis in Section 5.2 show quantitatively that this assumption is not critical. We then elaborate to show how this assumption fits the data better than a Cobb-Douglas production function.

Figure 1: US time-series data




*Notes:* Data period: 1982Q1-2012Q4. The figure depicts the following quarterly US trends: Civilian Unemployment Rate measured by the BLS; BAA Interest rate based on Moody's Seasoned BAA Corporate Bond Yield; Credit Spread equal to the difference between Moody's Seasoned BAA Corporate Bond Yield and 5-Year Treasury Constant Maturity Rate. The shaded vertical bars represent the NBER-dated recessions.

rectly impact the interest rate and the default rate that firms experience, and indirectly affect wages through bargaining. In order to focus our quantitative analysis of the model on the effects of financial shocks that affect the interest rate and the default, we analyze the model without productivity shocks.

The model features three mechanisms by which higher corporate interest rates and default can generate unemployment in the context of the DMP model.[6] The first channel is what we call the

[6]There is some DMP literature that uses financial conditions along with productivity shocks. Wasmer and Weil (2004) add a search dimension for locating capital while Petrosky-Nadeau and Wasmer (2013) quantify these effects. Petrosky-Nadeau (2014) amplifies productivity shocks with an endogenous financial constraints that depend on the productivity shock. Similarly, Chugh (2013) finds that financial shocks add quantitative power to productivity shocks. Boeri, Garibaldi, and Moen (2014) propose an innovative model with both productivity and financial shocks, and calibrate their model to replicate firm leverage ratios. In their paper, financial shocks are calibrated to the frequency and depth of financial crises. We differ from this literature in three ways. First, we study mechanisms not discussed in this literature. Second, we use BAA interest rates as our measure for financial shocks, giving us the advantage of being able to take financial shocks directly from the data. Finally, we abstract entirely from productivity shocks. Accordingly, this is not a paper on the 'Shimer Puzzle', as that literature is about whether or not the DMP model with productivity shocks can generate realistic volatility.

flow profit channel. If interest rates rise for firms then profits per worker will be reduced as the capital the worker uses becomes more expensive. Thus the incentive to post vacancies declines, and unemployment rises.[7] The second we call the vacancy cost channel. If firms need to have working capital in order to post a vacancy, such as space and a computer ready for the worker, then a rise in interest rates directly increases the costs of vacancies leading to higher unemployment.[8] The third channel is the ownership channel. Bankruptcy results in the owners of the firm losing their status as the claimants on any future profits. As bankruptcy rates increase, the owners expect fewer future profits, and thus post fewer vacancies, which leads to rising unemployment.[9] Notice that the first two channels rely simply on the costs of borrowing for firms rising, while the third mechanism depends on default rates.

Next, we analyze our results analytically by deriving the elasticity of labor market tightness with respect to each of the three channels in our model. In a recent paper Ljungqvist and Sargent (2014) provide an excellent description of how different versions of the DMP model generate large volatility from a small productivity shock through creating small surplus in the match between the worker and the firm.[10] We use our analysis to distinguish our model from that literature by showing that our model does not depend on that channel. Instead, the magnitude of the shock we feed into the model explains why our model is able to quantitatively account for the data, while a similarly calibrated version of the DMP model with productivity shocks cannot. At the same time we show that the ownership channel is small, and thus abstract from it in our quantitative analysis.

We calibrate the model to US data to match vacancy costs, average job finding rates, and average labor market tightness. We do not target any business cycle statistics. Focusing on the other two channels, the model is able to produce quantitatively significant business cycle fluctuations that are in line with the data, generating about 80% of the observed volatility. Slightly more than

[7] Ippolito, Ozdagli, and Perez (2013) study how monetary policy shocks affect firm profits through devaluing their debt payments. This is similar to our flow profit mechanism discussed here. We differ in studying unemployment dynamics, however the spirit of their exercise, being the importance of policy set by the Federal Reserve, can be seen in Section 5.3.

[8] Working capital is important in a number of papers, such as Bigio (forthcoming) and Jermann and Quadrini (2012). The use of working capital in order to make financial shocks important in a quantitative model is common in the literature, such as in Christiano, Eichenbaum, and Trabandt (2014).

[9] Yashiv (2006) and Hall (2014) both study the effects of discount factor shocks, which is similar in spirit to our ownership channel.

[10] Shimer (2005) launched a literature on if/how the DMP model could be made consistent with the empirical realities of unemployment volatility given low volatility in productivity. This literature is too vast to provide a complete summary for. In addition to those papers cited previously, see Hall (2005), Hall and Milgrom (2008), Gertler and Trigari (2009), and Pissarides (2009). Cooper, Haltiwanger, and Willis (2007) show that modeling firm-level shocks under the assumption of non-convexities adds to volatility.

half of the volatility comes from the flow profit channel, while the rest comes from the vacancy cost channel. Our analysis suggests that these mechanisms do not interact. That is, the volatility generated by each mechanism independently adds up to the total created by the model.

We perform a series of robustness analyses on our quantitative exercise: with respect to important parameters often discussed in the literature, specifically the flow utility of unemployment, worker's bargaining power, and capital depreciation rates; by using various definitions of inflation; and by testing the importance of the assumption of fixed proportions of capital. The robustness analysis indicates that financial intermediation shocks explain between 50% to 100% of the cyclical variation in unemployment, vacancies, and tightness.

Taking the data to the Great Recession, we show that the model is able to explain about half of the rise in unemployment experienced at the beginning of the Great Recession, and that had the Federal Reserve not engaged in massive interventions lowering the Federal Funds Rate, unemployment rates would have been 6 percentage points higher than they were in reality. [11]

The most common force used in the literature to study business cycle fluctuations is productivity. We note that the correlation between unemployment and the interest rate and its spread are similar in magnitude to that of unemployment and productivity.[12] While we abstract from productivity shocks, it is possible with our world view that productivity shocks are an underlying cause of financial shocks. We are simply not taking a stand on the transmission mechanism from productivity to financial shocks, and instead focus on the financial shocks exclusively. An alternative interpretation of the underlying shock could be that uncertainty shocks, as in Christiano, Motto, and Rostagno (2014), are the driving force for financial shocks. In Appendix A we show how an uncertainty shock can generate interest rate shocks endogenously, allowing uncertainty to be a possible underlying cause of our financial shocks.[13]

We proceed as follows. In Section 2 we describe the model. In Section 3 we describe the equilibrium and the solution and then perform an analytic exercise to compare our results to those of the literature. We discuss the calibration strategy in Section 4. Section 5 studies the business

[11] Christiano, Eichenbaum, and Trabandt (2014) have an ambitious agenda of incorporating a New Keynesian model with elements of a search model of the labor market in order to explain the Great Recession. Their paper attempts to quantitatively breakdown which shocks were the most important for the Great Recession. They find that their financial wedge shock is the most important for determining economic activity in the Great Recession. This shock is equivalent to our financial intermediation shock, and they provide a very similar interpretation of what this shock is in reality. We differ in the mechanisms studied through which this shock affects the economy and the quantitative methodology used.

[12] In addition to the DMP literature mentioned earlier, productivity shocks have also been extensively studied by the Real Business Cycle literature.

[13] We thank Gadi Barlevy for this suggestion.

cycle properties of the model, checks robustness of the results to various parameters and model specifications. We then perform an analysis of the Great Recession and the effects of the Fed's policies. We conclude in Section 6.

# 2 The Model

Our point of departure is the standard DMP model with capital. We replace shocks to productivity with exogenous shocks to the default rate and to the cost of financial intermediation. Unemployment, $u$, vacancies, $v$, and market tightness, $\theta = \frac{v}{u}$ are studied as endogenous equilibrium objects. We describe the model in full detail in this section.

## 2.1 Workers, Banks, and Firms

There is a measure one of infinitely lived, risk-neutral workers and a continuum of infinitely lived firms. Workers maximize their expected lifetime utility:

$$\mathbb{E} \sum_{t=0}^{\infty} \beta^t y_t, \tag{1}$$

where $y_t$ represents the workers' income (or utility) in a given time period, and $\beta$ is the discount factor. They make a savings/consumption choice with respect to a risk free interest rate $r_f$, resulting in capital income of $r_f k_w$, where $k_w$ is the capital the workers own. Workers' flow utility is thus $w + r_f k_w$ when employed and $b + r_f k_w$ when unemployed.

Banks are risk neutral entities that borrow from workers at rate $r_f$ and lend to firms at the rate of $r$. They face intermediation costs at rate $x$ and a default risk rate $d$ with recovery rate $\zeta$. Banks operate in a competitive environment and maximize period profits, per unit of capital, given by:

$$\pi_b = (1-d)(1+r-x) + d\zeta(1+r-x) - (1+r_f). \tag{2}$$

The intermediation cost $x$ can have various interpretations. In the current form of Equation 2 this cost is faced by banks during lending. Equivalently, $x$ could have been put in the $(1+r_f)$ term, implying the costs are experienced when banks borrow.[14] Under this interpretation changes in $x$

[14]During calibration, we will identify $x$ based on shocks to the interest rates perceived by firms in the data. Thus $x$ can be thought of as any shock that causes interest rates to fluctuate, and allows us to have interest rate shocks while maintaining an equilibrium model.

could come from shocks to the risk-free interest rate, increased regulation on banks, consumers being less willing to lend to banks, a breakdown in inter-bank lending, or, as can be seen in Appendix A, firm level uncertainty shocks. Finally, notice that the use of the financial intermediation cost in addition to the default shock in Equation 2 is consistent with the finance literature that finds that observed default cannot account for the entire spread.

Firms produce using workers and capital. We assume that capital per worker is fixed and that output is linear in the number of workers, making production a Leontief function.[15] Aggregate output is thus given by:

$$Q(L, K) = \min\{pL, \frac{K}{\phi}\}, \tag{3}$$

where $p$ is labor productivity, and $K$ and $L$ are aggregate capital and labor employed, respectively. $\phi$ controls the capital per worker, $k$. As we will make clear in the calibration section, we study shocks resulting in deviations from trends in the default rates and financial intermediation costs. Thus, the implicit assumption behind Equation 3 is that firms have short run adjustment costs and cannot respond to business cycle level shocks.[16]

Suppressing the fixed capital component of production gives us production as a function of labor:

$$q(L) = pL, \tag{4}$$

where $K$ is implied to be $\frac{pL}{\phi}$.

Period accounting profits for the representative firm that is matched with a worker are thus:

$$\Pi = p - w - rk - \delta k, \tag{5}$$

where $w$ is the wage rate, $\delta$ is the depreciation rate, and $r$ is the interest rate. In contrast to the standard DMP model, where $p$ follows a Markov process, we assume that the interest rate $r$, is

[15] The use of working capital in our model is similar in spirit to the quantitative exercise performed by Christiano, Eichenbaum, and Trabandt (2014), who in turn cites Bigio (forthcoming) as a theoretical foundation for this assumption.

[16] Alternatively, consider a Cobb-Douglas formulation. In response to interest rate shifts, capital per worker would change, leading in turn to worker productivity fluctuations. Given that productivity moves very little over the business cycle, with a standard deviation of about 1%, large adjustment costs would be necessary in order to not have counterfactually large movements in productivity, bringing the model close to Leontief. Furthermore, given our interest in abstracting from productivity shocks, it is necessary to keep output per worker constant in the model. For completeness, we analyze the Cobb-Douglas case in Section 5.2, and confirm that our results are quantitatively important even under the Cobb-Douglas formulation.

determined by the vector of shocks $z = (x, d)$, where $z$ follows a Markov process $G(z', z) = Pr(z_{t+1} \leq z | z_t = z)$, where a next period variable is denoted by a prime ($'$). We take the productivity rate, $p$, as a constant.

Firms choose how many vacancies to post each period at cost $c$ per vacancy, which depends on the interest rate. The implied assumption is that part of the vacancy cost is working capital. We discuss this in more detail in Section 4.

## 2.2 Matching

Vacant jobs ($v$) and unemployed workers ($u$) are randomly matched according to a constant returns to scale matching technology. The matching function, $M(u, v)$, represents the number of matches in a period. We follow Ramey, den Haan, and Watson (2000) in picking our matching function:

$$M(u, v) = \frac{uv}{(u^l + v^l)^{\frac{1}{l}}}, \tag{6}$$

where $l$ is a parameter that controls the matching technology. This functional form has the desirable properties that the job finding rate for a worker and the job filling rate for a firm are always between 0 and 1.[17] The job finding rate for a worker is $\lambda^w = \frac{M(u,v)}{u}$. Similarly, the job filling rate for the firm is $\lambda^f = \frac{M(u,v)}{v}$. Note that the job filling rate depends only on market tightness, $\frac{v}{u}$, denoted by $\theta$.

## 2.3 Loss of ownership and separations

Denote the state of the economy to be $s$, and thus all state-dependent variables have subscript $s$. A match in our model could terminate in two different ways. First, a match separates with periodic probability $\sigma$ that is independent of the state. Second, a match can terminate due to default. When a bankruptcy occurs, the firm loses ownership over the future profit flow from the match. The effective separation rate from the match for the firm will thus be $\sigma^f_s = \sigma + (1 - \sigma) d_s$. We assume that workers do not experience separations due to default.[18] Therefore, the separation rate for workers $\sigma^w$, is a state-invariant separation rate given by $\sigma^w = \sigma$.

[17] Using a standard Cobb-Douglas matching function instead is not crucial for either the qualitative or quantitative results.

[18] We make this assumption to focus on the channels outlined in the paper, which study the effects of default/interest rates on firms. Accordingly, we abstract from direct affects of default on workers.

The evolution of the number of unemployed workers, $u$, can be described by:

$$u' = (1 - \lambda^w)u + \sigma^w(1 - u). \tag{7}$$

### 2.4 Aggregate Resource Constraint

Investment, $I$, in the economy includes two components as follows:

$$I = vc_s + (1 - \sigma^w)(\delta + x + d(1 - \zeta))(1 - u)k. \tag{8}$$

The first investment component is the resources put into opening vacancies, $vc_s$. This includes both the working capital and the labor input associated with posting vacancies. The second investment component is replenishing the capital of current workers who do not lose their job. Their capital loses value through depreciation, and default, as well as accounting for the financial intermediation cost.

Total resources in the economy is the output produced by employed workers, $Y = (1 - u)p$. Expenditures are consumption of workers $C$ and investment $I$. Thus the aggregate resource constraint is given by:

$$C + I = Y. \tag{9}$$

## 3 Equilibrium

There are two asset markets: that between the bank and the firm and that between the bank and the workers. Risk neutrality and the workers' Euler equation imply that $r_f = \frac{1-\beta}{\beta}$, and that at that interest rate, workers are completely indifferent between saving and consuming. Note that this interest rate is state invariant.

Given the competitive nature of the banking industry, the zero profits condition gives us the relationship of:

$$1 + r_f = (1 - d_s)(1 + r_s - x_s) + d_s\zeta(1 + r_s - x_s). \tag{10}$$

At the interest rate $r_s$ described in Equation 10, the banks are willing to provide as much capital to the firms as they demand, clearing the market.

Markets thus clear at the rate $r_f = \frac{1-\beta}{\beta}$ in the worker/bank asset market and zero-profit interest rate in the bank/firm asset market given by Equation 10.

## 3.1 Workers' Value Functions

In this subsection we specify the workers' optimization problems.

Let $W_s$ denote the value function of an employed worker at state $s$. Let $U_s$ denote the value function of an unemployed worker. Workers move between employment and unemployment according to the (endogenous) job finding rate ($\lambda_s^w$), and the (exogenous) separation rate $\sigma^w$. Workers take probabilities parametrically.

The workers' wage, which is determined by Nash equilibrium as explained below, is $w$. Unemployed workers receive a utility value of $b$. This represents the value of leisure and home-production. Both types of workers receive dividend income $r_f k_w$. The values of employment and unemployment in state $s$, $W_s$ and $U_s$ are equal to:

$$
\begin{aligned}
W_s &= w_s + r_f k_w + \beta \left\{ (1-\sigma^w) E_s W_{s'} + \sigma^w E_s U_{s'} \right\} && (11) \\
U_s &= b + r_f k_w + \beta \left\{ \lambda_s^w E_s W_{s'} + (1-\lambda_s^w) E_s U_{s'} \right\}, && (12)
\end{aligned}
$$

where $E_s$ is the expectation operator over the subsequent period state. Note that when calculating the surplus for a worker of being employed versus unemployed, $W_s - U_s$, the dividend income drops out.

## 3.2 Firms' Value Functions

Firms create jobs, rent capital from banks, pay wages, and produce. The firm maximizes the discounted present value of its profits. To create a job, a firm first posts a vacancy. There is a flow cost of posting a vacancy, denoted by $c_s$, which depends on the interest rate. The value of posting a vacancy, $V_s$ , is:

$$
V_s = -c_s + \beta \left\{ \lambda_s^f E_s J_{s'} + \left(1-\lambda_s^f\right) E_s V_{s'} \right\}, \quad (13)
$$

The firm discounts the future at the rate $\beta$. $J_s$ is the value of a job filled by a worker, whose value, given the wage $w_s$, is:

$$J_s = p - w_s - (r_s + \delta)k + \beta \left\{ \left(1 - \sigma_s^f\right) E_s J_{s'} + \sigma_s^f E_s V_{s'} \right\}. \tag{14}$$

## 3.3 Wage determination

The wage is determined by generalized Nash bargaining. Wages are set period by period in spot markets. The Nash bargaining solution solves the problem:

$$\max_{w_s} \left(W_s - U_s\right)^{\gamma} \left(J_s - V_s\right)^{1-\gamma}, \tag{15}$$

where $\gamma \in (0, 1)$ represents the bargaining power of the worker.

## 3.4 Goods Market Clearing

For every state of the economy, we calculate market tightness. Given the level of employment and market tightness, we can calculate investment $I$ from Equation 8. Finally, output is given by $Y = (1 - u)p$, which allows us to calculate consumption $C$ from Equation 9.

Since workers are indifferent between consumption and investment at the market-clearing interest rates, the aggregate resource constraint holds as long as investment does not rise above $p(1 - u)$.

## 3.5 Equilibrium analysis

We now solve the model, and discuss the mechanisms introduced in the context of the model solution. The state of the economy is $\{x, d\}_s$, which in turn determines $r_s$, according to Equation 10. Define the total surplus of a match between the worker and the firm as $S_s = (J_s - V_s) + (W_s - U_s)$. With free entry implying $V_s = 0 \; \forall s \in \mathbf{S}$ the surplus is equal to:

$$S_s = p - b - (r_s - \delta)k + \beta \left\{ \left(1 - \sigma_s^f\right) E_s S_{s'} - \left(\theta_s \lambda^f(\theta_s) - \sigma_s^f + \sigma^w\right) E_s \left(W_{s'} - U_{s'}\right) \right\} \tag{16}$$

From the maximization of Nash bargaining in (15) we get that:

$$\frac{W_s - U_s}{\gamma} = S_s = \frac{J_s}{1 - \gamma}. \tag{17}$$

Using the free-entry condition, $\forall s$, in Equation 13, the number of vacancies, $v_s$, posted in a given state is picked in order that market tightness, $\theta_s = \frac{v_s}{u_s}$, satisfies:

$$E_s S_{s'} = \frac{c_s}{(1-\gamma)\beta\lambda_s^f}. \tag{18}$$

Using the condition from (18) in (16), we arrive at:

$$S_s = p - b - (r_s + \delta)k + \beta \left\{ \left(1 - \sigma_s^f\right) E_s S_{s'} - \frac{\left(\theta\lambda^f(\theta) - \sigma_s^f + \sigma^w\right)\gamma}{(1-\gamma)\,\lambda^f(\theta)} \frac{c_s}{\beta} \right\}. \tag{19}$$

The number of variables is then twice the number of states $\{\theta_s, S_s\}_{s\in\mathbf{S}}$ and there is an equivalent number of equilibrium conditions in Equations 18 and 19.

## Mechanisms

Equation (19) is instrumental in understanding the mechanisms through which firms and workers respond to the default and financial intermediation shocks, and consequentially affect unemployment, vacancies and market tightness, as follows:

1. When the interest rate rises, there is a smaller flow surplus available to split between the firm and the worker. This is captured by $r_s k$ in Equation 19. The decline in surplus reduces the incentives for firms to post vacancies, resulting in a rise in unemployment. We call this channel the *flow profit channel*.

   This channel is closely related to how productivity shocks affect the vacancies decision in the standard model. There, an adverse productivity shock decreases the flow surplus by reducing current and expected revenues. Here, an adverse financial shock affects the cost of acquiring capital, thus increasing current and expected cost of operation. In either case, firms respond by reducing the number of vacancies in response to decreasing profits.

2. The capital component of vacancy costs rise proportionally with the interest rate, $r$, as is captured by $c_s$ in Equation 19.[19] The idea is that if a firm needs working capital in order to have a position available, then when interest rates rise, this component of vacancy costs rises as well. Firms thus post fewer vacancies, and unemployment rises. We call this the *vacancy cost channel*.

[19] The components of the vacancy cost are explained more thoroughly in Section 4.3.

3. The default rate (inversely) determines how long the owner of the firm expects to remain claimant on the profits generated by the match, as captured by $\sigma_s^f$. When this rate increases, the expected profit the owner receives decreases. As a result, the incentive to post vacancies declines, thus increasing unemployment. We call this channel the *ownership channel*.[20]

### 3.6 Analytic Discussion

In this section we study the three mechanisms analytically. We derive the elasticity of market tightness with respect to the shock using the equilibrium condition of the steady-state model. When multiplied by the standard deviation of the shock, this elasticity is a good prediction of the quantitative results with respect to volatility.

In order to illustrate how our shocks create large volatility of unemployment, vacancies, and market tightness, we compare with the productivity literature. Accordingly, we first replicate the analysis of productivity shocks in the DMP model literature, and then separately analyze each of our mechanisms. The main point is that, for productivity shocks to matter, the elasticity of market tightness to productivity has to be large in a DMP model. Alternatively, for financial shocks to matter, the elasticity of market tightness to interest rates can be small as interest rate shocks are larger.

We begin with the analysis of the standard DMP model with productivity shocks. The object of interest can be derived from the steady-state equilibrium condition as:

$$\frac{\partial \log \theta}{\partial \log p} = \underbrace{\frac{p}{p-b}}_{\text{fundamental surplus}} * \Upsilon, \tag{20}$$

where variables without a state index represent the steady-state values. $\Upsilon$ is equal to $\frac{r_f+\sigma+\gamma\theta\lambda^f(\theta)}{\eta(r_f+\sigma)+\gamma\theta\lambda^f(\theta)}$ where $\eta$ is the elasticity of matching with respect to unemployment. Ljungqvist and Sargent (2014) study this and other DMP versions and calibrations that are able to generate strong volatility in labor market tightness using productivity shocks. Since reasonably calibrated models set the value of $\Upsilon$ close to 1 (e.g., in our calibration it is 1.03), in order to generate a large volatility of $\theta$, with a small shock to productivity, the first term $\left(\frac{p}{p-b}\right)$ must be large. Since $p$ is a matter of normalization, Ljungqvist and Sargent (2014) emphasize the importance of the $p-b$ term and call

[20]Notice that our assumption that workers do not separate from the firm following a separation shock is present in the numerator of the last term. An increase in default through this term dampens the decrease in the surplus because the worker continues working even after a default takes place.

it the *fundamental surplus*.

Turning to our model, we now study each of the three channels separately. We start with the the flow profit channel. The only adjustment that is needed for the equilibrium condition is substituting $p$ by $p-(r+\delta)k$:

$$\frac{1-\gamma}{c}(p-b-(r+\delta)k)=\frac{r_f+\sigma}{\lambda^f(\theta)}+\gamma\theta. \tag{21}$$

In the absence of the default shock the only shock is $x$ and equation 10 in this case implies that $x$ and $r$ are the same up to a scalar shift. For simplicity we therefore write the elasticity of $\theta$ w.r.t. $r$ as follows:

$$\frac{\partial\log\theta}{\partial\log r}=-\frac{rk}{\underbrace{p-rk-\delta k-b}_{\text{fundamental surplus}}}*\Upsilon \tag{22}$$

Comparison between this elasticity and the one associated with productivity shocks is revealing in the way that our model operates. As will become clear in the calibration $p-\bar{r}k-\delta k$ in our steady-state model is identical to $p$ in the canonical model. Therefore, the fundamental surplus is identical in both 20 and 22. On the other hand, the numerator in 22 is actually smaller than that in 20. This is simply because the interest rate affects only the capital cost as opposed to the productivity shock affecting the whole income. Therefore, the elasticity in our model is lower than that of the model with productivity shocks. The total effect of the shock, however, is determined by the elasticity multiplied by the standard deviation of the shock. This fact is at the heart of the quantitative power of financial shocks to create labor-market volatility. We will return to this point in the quantitative analysis that follows.

We now focus on the vacancy cost channel. The only change in Equation 21 is that now the cost of capital is assumed to be insensitive to $r$ and instead the vacancy cost $c$ becomes $c(r)$. From this steady-state condition we derive the elasticity of $\theta$ w.r.t. the interest rate to be:

$$\frac{\partial\log\theta}{\partial\log r}=\frac{rc_k}{c}*\Upsilon \tag{23}$$

Notice that $\Upsilon$ is simply the elasticity $\theta$ with respect to the vacancy cost $c$. We assume that the interest rate only affects a fraction $\frac{rc_k}{c}$ of the vacancy cost, and therefore $\Upsilon$ is multiplied by this proportion. Although that denominator does not have the fundamental surplus interpretation as in the flow profit channel, the fraction multiplying $\Upsilon$ is smaller than unity, implying that the elasticity cannot explain volatility as in models that work through the fundamental surplus channel. Instead, and similar to the previous channel, it is the magnitude of the shock that matters for the results.

We now turn to the effect of the default shock on volatility through the ownership channel. Abstracting from the $x$ shock, the steady state condition for the case where default is the only shock is:

$$\frac{1-\gamma}{c}(p-b) = \frac{r_f + \sigma + (1-\sigma)d(1-\gamma)}{\lambda^f(\theta)} + \gamma\theta \tag{24}$$

The elasticity of market tightness with respect to default in this case is as follows:

$$\frac{\partial \log \theta}{\partial \log d} = \frac{(1-\sigma)(1-\gamma)d}{\eta(1-\sigma)(1-\gamma)d + \eta(r_f+\sigma) + \gamma\lambda^f(\theta)\theta} \equiv \Omega \tag{25}$$

Comparing this elasticity to the value of $\Upsilon$ above shades some light on the quantitative power of the ownership channel. Taking into account that the average separation in our model includes both the average separation $\sigma$ and the average default, the denominator of the two terms is the same. The question then is how large is the numerator of $\Omega$ in 25 relative to that of $\Upsilon$. Giving this mechanism its best chance, we put a zero value for workers' bargaining power $\gamma$ and ignore $r_f$ then the comparison is between the rates of separations $(\sigma)$ and defaults $((1-\sigma)d)$. Default is roughly 5% as big as separations, or a ratio of 20 between $\Upsilon$ and $\Omega$.[21] This tells us that even under those extreme assumptions on $\{r_f, \gamma\}$ the ownership channel has little quantitative power, at least relative to the other mechanisms.

Does this mean that default does not matter for firms? Not quite. In our model defaults can affect firms in two ways, a direct effect through the ownership channel, but also through an indirect effect of default on the equilibrium interest rate as in Equation 10. Notice that the fact that the direct affect of default on the ownership channel is weak does not imply that the indirect affect of default through interest rates cannot be strong.

[21] Elton (2001) calculates default probabilities for BAA firms. While the propensity to default depends on how old the loan is, the average rate is about 1% per *year*. Separations between workers and firms are calculated by Shimer (2005) to be about 2.1% per *month*.

# 4 Calibration

We calibrate the model to the US data, without targeting any business cycle statistics. We set some parameters based on a-priori information, and some based on matching model moments to data moments. We then use the model to replicate business cycle statistics related to unemployment, vacancies, and market tightness, and compare the model output to the actual data.

In the last section we showed the limited quantitative ability of the ownership channel. In order to simplify the quantitative analysis and to focus on the two mechanisms that have quantitative significance we abstract from default shocks in the quantitative analysis and therefore impose that $\sigma_s^f = \sigma^w = \sigma$.

## 4.1 Interest Rate Shocks

We are left with a financial intermediation shock $x$. We use BAA corprorate interest rates as the basis for our analysis. Without default, Equation 10 becomes:

$$r_s = r_f + x_s. \tag{26}$$

Given a constant $r_f$, $x$ becomes exactly identified from the real BAA interest rate. Accordingly, we estimate the shock process of interest rates in the data and feed them into the model. For our measure of inflation we use the core producer price index (PPI). We choose this deflator because the focus of our analysis is firms.[22] The quarterly series are in HP log deviations.[23]

We assume that $r$ follows a first-order Markov process given by:

$$r = \rho_r r_{-1} + \epsilon_r. \tag{27}$$

$$\epsilon_r \sim N(0, \sigma_\epsilon). \tag{28}$$

[22]We show in Section 5.2 that the model also generates significant volatility under different inflation specifications.

[23]Recall that using deviations implies that we are assuming firms can respond perfectly to *trends* in financial conditions, but are surprised by shocks at the business-cycle frequency. Using deviations along with a Leontief production function in Equation 3 can be interpreted as firms being able to completely adjust to interest rate trends, while having large adjustment costs to shocks at the business-cycle frequency.

## 4.2 Normalization

We normalize the firms' revenue net of the average capital cost, $p - (\bar{r_s} + \delta)k$, to be 1. Thus we can write flow match surplus to be $1 - (r_s - \bar{r_s})k$, or $1 - \Delta r_s k$, where $\Delta r_s = r_s - \bar{r_s}$. We now rewrite equation 19 accordingly:

$$S_s = 1 - b - \Delta r_s k + \beta \left\{ (1 - \sigma) E_s S_{s'} - \frac{\theta \gamma}{(1 - \gamma)} \frac{c_s}{\beta} \right\}. \tag{29}$$

This normalization is standard in the DMP literature with productivity shocks. We differ from this literature by assuming that productivity is constant, in order to focus on the effects of financial shocks.

## 4.3 Parameters

We begin by setting the time period to be a week in order to account for aggregation bias. We have 9 parameters in this model, $(\sigma, \beta, c, \gamma, \delta, l, b, \rho_r, \sigma_\epsilon)$. We set $(\sigma, \beta, c, \gamma, \delta)$ with a-priori information, and choose $(l, b)$ to match the average job finding rate and average market tightness in the data. Additionally, recall that the model is weekly while the data is quarterly. To convert the time frame of the shock process, we pick $(\rho_r, \sigma_\epsilon)$ on a weekly basis such that, after simulating the model, the estimated quarterly process of the interest rate in the model lines up with its data equivalent.[24] Table 1 contains the a-priori and moment matching parameters. Table 2 compares the moments in the data and model. Table 3 presents the parameters of the interest rate process used in the model.

We begin by describing the a-priori parameters. Shimer (2005) calculates the monthly job separation rate, which is $0.0081$ at a weekly rate. The discount rate is set to $0.99^{\frac{1}{12}}$, representing a quarterly discount rate of $0.99$, or a risk-free interest rate of 4%. Hagedorn and Manovskii (2008) calculate the average vacancy cost, $c$, to be $0.584$, which is composed of an average capital cost of $0.474$ and a fixed labor cost of $0.11$. Part of the capital component of this cost varies proportionally with the interest rate. We denote this part $c_k$. It is equal to the proportion of the total capital costs due to interest rates. That is, $c_k = \frac{\bar{r}}{\bar{r}+\delta}0.474$. The part of the capital cost that is due to deprecation is therefore $c_\delta = (1 - \frac{\bar{r}}{\bar{r}+\delta})0.474$. Thus, $c = c_k(1 + \frac{\Delta r}{\bar{r}}) + c_l + c_\delta$. We set $\gamma$ to be $0.50$, following

[24] To elaborate, we estimate a weekly AR(1) process on the log deviations of HP-filtered (1600) quarterly real BAA interest rate. We then convert this process from a quarterly to a weekly process. The algorithm to do so is to first guess a weekly process, then simulate and aggregate the weeks to quarters. Finally, HP filter the simulated quarters, and estimate the income process on the simulated data. We repeat until the simulated data imply quarterly AR(1) parameters as close as possible to those of the actual data process. The results are shown in Table 3.

Table 1: Parameter Values

| *Parameter* | *Meaning* | *Value* | *Identification* |
|---|---|---|---|
| | A-priori parameters | | |
| $\sigma$ | Job Separation | $0.0081$ | |
| $\beta$ | Discount Rate | $0.99^{\frac{1}{12}}$ | Litearture - see text |
| $c$ | Vacancy Costs | $0.584$ | |
| $\gamma$ | Worker Bargaining Weight | $0.50$ | |
| $\delta$ | Depreciation Rate | $0.06^{\frac{1}{52}}$ | |
| | Internally calibrated | | |
| $l$ | Matching Parameter | $0.41$ | Matching Data Moment |
| $b$ | Unemployment Flow Utility | $0.60$ | |

Table 2: Moments: Data and Model

| *Moment* | *Data* | *Model* |
|---|---|---|
| Job Finding Rate | $0.139$ | $0.139$ |
| Market Tightness | $0.634$ | $0.634$ |

Table 3: Shock Processes

| *Moment* | *Data* | *Model* | *Parameter* |
|---|---|---|---|
| Frequency | Quarterly | Quarterly | Weekly |
| $\rho_r$ | 0.799 | 0.798 | 0.996 |
| $\sigma_\epsilon$ | 0.075 | 0.074 | 0.028 |

Boeri, Garibaldi, and Moen (2014) who argue that this is a middle ground of the values used in the literature. We set $\delta$ at 6% annually following Caselli (2005).

We now turn to the internally calibrated parameters, $l$, and $b$. We target the average job finding rate and the average market tightness, which Hagedorn and Manovskii (2008) calculate to be $0.139$ and $0.634$, respectively. Picking $b$ and $l$ to minimize the distance between model and data moments, we arrive at $b = 0.60$ and $l = 0.41$. The flow utility of an unemployed worker, $b$, is an intermediate value for this parameter used in the literature.[25] This parameter is essential for controlling the amount of volatility created by the model as shown in Section 5.2. This value implies an average flow surplus in our model $0.4$, implying that our results are not driven by a small surplus.

# 5 Results

In this Section, we first describe the business cycle statistics of the calibrated model with a breakdown of the various mechanisms. We then perform various robustness analyses. Finally, we show the model implications for the Great Recession.

## 5.1 Business Cycle Statistics

We follow the literature in calculating the business cycle statistics of unemployment, vacancies, and market tightness in the calibrated model.[26] We report in Panel A of Table 4 the US time series data for the period 1982 to 2012 regarding these series, their autocorrelations, standard deviations, and correlations.

Panel B of Table 4 shows the model counterpart for the US economy. It should be emphasized that these moments are *not* targeted, but rather a result of the calibration strategy described above in a DMP model with financial intermediation shocks. The model is able to produce volatility in all moments of the same order of magnitude as in the data. Specifically, the volatility of unemployment, vacancies, and market tightness are all about 80% of that observed in the data.

The persistence of unemployment, vacancies, and tightness, are somewhat lower than their empirical counterparts, however, not extraordinarily so as compared to other papers in the DMP literature.

[25] Shimer (2005) used a low value of 0.4. In contrast, by using a high value of 0.955 Hagedorn and Manovskii (2008) created a small enough surplus that resulted in strong volatility of the business cycles variables. Based on the Frisch elasticity, Hall and Milgrom (2008) reach a value of 0.71.

[26] For consistency, all variables, unless otherwise indicated, are reported after aggregating the weekly data into quarterly, as HP log deviations, with a smoothing factor of 1600.

Table 4: Quarterly Statistics Data versus Model

| **Panel A: U.S. Data, 1982:1 to 2012:4** | | | | |
|---|---|---|---|---|
| | $u$ | $v$ | $\frac{v}{u}$ | $r$ |
| Std Dev | 0.11 | 0.12 | 0.22 | 0.14 |
| Autocorrelation | 0.94 | 0.91 | 0.93 | 0.79 |
| Correlation with $u$ | 1.00 | −0.89 | −0.97 | 0.26 |
| Correlation with $v$ | – | 1.00 | 0.97 | −0.23 |
| Correlation with $\theta$ | – | – | 1.00 | −0.25 |
| **Panel B: Model** | | | | |
| Std Dev | 0.09 | 0.11 | 0.19 | 0.14 |
| Autocorrelation | 0.86 | 0.61 | 0.78 | 0.80 |
| Correlation with $u$ | 1.00 | −0.71 | −0.91 | 0.64 |
| Correlation with $v$ | – | 1.00 | 0.94 | −0.26 |
| Correlation with $\theta$ | – | – | 1.00 | −0.47 |

*Notes*: All data are logged and HP filtered. U.S. data: 1982Q1-2012Q4. model: Quarterly averages of simulated data, 120,000 observations at weekly frequency.

Table 5: Break Down of Mechanisms

| *Mechanisms* | *u* | *v* | *v/u* |
|---|---|---|---|
| Data | 0.11 | 0.12 | 0.22 |
| All | 0.09 | 0.11 | 0.19 |
| Profit | 0.06 | 0.07 | 0.13 |
| Vacancy | 0.03 | 0.04 | 0.06 |

*Notes*: All data are logged and HP filtered. U.S. data: 1982Q1-2012Q4. model: Quarterly averages of simulated data, 120,000 observations at weekly frequency.

### 5.1.1 Breakdown of Mechanisms

In Table 5, we break down the strength of the various mechanisms in order to learn their relative strengths. We focus only on the standard deviation as the other statistics are similar to the ones in Table 4. The 'data' row is the US data reported in Table 4. The 'All' row is the model standard deviations reported in Table 4 Panel B. The 'Profit' row is the standard deviation of each series when only the capital cost for production fluctuates and vacancy costs remain constant. The 'Vacancy' row describes the case where instead only the vacancy cost fluctuates and the capital cost for production remains constant.

These results show that slightly more than half of the volatility in the model comes from the flow profit channel, while slightly less comes from the vacancy cost channel. There does not seem to be an interaction between them, as summing the effects of each individually results in the total volatility the model generates.

In Section 3.6 we argued that although the elasticity of market tightness w.r.t. the interest rate is smaller than unity, the model may still be able to generate substantial volatility in labor-market variables due to the large volatility of financial shocks. We now use the numbers from our calibration in the equations provided above. For the flow profit channel using Equation 22 we set the numerator that reflects the capital share to $\frac{1}{3}$ and the denominator to $1 - b = 0.4$. This results in an elasticity of 0.833, or half of what Shimer (2005) achieves in his calibration $\left(\frac{p}{p-b} = \frac{1}{1-0.4} = 1.67\right)$. On the other hand our shock is 14 times as large as that of labor productivity, resulting in an effect that is 12 times larger, or a standard deviation of 0.12, very close to the volatility we get in the simulations. Turning to the vacancy cost channel, the fraction in Equation 23 in our calibration is 0.425. When multiplied by the volatility of the interest rate, 0.14, we get 0.06, which is the volatility generated by the vacancy cost channel.

## 5.2 Robustness

In this Section, we perform robustness checks on: the parameter values of $(b, \gamma, \delta)$; the interest rate assuming different measures of inflation; and HP deviations in the *level* of interest rates rather than the *log* of the interest rates.[27] Additionally, we replace the assumption of a Leontief production function by assuming a Cobb-Douglas production function with perfect flexibility of capital.

The flow utility value of unemployment, $b$, is a key parameter in the literature. Its importance comes from its potentially strong effect on surplus as discussed in Section 3.6. When lowering this value to 0.4 we receive somewhat lower, yet significant, volatility.[28] Using a value of $0.7$ that is in line with recent literature (e.g. Hall and Milgrom (2008)) leads to volatility almost exactly as that of the data. The reader can easily verify that the results of that sensitivity analysis are quantitatively consistent with the analysis in Section 3.6.

Workers' bargaining weight, $\gamma$, is an additional parameter that affects volatility. Although this parameter does not affect the surplus itself, it affects the share of the surplus that goes to firms. We check using both a higher value for $\gamma$, 0.72, and a lower value, 0.30. In both cases, the results are about as strong as in the benchmark, indicating robustness to this parameter choice.

We continue with the depreciation rate, $\delta$. The reason that this parameter value matters is that it dictates the fraction of capital costs that is subject to shocks.[29] The result can be seen in Table 6 where we set $\delta = 8\%$. Volatility is somewhat lower, but still significant.

Our model requires using real interest rates. To impute the real BAA interest rate from the nominal one we have used the core PPI. This index measures the average changes in prices received by domestic producers for their output. The core index excludes food and energy. As an alternative index we use the core Consumer Price Index (CPI). The implied volatility of the interest rate goes down from 0.14 to 0.11 and the volatility in this exercise is lower for all variables. We end by examining the model in the case of interest rates deviations being measured in levels rather than logs, in order to make sure that the interest rate approaching 0 does not influence the results. Volatility changes somewhat, but is still significant for all three variables. Table 6 describes the results.

[27] We thank Jordi Gali for making the suggestion of studying level deviations.

[28] It is well known that, with productivity shocks, increasing $b$ from 0.4 to 0.6 would not make a large difference because the magnitude of volatility is small in any case. Here, in comparison, the magnitude of volatility is substantial and therefore this parameter matters.

[29] Specifically, total capital costs to a firm are $r + \delta$. Thus, $\frac{r}{r+\delta}$ of the cost of the capital fluctuates with respect to a financial shock. Higher values of $\delta$ accordingly correspond to less volatility.

Table 6: Robustness

| *Robustness* | *u* | *v* | *v/u* | r |
|---|---|---|---|---|
| Data | 0.11 | 0.12 | 0.22 | 0.14 |
| Benchmark | 0.09 | 0.11 | 0.19 | 0.14 |
| b=0.4 | 0.06 | 0.07 | 0.13 | 0.14 |
| $\gamma$=0.30 | 0.08 | 0.10 | 0.18 | 0.14 |
| $\gamma$=0.72 | 0.10 | 0.13 | 0.20 | 0.14 |
| $\delta$=0.08 | 0.08 | 0.09 | 0.15 | 0.14 |
| CPI | 0.06 | 0.07 | 0.12 | 0.11 |
| Levels | 0.07 | 0.08 | 0.14 | 0.8% |

*Notes*: Standard deviations for various robustness tests. All data are logged and HP filtered. U.S. data: 1982Q1-2012Q4. model: Quarterly averages of simulated data, 120,000 observations at weekly frequency.

**Cobb Douglas Production Function**

Finally, we analyze the importance of the Leontief assumption. We start by using a Cobb-Douglas production function, where output per worker is determined by:

$$q(k) = Ak^{\alpha}. \tag{30}$$

Every period, the firm chooses capital to equate its marginal product with marginal cost. This means that the capital choice per worker, as a function of the interest rate, will be:

$$k = \left(\frac{r+\delta}{\alpha A}\right)^{\frac{1}{\alpha-1}}. \tag{31}$$

We focus on the flow profit channel in order to isolate the effects of the Leontief assumption. Table 7 shows the breakdown of these exercises. The data and benchmark are as in Table 5. The Cobb-Douglas formulation gives approximately $\frac{2}{3}$ of the volatility the model gives in the benchmark case. This level of volatility is quantitatively important, especially considering that it only captures one of our two main mechanisms.

While our benchmark model had perfect inflexibility of capital, the Cobb-Douglas model has perfect capital flexibility. In the latter case output per worker is changing as interest rate shocks

Table 7: Break Down of Leontief Assumption

| *Mechanisms* | *u* | *v* | *v/u* |
|---|---|---|---|
| Data | 0.11 | 0.12 | 0.22 |
| Benchmark- Flow profit | 0.06 | 0.07 | 0.13 |
| Cobb-Douglas- Flow profit | 0.04 | 0.06 | 0.10 |

*Notes*: All data are logged and HP filtered. U.S. data: 1982Q1-2012Q4. model: Quarterly averages of simulated data, 120,000 observations at weekly frequency.

cause capital changes. The result is that productivity moves in the model with an HP filtered log standard deviation of 0.035, which is significantly larger than its empirical counterpart of 0.01. The counterfactually large movements in output per worker in the Cobb-Douglas formulation suggest that there are large adjustment costs, which in turn implies that the benchmark formulation is closer to reality.[30]

Finally, we verify that the unemployment volatility we get in this robustness exercise is not due to the cost of capital changing. We perform an exercise where the amount of capital moves as in Equation 31, but hold constant output per worker. This is a conservative way of evaluating the model with a Cobb-Douglas formulation, as otherwise output per worker decreases with higher interest rates, leading to reduced surplus. The results remain almost unchanged.

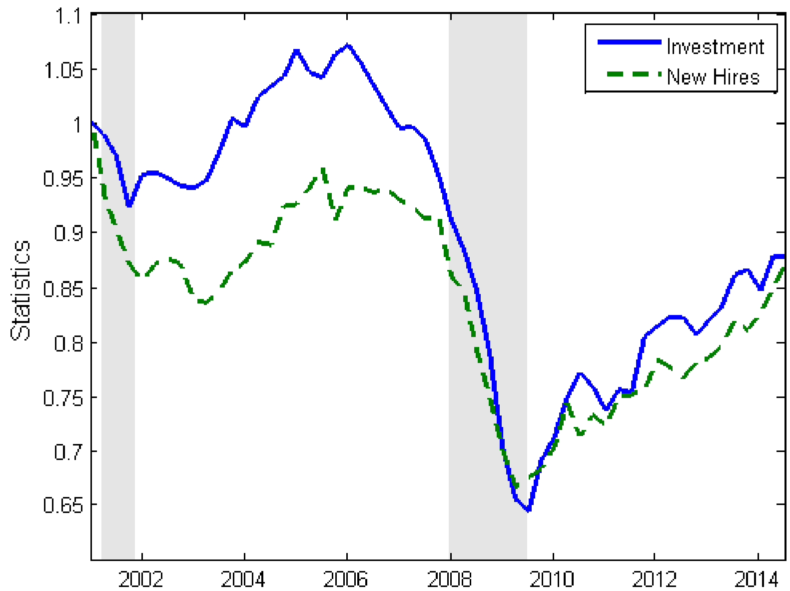
Notice that our assumption of a Leontief production function implies that investment and hiring move one for one. This implication is supported empirically at the aggregate level, as shown in Figure 2. Alternatively, Cobb-Douglas misses the relative movements of investment and hiring. In particular, the baseline model with a Leontief production function implies no volatility in the ratio between investment and hiring. The standard deviation of the log of this ratio is 0.05 in the data, while it is 0.28 in the Cobb-Douglas model. This comparison again shows how the Leontief assumption is much closer to the data than a Cobb-Douglas formulation of the model would be.[31]

While the truth is somewhere in between these two extremes of Leontief and Cobb-Douglas, our analysis implies that Leontief is a reasonable assumption relative to the data in terms of the

[30]Notice that if we wanted to match the movements of output per worker, we would have to include adjustment costs. In such a model, heterogeneity in age, coupled with S-s style adjustment, implies that not all firms will have the same capital level. Accordingly, we would need to keep track of the previous period distribution of capital by firm, which then makes the model both significantly harder to solve, as well as impossible to study analytically.

[31]Doing the same exercise with log deviations of the HP filtered processes yields 0.15 in the Cobb-Douglas model and 0.03 in the data.

Figure 2: US time-series data




*Notes:* Data period: 2001Q1-2014Q3. This Figure depicts the following quarterly US trends: Real Gross Private Domestic Investment from the BLS; Hires: Total Nonfarm from the U.S. Department of Commerce: Bureau of Economic Analysis. The shaded vertical bars represent the NBER-dated recessions. Each series is normalized by its value in 2001Q1.

ratio of investment to hiring and the volatility of output per worker, especially given that we only study deviations from trend interest rates.

## 5.3 What about the Great Recession?

In this Section, we simulate the Great Recession in the model in order to study how much of the unemployment dynamics can be accounted for by financial shocks. Beginning in July 2007, the Federal Reserve started lowering the Federal Funds interest rate, eventually reaching the zero lower bound. We ask the model to predict what unemployment rates would have been during the Great Recession had the Fed *not* engaged in this policy.

We proceed in two steps. First, using the actual data on realized interest rates, we simulate the model from 1982Q1 until 2012Q4. We then simulate the model had the Fed not lowered interest rates during the Great Recession. To do so, we add to the interest rate that is used in the model the

Figure 3: The Great Recession

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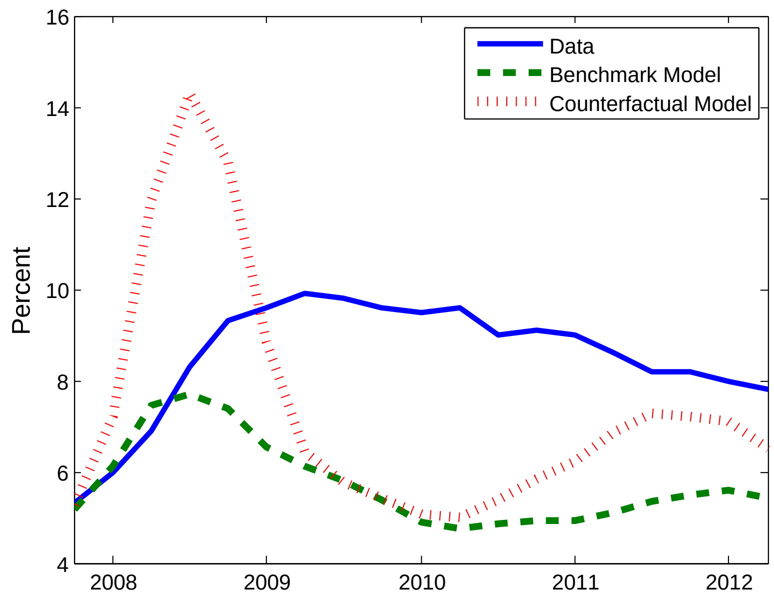


*Notes:* Sample period: 2008Q2-2012Q4. The figure depicts the following quarterly trends. Data: Civilian Unemployment Rate measured by the BLS; Benchmark Model: simulations based on actual real BAA interest rate. Counterfactual Model: simulations based on counterfactual BAA interest rates implied by equation 32.

difference between the Federal Funds rate at a given time $t$ and the rate in 2008Q2.[32] That is:

$$r_c = r_t + (f_{2008Q2} - f_t), \tag{32}$$

where $r_c$ is the counterfactual interest rate used, $r_t$ is the actual interest rate in the data, and $f_t$ is the federal funds rate at time $t$.

Figure 3 shows the results, graphing from July 2007 until December 2012. The benchmark model, labeled as such in the figure, under-predicts the rise in unemployment, but is still consistent with explaining about half of the rise in unemployment experienced during the Great Recession. The model economy then experiences a sharp reduction in unemployment consistent with interest rates falling in the data, and a low persistence of unemployment in the model. Thus, the basic model can explain a large portion of the initial rise in unemployment, but cannot account for its persistence over the course of the Great Recession.

We now turn our attention to the counterfactual unemployment series. This simulation, labeled

[32]We use 2008Q2 as our benchmark as Lehman Brothers failed during 2008Q3.

as ‘Counterfactual Model’ in the figure, shows that the model would have predicted much higher unemployment rates had the Fed not lowered interest rates, specifically 6 percentage points. The implication is thus that monetary policy had a strongly beneficial impact on the severity of the Great Recession.

# 6 Conclusion

In this paper, we build a parsimonious equilibrium model of how financial shocks, in particular interest rate and default shocks, affect unemployment. We study the model analytically, and then quantify it to the US economy in order to study the aggregate affects of financial shocks on unemployment. Without targeting business cycle statistics, the model is able to account for about 80% of the volatility of unemployment, vacancies, and labor market tightness. Simulation results show that the model can account for about half of the rise in unemployment during the Great Recession, and that unemployment would have been about 6% higher had the Federal Reserve not intervened.

In the course of our analysis, we study three mechanisms by which interest rates and default affect unemployment. In particular, adverse interest rate shocks reduce the flow surplus of matches between workers and firms, leading to less vacancy creation. Additionally, higher interest rates increase vacancy costs, which also increases unemployment. Finally, default risk reduces the match value as there is added risk that firms get expropriated from their current owners upon default. Our analysis indicates that the first two channels are of great quantitative importance, while the third is not. Despite the fact that default does not explicitly matter for unemployment, its indirect effect on unemployment through interest rates for firms can be significant.

One possible avenue for future research would be to include heterogeneity in firm size, with a particular focus on small firm that are highly dependent on debt. Another would be to embed our model into a Dynamic Stochastic General Equilibrium model in order to study the effects of monetary policy on unemployment through the mechanisms studied in this paper.

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# Appendices

## A Uncertainty and endogenous interest rate

In this appendix we describe a simple model that illustrates how uncertainty in the return to firms' productivity endogenously affects the interest rate. Thus, we can think of uncertainty shocks as being another source of interest rate shocks leading to volatility of $x$ in the model. Thus, the findings of Christiano, Motto, and Rostagno (2014) and Gilchrist, Sim, and Zakrajek (2014) can also imply shocks to interest rates, with effects as described in this paper.

There is a measure one continuum of firms that engage in risky projects. Each project requires an input that is normalized to unity. The output $\omega$ is distributed $\omega \sim G = unif\left(\mu-\sigma,\mu+\sigma\right).$ We assume that the output $\omega$ is non-negative, i.e., $\mu \geq \sigma$.

Firms have access to competitive financial intermediaries that finance the cost of the input. The financial intermediaries have access to a risk free asset at a periodic cost of $r_f$ and set the risky interest rate $r$ to firms. Denote $R = 1 + r$. Firms whose return on investment is below $R$ cannot pay back the entirety of their loan and declare bankruptcy. The measure of firms that go bankrupt is then $G\left(R\right).$ We assume for simplicity that bankrupt firms do not pay back to the financial intermediaries (e.g., due to agency/monitoring problems).

The revenue of financial intermediaries is $\left(1-G\left(R\right)\right)R$. Given the uniform distribution the revenue can be written as $\frac{(\mu+\sigma)R-R^2}{2\sigma}$. This term is an inverse U-shape. When $R=0$ the revenue is zero because, while no firm declares bankruptcy, they all pay back $0$. When $R=\mu+\sigma$ the revenue is zero because all firms are bankrupt.

The financial intermediaries set $R$ competitively such that the average return on the loan is equal to $R_f(=1+r_f)$. The zero profit condition is:

$$R_f = \left(1-G\left(R\right)\right)R. \tag{33}$$

Using the assumption on uniform distribution of the return, this can be written as:

$$\begin{aligned} R_f &= \left(1-\frac{R-(\mu-\sigma)}{2\sigma}\right)R \\ R^2-\left(\mu+\sigma\right)R-2R_f\sigma &= 0 \end{aligned} \tag{34}$$

We make the parametric assumption that $R_f \leq \frac{(\mu+\sigma)^2}{8\sigma}$, where $\frac{(\mu+\sigma)^2}{8\sigma} = \max_R \frac{(\mu+\sigma)R-R^2}{2\sigma}$.

Otherwise financial intermediaries will never lend to firms.

The zero profit condition has therefore two solutions: $R^- = \frac{\sigma+\mu}{2} - \frac{1}{2}\sqrt{(\sigma+\mu)^2 - 8R_f\sigma}$ and $R^+ = \frac{\sigma+\mu}{2} + \frac{1}{2}\sqrt{(\sigma+\mu)^2 - 8R_f\sigma}$ . We rule out $R^+$ since firms will strictly prefer to borrow at $R^- + \varepsilon$ such that $R^-$ is the only possible equilibrium in this economy.

We now differentiate $R^-$ with respect to $\sigma$ to study the effect of uncertainty on the endogenous interest rate.

$$\begin{aligned} R^- &= \frac{\sigma+\mu}{2} - \frac{1}{2}\sqrt{(\sigma+\mu)^2 - 8R_f\sigma} \\ \frac{\partial R^-}{\partial \sigma} &= 1 - \frac{\sigma+\mu-4R_f}{\sqrt{(\sigma+\mu)^2 - 8R_f\sigma}} \end{aligned}$$

We now show that this derivative is positive. If case I: $\sigma+\mu-4R_f \leq 0$ then the derivative is trivially positive. It is left to show that if Case II: $\sigma+\mu-4R_f > 0$ holds then the derivative is positive.

$$\begin{aligned} 1 - \frac{\sigma+\mu-4R_f}{\sqrt{(\sigma+\mu)^2 - 8R_f\sigma}} &> 0 \\ \sqrt{(\sigma+\mu)^2 - 8R_f\sigma} &> \sigma+\mu-4R_f \\ (\sigma+\mu)^2 - 8R_f\sigma &> (\sigma+\mu)^2 - 8(\sigma+\mu)R_f + 16R_f^2 \\ R_f &< \frac{\mu}{2} \end{aligned} \tag{35}$$

This condition is guaranteed as follows:

$$R_f < \frac{\sigma+\mu}{4} \leq \frac{\mu+\mu}{4} = \frac{\mu}{2}. \tag{36}$$

The first inequality is defined by in case II. The second inequity is based on the assumption of non-negative output ($\mu > \sigma$).

This example illustrates how taking an interest rate shock (and the implied spread shock) can be a reduced form for a more primitive uncertainty shock.